CIB WORKING COMMISSION
W099 - SAFETY AND HEALTH IN CONSTRUCTION

PAPERS AND POSTGRADUATE PAPERS FROM THE SPECIAL TRACK
HELD AT THE CIB WORLD BUILDING CONGRESS 2010, 10-13 MAY 2010
THE LOWRY, SALFORD QUAYS, UNITED KINGDOM

Selected papers from the Proceedings of the 18th CIB World Building Congress.
Proceedings edited by: Professor Peter Barrett, Professor Dilanthi Amaratunga, Dr. Richard Haigh, Dr. Kaushal Keraminiyage and Dr. Chaminda Pathirage

W099 Special Track Papers (excluding Postgraduate Papers) reviewed by: Alistair Gibb, Billy Hare, Charlotte Brace, John Gambatese, Helen Lingard, Jeff Lew, Mayca Rubio and Phil Bust

CIB Publication 357
W099 - SAFETY AND HEALTH IN CONSTRUCTION

PAPERS AND POSTGRADUATE PAPERS FROM THE SPECIAL TRACK

The Commission is committed to the advancement of safety and health of construction workers. The tools necessary to accomplish this end include designing, preplanning, training, management commitment and the development of a safety culture. A country's involvement with construction safety is influenced by factors like: varying labour forces, shifting economies, insurance rates, legal ramifications and technological development.
CONTENTS

Papers

High-Rise Towers: An Integrated Approach Between Climbing Formworks and Stationary Booms
Ciribini, A.L.C. Tramajoni, M.

13

RMAA Safety Performance - How Does It Compare With Greenfield Projects?

25

An Algorithm for Classifying Error Types of Front-Line Workers: A Case Study of Occupational Accidents in Construction Sites
Saurin, T.A. Costella, M.G. Costella, M.F.

Designing for Safety - Applications for the Construction Industry
Lew, J.J. Lentz, T.J.

37

Integration of Safety in the Building Delivery System
Jørgensen, K. Sander, D. Staghnj, A.

46

Identifying Potential Health and Safety Risks at the Pre-Construction Stage
Ganolells, M. Casals, M. Forcada, N. Roca, X. Fuertes, A. Macarulla, M. Vilella, Q.

59

Construction Management Health and Safety (H&S) Course Content: Towards the Optimum
Smallwood, J.

74

Utility Risk Management Education for Engineers
Lew, J.J. Anspach, J.

85

The Role of Health and Safety Coordinator in Sweden and Italy Construction Industry
Aulin, R. Capone, P.

93

How Can We Prevent Construction Accidents? Outcomes from a Stakeholder Consultation: Project and Workplace Influences
Gibb, A. Brace, C. Pendlebury, M. Bust, P.D.

107

4D-BIM for Construction Safety Planning
Sulankivi, K. Kähkönen, K. Mäkelä, T. Kiviniemi, M.

117

Safety Performance of Native and Migrant Employees on Construction Sites
Choudhry, R.M. Fang, D.

129
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development of a Practical Guide for Silica Dust Exposure Limits for Concrete Saw Cutting Methods</td>
<td>136</td>
</tr>
<tr>
<td>Middaugh, B. Hubbard, B. Zimmerman, N. McGlothlin, J.</td>
<td></td>
</tr>
<tr>
<td>The Effect of Illuminance on Task Performance</td>
<td>147</td>
</tr>
<tr>
<td>Hinze, J. Taminosian, Z. Olbina, S.</td>
<td></td>
</tr>
<tr>
<td>A Model for Implementing Focused Safety Initiatives</td>
<td>160</td>
</tr>
<tr>
<td>Hinze, J.</td>
<td></td>
</tr>
<tr>
<td>Site Manager Training and Safety Performance</td>
<td>173</td>
</tr>
<tr>
<td>Hare, B. Cameron, I.</td>
<td></td>
</tr>
<tr>
<td>Understanding the True Costs of Construction Accidents in the Australian Construction Industry</td>
<td>184</td>
</tr>
<tr>
<td>Sun, A.C.S. Zou, P.X.W.</td>
<td></td>
</tr>
<tr>
<td>Return on Investment of Safety Risk Management System in Construction</td>
<td>199</td>
</tr>
<tr>
<td>Zou, P.X.W. Sun, A.C.S. Long, B. Marix-Evans, P.</td>
<td></td>
</tr>
<tr>
<td><strong>Postgraduate Papers</strong></td>
<td></td>
</tr>
<tr>
<td>Sharing Construction Safety Knowledge Through Social Networks</td>
<td>215</td>
</tr>
<tr>
<td>Fang, D. Huang, J. Fong, P.S.W.</td>
<td></td>
</tr>
<tr>
<td>Modelling the Dynamics of Safety on Construction Projects: An Undiscovered Rework Perspective</td>
<td>227</td>
</tr>
<tr>
<td>Irumba, R. Kerali, A.G. Wilhelmsson, M.</td>
<td></td>
</tr>
<tr>
<td>Exploring the Influence of Construction Project Features in Accident Causation</td>
<td>241</td>
</tr>
<tr>
<td>Manu, P. Ankrah, N. Proverbs, D. Suresh, S.</td>
<td></td>
</tr>
<tr>
<td>The Evolution of Construction Accident Causation</td>
<td>253</td>
</tr>
<tr>
<td>Li, R.Y.M. Poon, S.W.</td>
<td></td>
</tr>
<tr>
<td>The Communication of Health and Safety Information in Construction</td>
<td>265</td>
</tr>
<tr>
<td>Ulang, N.M. Gibb, A.G.F. Anumba, C.J.</td>
<td></td>
</tr>
<tr>
<td>Airport Security: Structural Zoning in Developing Countries</td>
<td>278</td>
</tr>
<tr>
<td>Elzawi, A. Eaton, D.</td>
<td></td>
</tr>
<tr>
<td>CIB Brochure</td>
<td>289</td>
</tr>
<tr>
<td>Disclaimer</td>
<td>291</td>
</tr>
</tbody>
</table>
High-Rise Towers: an Integrated Approach between Climbing Formworks and Stationary Booms

Ciribini, A.L.C.
DICATA, Università degli Studi di Brescia
(email: angelo.ciribini@ing.unibs.it)
Tramajoni, M.
Peri Italia
(email: marco.tramajoni@peri.it)

Abstract

The Research aims to investigate how a Construction Management System dealing with the erection of the High-rise Towers could be enhanced. Furthermore, such an effective and proactive Management System purports that the integration between the climbing concrete forming machines and the concrete pumping, pouring and placing devices must be achieved. First of all, the methodology adopted by the Research Unit required to perform a comparative analysis, in close cooperation with the Leading World Manufacturers, through the investigation of the most effective managerial and technical available options. Furthermore, the investigation performed by the Research Unit took into account some meaningful case-studies (located in Germany, Italy, Spain, Sweden, and Switzerland). The main conclusion lies with the need for distinguishing amongst different kinds of High-rise Tower (depending on its heights and shapes) and the preferred models of Site Management to be followed.

Keywords: high-rise towers, site management, formworks, concrete pumping system.
1. The formwork and steel fixing systems

In Italy, the poor performances and the lack of managerial skills affecting the construction sites are due to an absence of the co-operation amongst the various Players (Client Organizations, Main Contractors, Sub-Contractors, and Suppliers). Indeed, quite often it happens that a Public or Private Client Awarding Organization seems to neglect the Site Management-oriented topics. Likewise, the Main Contractor does not want to be really involved into the Site Management-related solutions, preferring to leave the choice of the preferred formwork, steel fixing and pumping systems to its first-tier Sub-Contractors. Nevertheless, the Trade Contractors are sometimes forced to cope with a reduced margin profit and are not so available to take into account a wide spectrum of managerial and technical options in order to find out the most viable one. Therefore, it can happen that the original Site Plan must be suddenly amended because, for instance, the Trade Contractor decides to use a formwork climbing system instead of a self-climbing one, as it was previously planned and agreed during the tendering phase. Such a change to the original Site Plan, increases, of course, the total amount of the contract and modify the features of the tower crane to be installed: the results of the amendments to the original Plan might cause unforeseen risks and could cause a lot of delays and claims.

However, according to a worldwide leading Manufacturer, large formwork elements on a retractable climbing scaffold have been adopted for the first time in 1972 for the construction of the Dresdner Bank Building in Mannheim, Germany. On that occasion, the formworks and climbing scaffolds were lifted with a single pick of the tower crane. Moreover, the first self-climbing system has been used in 1977 to build the Reichenberger Grund Valley Bridge, in Germany, too.

The Research aims to investigate how the construction of some recent High-rise Towers has been planned and scheduled in several European Countries (Germany, Italy, Spain, Sweden, and Switzerland). The Researchers tried to identify the most effective usage of the formwork climbing or self-climbing devices, concrete pumping systems, pouring and placing equipments, to assure the most suitable co-ordination with the tower cranes in order to improve the handling of the materials and tools. The main goal to be attained was focused upon the preferable options to be used when a Construction Managers, acting on the behalf of a General Contractor, has to plan a Site Layout concerning such a Large Project.

Indeed, a Construction Manager has to decide which constraints should be considered when choosing (to hire or to buy) a concrete forming machine in order to build the reinforced concrete-framed Core of a High-rise Tower or of a Multi-Storey Building. On the other hand, the standardized solutions for the climbing systems have to be tailored to a specific site and to the building requirements for forming the Core.

Furthermore, the ways to assembly the formworks vary depending on the concrete pumping, pouring and placing systems and on the crane-lifting devices. A meaningful finding that the Researchers highlighted shows that the most effective solution needs to introduce the crane-independency of the formwork system, in order to speed up the works and to make easier the operations during all weather conditions (through a wind protection panel which is often also used as an advertising area or
surface). The Crane-independency deals with the forming, striking and climbing, and allows the work procedures to be accelerated on the Construction Site, without any increase of the Health & Safety-related risk levels. In such a manner, different kinds of gangs and crews (carpenters, steel-fixers, concrete pumpers, etc.) could work over the platform without any risk to fall from the height, too.

The self-climbing movement is allowed by a rail in order to make sure that the units are always connected to the building by the means of a climbing shoe which has been conceived to do so. The climbing shoe guides the rail during the moving process to the next connecting unit. With the climbing systems any asymmetrical load distribution can be adjusted by a hydraulic system. Indeed, just the hydraulic jacks which lift the whole units through a mobile equipment (a noiseless 2, 4, 6 or 8-fold operational hydraulic pump), make free carpenters, steel-fixers and concrete pumpers from the assistance of the tower crane. The climbing mechanism has a lifting power of approximately 100 kN and raises the unit to the next concrete pouring step without the need of any intermediate anchor at a speed of 0.3 m/min.

A climbing cylinder for the self-climbing formwork system has been conceived in a manner that it can be handled, used and also shifted more easily. Anyway, a highly performing bracket spacing reduces the amount of the anchors to be fixed: the system can be climbed just the day after the pouring of the concrete. Finally, the whole movable system is mounted on a carriage which can be retracted by 90 cm without any usage of the tower crane. Moreover, a special version of the formwork system functions with one bracket which makes possible to hang both formwork sides on one gallow: even the opposite working platform is attached to the same gallow.
Therefore, the tower cranes might be made available for other tasks (e.g. to handle materials, tools, etc.), without interfering with the concrete pumping, pouring and placing-oriented tasks. On the other hand, by the means of a platform, the steel bars might be stored on the enclosed working platform before the further climbing lift: the climbing tasks can be achieved during wind speeds of up to 72 Km/h.

The main versions of a movable forming machine depend on:

- the need for a large working and storage area;
- the monolithical concrete pouring of the slabs and walls.

The complete cycle of moving the formwork, the platform and the placing boom to the next section can be performed in approximately 15 minutes. When folding out and mounting on a self-climbing formwork, the pouring and placing of the concrete could be managed through a stationary boom, instead of the traditional buckets. However, the choice of the most effective solution depends on how many levels (usually 1 till 3) in advance the shuttered Core has to be climbed and on the amount of days needed to achieve a complete storey (usually 3 till 10-day cycles). Very often the scheduling of the tasks to be performed shows as a compelling requirement to concrete the Core walls two or three levels in advance of the slabs.

Likewise, the stationary boom for the concrete pumping could be self-climbed or can climbed on a climbing formwork system, if required. Otherwise, if a climbing formwork has to be moved by the means of a tower crane, the Site Planner must not neglect the location of the tower crane itself and the assessment of its usage cycles in order to carefully choose the most suitable climbing system.

When scheduling a lot of tasks to be performed, the usage of the tower crane must be assessed in centesimal hours according to a weekly survey of the amount of handling movements that should be performed by a tower crane operator. Once defined the total amount of the hours for the usage of the tower crane, the idle times have to be evaluated, too.

The Research Unit reckoned, according to a survey it accomplished, that the usage of a tower crane could reach up to 85% of its potential, considering different reasons for the delays. However, the productivity rate in a working cycle should be assessed in hrs/m².

The duration of the formwork-related activities must broken down in:

- base time;
- additional time;
- idle time.
The main activities could be listed as follows:

- assembling the formworks;
- positioning the compensations.
- dismantling the formworks;
- removing the anchors;
- cleaning and handling the formworks;
- positioning and closing again the temporary equipment.

The time needed to assemble the compensations includes the changes to be made to the parts suitable to be used again. The additional time entails that the activities involving the positioning of the box-outs have been considered. During the idle time any interruption is to be considered: such an idle time could be due to the wait for materials, handling movements, etc.

<table>
<thead>
<tr>
<th>Systems</th>
<th>Traditional</th>
<th>Self-Climbing</th>
<th>Climbing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base time [hrs/m²]</td>
<td>appr. 0,35</td>
<td>appr. 0,35</td>
<td>appr. 0,30</td>
</tr>
<tr>
<td>Assembling the formworks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dismantling the formworks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handling</td>
<td>appr. 0,35</td>
<td>appr. 0,05</td>
<td>-</td>
</tr>
<tr>
<td>Compensations</td>
<td>variable</td>
<td>variable</td>
<td>variable</td>
</tr>
<tr>
<td>Additional activities [hrs/m²]</td>
<td>ca. 0,2</td>
<td>ca. 0,2</td>
<td>ca. 0,2</td>
</tr>
<tr>
<td>Idle time [hrs/m²]</td>
<td>variable</td>
<td>variable</td>
<td>variable</td>
</tr>
</tbody>
</table>

Figure 4: The assessment of the duration of the tasks (Doka)

Furthermore, some additional elevators or stairs might be installed, because of the Health & Safety Plan, within the Building Core in order to allow the gangers to exit from the workplace in the case of emergency. From this point of view, the Site Manager has to pay special attention for a self-climbing stationary boom and a self-climbing tower crane installed on the same site area.
However, all crews and gangs must have free access to the formwork and climbing units to use the mobile hydraulic climbing device, too. Eventually, the Research Unit gathered a set of records dealing with the productivity rates of the different climbing systems: a range from three or four to ten days to complete a floor has been recorded.

2. The concrete pumping, placing and pouring system

The placing and pouring of some 1000 m² of concrete involves shuttering and striking: the productivity rate has been assessed in 0.35 hrs/m² (mean value). Therefore, it follows that: 0.35hrs/m² * 1000 m² = 350 hours. Such an assessment can be reliable only if only a worker has been assumed to be assigned to the task, but really this value depends on the amount of the available workers and the workable days, too. The operations of installing and dismantling the forming system through a tower crane or a self-climbing system could be quite similar, but, when using the self-climbing method, the time needed to the handling of the device could be remarkably reduced.

Moreover, the formwork system that needs the availability of a tower crane implies a greater number of workers, raising the total amount of the worked hours. This is to be said without looking at the workers required for the handling by the means of the tower crane: the greater the cost of a self-climbing system can be, it will be counterbalanced from the advantages deriving from a reduction of the usage time, leaving the tower crane free to accomplish any other tasks.

It is also important to evaluate times and costs dealing with the positioning of the steel bars and cages. The best choice of the system to be used between that one which allows to build the Tower Core in advance and the second one which allows to construct at the same time the walls and the slabs would be affected by such variables. Indeed, it could be assessed 50-100 kg/man-hours for fixing the steel bars and 100-200 kg/man-hours for positioning the steel cages.

As far as the concrete pumping, placing and pouring-related tasks are concerned, the Research Unit estimated approximately a rate of 10-15 m³/hour for the traditionally concrete placing system, with the support of a tower crane, and of 20-25 m³/hours if a wheeled pump and a placing boom have been chosen.

3. The alternatives

When building a High-rise Tower a closer integration between the formwork system and the pumping one is needed. Such an integration can be managed in various ways: as it has already been said, the stationary boom can be handled together with the self-climbing equipment or could be moved through an its own self-climbing mechanism.

The factors to be taken into account should listed as it follows:

- the shape of the High-rise Tower;
• the sequencing of the activities;
• the features of the construction cycles;
• the steel-framed reinforcement method;
• the climbing of the stationary boom.

The main solutions suitable to cope with the construction of the Building Core of a High-rise Tower are basically two:

• to build the walls early, in order to climb the shafts two or three cycles in advance;
• to build at the same time the walls and the slabs.

Each option, of course, encompasses some advantages and disadvantages. In the first case, the state of completion of the slabs must follow (two levels or three later) the placing and pouring of the walls, to make easier the handling of the self-climbing system or of the traditional method, depending on the climbing mechanisms.

The main advantage lies in the fact that when generating a safety-oriented independence between the building of the walls and the pouring of the slabs, any disruptions of the activities should be avoided in the case of a shortage of the supplies or of a failure of the equipments. As it has been already observed, such a solution is highly performing because of the modular features of the formwork system: therefore, only a few special parts are needed. The formwork’s heaviest parts are usually pre-assembled on the field and later handled with the tower crane in order to increase the productivity and to mitigate the risks.
When the Core of the Building is to be built in advance, a set of joints and anchors suitable to carry large loads allows to not slow down the productive cycle. On the other hand, if the pumping system uses a single duct, it is important that the distance between the level of the walls and the level of the slabs could not be too wide, in order to allow the stationary boom to effectively accomplish its function. Moreover, it is advisable to carefully estimate the amounts of the needed elements and the costs of the structural joints and anchors when advancing with the erection of the Core.

In the United States, it is stretched to adopt such a solution, that entails at the same time the concrete placing and pouring of the walls and slabs, in order to save the cost of the anchors, which could turn out in a large amount of parts because of the elevated seismic risks. In order to reducing the delays a briefing has to be daily held on the Construction Site, in order to define and co-ordinate the tasks which have to be carried out on that day, and to increase the productivity itself.

The choice of the formwork system is of crucial importance for the compliance to the cycles of construction. Indeed, only the systems which allow to save time in producing the slabs are conceivable and affordable in order to make effective the preferred solution, avoiding any delays. An usual solution to be used for the formworks is provided through the aluminum panel slab formwork, a modular system that has the advantage to remarkably reduce the times of striking. With such a drophead system, striking can be carried out after only one day (depending on the slab’s thickness and on the strength of the concrete). The drophead is released with a hammer blow which causes the formwork to drop 60 mm (panels and main beams).

The panels can be separated easily from the concrete and immediately used again for the next cycle. An alternative is provided with to the Contractors by the means of modular standardized tables that need to be preassembled. The props can be moved from the slab and return to the vertical position after that the table has been swung out over the guard-rail.
Moreover, the leading Manufactures are also nowadays providing the Contractors with some special lifts able to move the slab formworks without any tower crane, apart from the landing platforms. As it has been already mentioned, the cost/performance ratio is quite an important factor for the Site Management: the activities involving the formworks, which are labour-intensive, are often assessed as highly critical.

Being the productivity rate to build the slabs one of the critical points to be dealt with at the same time, the Site Planner must carefully counterweigh the labor costs (workmanship) and the duration of the tasks to be performed. When the productivity rate of the forming machine is so crucial for building the Core, the self-climbing formwork system appears more performing if coupled with the aluminum panel slab formworks. Otherwise, when coping with special features of the building, tableforms should be used. Nevertheless, if such an option must be adopted, a large storage area is needed.

Figure 7: The handling of a self-climbing formwork system (Peri)

In a High-rise Tower, when a self/climbing or a climbing pumping system has been adopted, it is important to analyze the environmental conditions which can affect the duration of the tasks, as well as the height of the Tower and the time needed to pump the concrete inside the ducts. The concrete must be pumped in a way suitable to maintain its features until it reaches the stationary boom. The pressure of the flow must be greater than the friction measurable within the surface of the ducts.

A rule of thumb entails that to pump a high-performing concrete, the cement content has to be fixed in 240 kg/m³ with 32 mm for the diameter of grains, whilst the sand content should be evaluated in 400
kg/m³ (diameter: < 0.25 mm). The diameter of the line ducts has to be 3-fold the diameter of the concrete grains and only high strength aggregates (diameter: 20 mm) must be used.

Furthermore, the pumped concrete must contain additives, like the silica smoke, able to reduce the weight of the concrete and the heat of hydration. When the concrete is pumped along a vertical straight within a cylindrical duct, the grains could badly move. Consequently, a sort of friction dealing with the duct sometimes could engender breakages and failures to the pumping system.

The environmental conditions can affect the concrete placing and pouring when the buckets are used because of such an activity does depend on the availability of the tower crane, whilst the self-climbing pumping system, although more expensive, is usually not troubled by the adverse weather conditions. Moreover, it is a good practice to install a line of emergency to pump the concrete, because any interruption to the concrete pumping, pouring and placing-related tasks, due to the failure of the duct, could cause serious consequences on the whole construction cycle. The ducts can be connected to the climbing platform or could be fixed on the column.

If the concrete pumping/related task suffers interruptions, the risk of wasting some cubic meters of concrete seems to be very high, because the ducts must be cleaned and the remaining concrete has to be discarded. This effort and requirement causes an increase of the costs, unless such a concrete could be used elsewhere on the site. The duct used as the line of transport of the concrete must be located in a hole within the beams or in a suitable void designed to install the elevators.

On the other hand, the climbing stationary boom moves after the initial phase from a built-on lifting device through the floors and shafts to the higher floors that still have to be built. The features of the stationary concrete booms are affected by the suggested length of the stationary boom’s arm (usually 32 m), which has to be installed and dismantled through another kind of truck-mounted crane.

### 4. Conclusions

The Research Unit listed the achieved main results as it follows:

- until 35-40 meters of height, the traditional climbing formwork system, moved by the means of a tower crane, is the most cost-effective;

- between 40 and 70 meters of height, the option which turns to the rail does work better, handled either with a climbing rail using the hydraulic pump or with a tower crane.

- It is also possible to manage the handling operations in adverse environmental conditions, thanks to a dedicated rail.

- Such an option allows the machine to be used as a hybrid system: as a formwork as well as a windscreen;
• beyond 70 meters of height, it is advisable to take into account the adoption of a self-climbing system with hydraulic jacks, in order to tremendously increase the production rate: the tower crane-independent forming, striking and climbing system accelerates the work procedures on the construction site.

Finally, apart from the choice of the most preferable option, in some case-studies the Contractor and the Sub-Contractors did find tremendous difficulties to dismantling a tower crane which has not been planned at the commencement of the works.

![Figure 8: Choosing a formwork machine](image)

As the Research Unit tried to highlight, the bad solutions are very often caused by mistakes occurred during the tendering phase, when the Bidders neglect to investigate all critical issues: they are forced to compete on the lowest price according to the rules defined by the Public or Private Client.

### 5. Acknowledgement

We would like to express our deep and sincere gratitude to Mauro Munaretti, Liebherr Italia. His wide knowledge and his logical way of thinking have been of great value for us. We are also grateful to our M.Sc. Students in Architectural and Civil Engineering at the University of Brescia Francesca Ardesi, Sergio Coletta and Sara Filippini.
References


Mola F., (2008), “Aspetti progettuali e tecniche costruttive per gli edifici alti”, Convegno ATE, Milano, Italy.


RMAA Safety Performance - How does It Compare with Greenfield Projects?

Chan, A.P.C.
Department of Building and Real Estate, The Hong Kong Polytechnic University
(email: bsachan@polyu.edu.hk)

Wong, F.K.W.
Department of Building and Real Estate, The Hong Kong Polytechnic University
(email: bskwwong@polyu.edu.hk)

Yam, M.C.H
Department of Building and Real Estate, The Hong Kong Polytechnic University
(email: bsmynam@polyu.edu.hk)

Chan, D.W.M.
Department of Building and Real Estate, The Hong Kong Polytechnic University
(email: bsdchanch@polyu.edu.hk)

Hon, C.K.H.
Department of Building and Real Estate, The Hong Kong Polytechnic University
(email: carol.hon@polyu.edu.hk)

Wang, Y.
Department of Building and Real Estate, The Hong Kong Polytechnic University
(email: 06896751d@polyu.edu.hk)

Dingsdag, D.
School of Natural Sciences, University of Western Sydney
(email: D.Dingsdag@uws.edu.au)

Biggs, H.
School of Psychology and Counselling, Queensland University of Technology
(email: h.biggs@qut.edu.au)

Abstract

Gross value of construction work in the repair, maintenance, minor alteration and addition (RMAA) sector in Hong Kong has expanded dramatically by 58% from 1998 to 2007, accounting for over 53% of the whole construction market in 2007. Unfortunately, the portion of industrial accidents arising from this sector also increased substantially during the same period. It is important to improve the safety performance of the RMAA sector. This paper has set out the objectives to examine safety statistics of RMAA works; to compare them with those of greenfield projects; and more importantly, to highlight potential hurdles encountered in the process of comparison and finally to provide effective recommendations for overcoming these impediments. To strive for continuous safety improvement of RMAA works, comparable safety statistics should be compiled for this sector.

Keywords: RMAA, greenfield, safety performance, accident statistics
1. Introduction

Unlike other Chinese mainland mega cities which are currently under substantial demand for new construction, the focus of the construction industry in Hong Kong has started to shift to the repair, maintenance, minor alteration and addition (RMAA) sector. According to the Rating and Valuation Department (2009), over sixty percent of private domestic buildings in Hong Kong have been completed for more than 20 years. Ageing and deterioration of old buildings and infrastructures have stimulated an increasing need of RMAA works, which accounted for approximately 53% of the whole construction market in terms of gross value of work in 2007, representing a dramatic expansion by 58% between 1998 and 2007.

The increasing volume of RMAA projects has inevitably brought about more concerns over safety performance in this sector. As reported by the Labour Department (2008), the percentage of industrial accidents in RMAA projects to all construction injuries has almost trebled over the past decade, standing at over 50% in 2007. The need to improve safety performance in this growing sector is all the while more urgent.

To strive for continuous safety improvement in the RMAA sector, a set of well compiled accident statistics is imperative to enable industrial practitioners, researchers and government bodies to monitor its safety performance and formulate intervention strategies. In this regard, this paper aims to analyze safety statistics of RMAA works; to compare them with those of greenfield projects; and more importantly, to identify shortcomings of the process of comparison and finally to recommend some necessary remedial measures for improvement.

2. An overview of RMAA works

The concept of building life cycle provides the necessary ground for defining RMAA works. The life cycle of a building is the time interval that commences with the initiation of the development decision and terminates with the disposal of the asset (BS3811:1993). Within this interval, repair and maintenance is usually the process spanning over the longest period, compared with other processes such as acquisition and demolition. As soon as being constructed the building begins to deteriorate, such that maintenance activities are required to ensure that the fabric and facilities of the building function at an acceptable level.

According to the BS3811:1993, maintenance is defined as “the combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a

---

1 A greenfield project is one which is not constrained by prior work. It is constructing on unused land where there is no need to remodel or demolish an existing structure. Such projects are often coveted by engineers. Some examples of greenfield projects are new factories, power plants or airports which are built from scratch.’ (Pradeep Jain, Agra, 2006)
state in which it can perform a required function’. This definition involves two processes: ‘retaining’, i.e. work carried out in anticipation of failure, and “restoring”, i.e. work carried out after failure. The former is usually referred as “preventive maintenance” while the latter is often perceived as “corrective maintenance” (Wordsworth, 2001). Repair is defined in the same standards as ‘that part of corrective maintenance in which manual actions are performed on the item’. Repair and maintenance therefore covers all the activities undertaken to sustain the performance of both the building fabric and the associated services installations.

It is generally conceded that repair and maintenance should also include a reasonable element of improvement (Wordsworth, 2001). For example, as a result of technological development, worn out building services installations would usually be replaced with up-to-date systems. However, the phrase ‘to retain or to restore’ under the definition of maintenance suggests the initial standard be taken as the proper basis. If the required function is altered or raised in standard where retaining or replacing the existing components may not be able to serve the needs, minor alteration and addition works would be required.

Although both deal with existing buildings, RMAA works are clearly different from major redevelopment work as the former is undertaken to maintain the existing functional life of a building whilst the latter creates a new one. Major redevelopments usually involve large-scale improvement or conversion work and aim at largely adapting to or increasing the utility of the building. Conversion is usually triggered by the substantial changes in the major use of the building and improvement driven by the need for an overall upgrading of the functional performance to make a building safer, healthier, more efficient, economical, comfortable, convenient or attractive (Catt and Catt, 1981).

3. The rise of RMAA works in Hong Kong

3.1 Increased market share

As a highly developed international metropolis, Hong Kong may have already built most of the buildings and infrastructures required to meet the social and economic demands. Hence, it is not surprising to see a gradual decline in investment of new construction works in Hong Kong over the past decade. By contrast, the repair, maintenance, minor alteration and addition (RMAA) sector has expanded significantly during this period, due to the ageing and deterioration of existing built environment. According to the Rating and Valuation Department (2009), over 60% of private domestic buildings have been completed for more than 20 years. The need to upkeep the performance of such huge amount of old buildings alone already suggests a promising future for the RMAA sector.

Table 1 gives information about the gross value of construction work over the last ten years. In terms of market share, the RMAA sector has surpassed new works sector for the first time in 2006, contributing to 53.5% of the total construction market in that year. The proportion of RMAA works to total construction market has doubled between 1998 and 2007 with a drastic increase by nearly 60% in gross value.
Table 1: Gross value of construction work at current market prices (1998-2007)

Unit: HK$ million at current prices

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential (A)</td>
<td>48 761</td>
<td>56 225</td>
<td>51 920</td>
<td>41 774</td>
<td>36 503</td>
<td>28 612</td>
<td>20 085</td>
<td>16 945</td>
<td>15 518</td>
<td>16 064</td>
</tr>
<tr>
<td>Non-residential</td>
<td>33 866</td>
<td>20 455</td>
<td>17 407</td>
<td>16 026</td>
<td>16 502</td>
<td>18 243</td>
<td>17 425</td>
<td>17 060</td>
<td>14 161</td>
<td>17 289</td>
</tr>
<tr>
<td>Civil Engineering</td>
<td>19 349</td>
<td>16 873</td>
<td>20 583</td>
<td>24 491</td>
<td>21 358</td>
<td>20 710</td>
<td>19 044</td>
<td>14 686</td>
<td>12 311</td>
<td>10 123</td>
</tr>
<tr>
<td>Total Construction Investment (A+B+C)</td>
<td>101 975</td>
<td>93 553</td>
<td>89 910</td>
<td>82 290</td>
<td>74 362</td>
<td>67 564</td>
<td>56 553</td>
<td>48 691</td>
<td>41 990</td>
<td>43 476</td>
</tr>
<tr>
<td>Repair, Maintenance, Minor Alteration and Addition (D)</td>
<td>31 341</td>
<td>32 884</td>
<td>32 161</td>
<td>31 696</td>
<td>31 638</td>
<td>31 468</td>
<td>36 618</td>
<td>42 160</td>
<td>48 240</td>
<td>49 390</td>
</tr>
<tr>
<td>Total Construction Market (A+B+C+D)</td>
<td>133 316</td>
<td>126 437</td>
<td>122 071</td>
<td>113 986</td>
<td>106 000</td>
<td>99 032</td>
<td>93 171</td>
<td>90 851</td>
<td>90 230</td>
<td>92 866</td>
</tr>
<tr>
<td>Percentage of RMAA Works to Total Construction Market (%)</td>
<td>23.5</td>
<td>26.0</td>
<td>26.3</td>
<td>27.8</td>
<td>29.8</td>
<td>31.8</td>
<td>39.3</td>
<td>46.4</td>
<td>53.5</td>
<td>53.2</td>
</tr>
</tbody>
</table>

(Adapted from the “Report on the Quarterly Survey of Construction Output, Table 1A and Table 3, Census and Statistics Department (C&SD) of the HKSAR Government”)

1. C&SD named this figure as “Locations other than sites” which means “Works at locations other than construction sites includes minor new construction activities and renovation works at erected buildings and structures; and electrical and mechanical fitting works at locations other than construction sites”.

### 3.2 Additional government expenditure

Besides the increasing market demand for RMAA works, the Hong Kong SAR Government also planned to increase the capital expenditure in minor works projects in 2009-10 by HK$998 million, from HK$7,574 million to HK$8,562 million, in order to implement 22 additional minor works projects. The approved expenditure in the last financial year of 2008-09 is HK$6.9 billion.

According to the Administration (LegCo, 2009), the aim of implementing more minor works projects is to preserve and create jobs and support small and medium-sized enterprises under current economic recession, as this type of projects in general allows speedy implementation, is more labour intensive
as compared with major capital projects, and better suits the implementation capability of small to
medium-sized contractors.

The additional projects include refurbishment of the exterior of 50 government buildings, renovation
of aged protective surfaces of 500 slopes, the installation and retrofitting of energy-efficient facilities
for various government departments, and provision of green roofs on 40 government buildings.
According to a government spokesman, the additional expenditure is expected to create about 1,600
jobs and save energy cost of about HK$17 million and reduce the emission of over 14,000 tonnes of
carbon dioxide (CO2).

4. Comparison of safety performance

4.1 Safety performance of construction industry

Safety performance of the construction industry in Hong Kong has achieved continuous improvement
over the past decade. As shown in Table 2, the number of industrial accidents in the construction
industry dropped dramatically by 84.5%, from 19,588 in 1998 to 3,042 in 2007, whilst the accident
rate per 1,000 workers fell significantly by 75.6%, from 247.9 in 1998 to 60.6 in 2007. It should be
noted that the decrease in the accident rate (75.6%) is less significant than that in the accident number
(84.5%). This might be attributed to the shrinking construction market hence resulting in a decrease of
workers being engaged in this industry.

Table 2: Industrial Accidents of the construction industry (1998-2007)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) All reported construction accidents</td>
<td>19</td>
<td>14</td>
<td>11</td>
<td>9206</td>
<td>6239</td>
<td>4367</td>
<td>3833</td>
<td>3548</td>
<td>3400</td>
<td>3042</td>
</tr>
<tr>
<td></td>
<td>(56)</td>
<td>(29)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) Accident rate per 1 000 workers</td>
<td>247.9</td>
<td>198.4</td>
<td>149.8</td>
<td>114.6</td>
<td>85.2</td>
<td>68.1</td>
<td>60.3</td>
<td>59.9</td>
<td>64.3</td>
<td>60.6</td>
</tr>
<tr>
<td>(c) All reported accidents in RMAA projects</td>
<td>3510</td>
<td>3328</td>
<td>3402</td>
<td>2582</td>
<td>1925</td>
<td>1485</td>
<td>1454</td>
<td>1509</td>
<td>1697</td>
<td>1524</td>
</tr>
<tr>
<td></td>
<td>(7)</td>
<td>(10)</td>
<td>(12)</td>
<td>(4)</td>
<td>(10)</td>
<td>(8)</td>
<td>(6)</td>
<td>(12)</td>
<td>(9)</td>
<td>(6)</td>
</tr>
<tr>
<td>(i) No. of reported accidents in RMAA Works in public sector sites</td>
<td>466</td>
<td>449</td>
<td>475</td>
<td>331</td>
<td>250</td>
<td>158</td>
<td>104</td>
<td>64</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>(0)</td>
<td>(3)</td>
<td>(1)</td>
<td>(2)</td>
<td>(2)</td>
<td>(2)</td>
<td>(0)</td>
<td>(2)</td>
<td>(5)</td>
<td>(1)</td>
</tr>
<tr>
<td>(ii) No. of reported accidents in RMAA Works in private sector sites</td>
<td>3044</td>
<td>2879</td>
<td>2927</td>
<td>2251</td>
<td>1675</td>
<td>1327</td>
<td>1350</td>
<td>1445</td>
<td>1637</td>
<td>1474</td>
</tr>
<tr>
<td></td>
<td>(7)</td>
<td>(7)</td>
<td>(11)</td>
<td>(2)</td>
<td>(8)</td>
<td>(6)</td>
<td>(6)</td>
<td>(10)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>(d) All reported accidents in greenfield projects [(a)-(c)]</td>
<td>16078</td>
<td>10750</td>
<td>8523</td>
<td>6624</td>
<td>4314</td>
<td>2882</td>
<td>2379</td>
<td>2039</td>
<td>1703</td>
<td>1518</td>
</tr>
<tr>
<td></td>
<td>(49)</td>
<td>(37)</td>
<td>(17)</td>
<td>(24)</td>
<td>(14)</td>
<td>(17)</td>
<td>(11)</td>
<td>(13)</td>
<td>(7)</td>
<td>(13)</td>
</tr>
</tbody>
</table>
Percentage of RMAA accidents to all reported construction accidents

<table>
<thead>
<tr>
<th></th>
<th>17.9%</th>
<th>23.6%</th>
<th>28.5%</th>
<th>28.0%</th>
<th>30.9%</th>
<th>34.0%</th>
<th>37.9%</th>
<th>42.5%</th>
<th>49.9%</th>
<th>50.1%</th>
</tr>
</thead>
</table>

(Adapted from “Accidents in the Construction Industry of Hong Kong (1998 – 2007), Tables 1&2, Labour Department of the HKSAR Government”)

1. The figures cover accidents occurred to workers (employees) whose accidents are reported by their employers under the Employees’ Compensation Ordinance (ECO).

2. Figures in the brackets denote the number of fatalities.

3. The employment figures for computing the accident rate per 1,000 workers are based on the number of manual site workers published by the C&SD.

4. According to the C&SD, the employment figure for RMAA works is not available and hence, it is not possible to compute the accident rate for such sector.

5. Public sector sites include projects commissioned by the Government of the Hong Kong Special Administrative Region, Mass Transit Railway Corporation, Kowloon-Canton Railway Corporation and Airport Authority.

It is worth noting that the rate of decrease of the accident rate in the construction industry has slowed down in recent years, while the number of fatal accidents showed slight fluctuation between 2001 and 2007, after a sharp decrease from 1998 to 2000 (Figure 1).

Figure 1: Accident rate and number of fatal accidents in the construction industry (produced from Table 2)
4.2 RMAA projects vs. greenfield projects

Drastic improvement has been achieved in the safety performance of the greenfield sector with the number of industrial accidents dropping substantially by 90.6% from 16,078 in 1998 to 1,518 in 2007. In comparison, the change seems to be less significant in the RMAA sector, where the accident number decreased by 56.6% from 3,510 in 1998 to 1,524 in 2007 (Figure 2). Due to a slower falling rate in the number of RMAA accidents, the percentage of RMAA accidents to all construction accidents increased correspondingly from 17.9% in 1998 to 50.1% in 2007, already surpassing the portion of greenfield accidents.

Figure 2: Comparison of number of accidents between RMAA and greenfield projects (produced from Table 2)

Figure 3: Comparison of number of fatal accidents between RMAA and greenfield projects (produced from Table 2)
As to the number of fatal accidents, a much faster falling rate has also been recorded in the greenfield sector. There were 49 fatal construction accidents suffered in the greenfield sector in 1998 and the figure fell sharply to 13 in 2007, representing a decease by 73.5%. By contrast, the number of fatal accidents in the RMAA sector fluctuated significantly between 1998 and 2007 (Figure 3).

The large difference in the falling raw rates of the number of fatal and non-fatal accidents, however, is insufficient to justify which sector had a better safety performance. It should be noted that construction volume of RMAA projects has expanded substantially over the past decade, while the greenfield sector suffered considerable contraction. The change in construction volume will inevitably affect the probability of incidence in construction accidents. In other words, it is possible for a sector better regulated with safety rules to incur more occupational injuries given a larger volume of work.

The accident rate is usually used as a supplementary parameter to the number of accidents in comparing safety performance between different sectors since it offers the advantage of capturing the effect of construction volume on the frequency of accidents. Nonetheless, according to the Census and Statistics Department, there are no employment statistics available for RMAA works and hence, it is not possible to calculate the accident rate for this sector and compare it with other sectors.

In order to compare the safety performance between RMAA and greenfield projects based on existing data sets, the number of construction workers can be replaced by construction output for calculating the accident rate (e.g. accident rate per HK$ million). The authors understand that the same amount of money in the RMAA projects normally generates more employment opportunities than greenfield projects, due to their different nature (LegCo, 2009; Ng et al., 2007; Wong and Wong, 2006). However, using construction output offers a more reasonable approach when compared with looking solely at the number of accidents.

4.3 Difficulties encountered with data comparison

4.3.1 Ambiguities in classification of construction work

As shown in Figure 4, the Census and Statistics Department (C&SD) classifies construction works into two major categories, namely “construction works at construction sites” and “construction works at locations other than sites”. “Construction site refers to a demarcated locality where one or more major stages or processes of construction works such as site formation, piling, caissons and superstructure erection, are being carried on. It differs from fitting, decoration and other construction works done on erected buildings and structures. On a construction site, the entire building/structure in question, being unfinished, is not issued with a Certificate of Completion/Occupation Permit and is as yet not ready for use according to its intended purposes.” This definition implies the former category can be generally regarded as greenfield projects and the latter RMAA projects.

The Labour Department also classifies construction works into two categories, namely “new works” and “RMAA works” (Figure 5). “New Works refer to those construction sites where new development or re-development works are being carried out and of which the employment figures on
the number of manual site workers are captured and published by the Census and Statistics Department”, while “RMAA works means repair, maintenance, alteration and addition and refers to those minor works such as construction projects for village-type houses in the New Territories, minor alterations, repairs, maintenance and interior decoration of existing buildings”. It appears that the Labour Department follows the same criteria in classifying construction works, i.e. the scale of work distinguished by whether there is a site for the work to be executed and whether the employment figure of the manual workers can be captured by the C&SD.

4.3.2 Under-reporting of minor injuries

According to Clause 56 of the Construction Sites (Safety) Regulations, a contractor is not required to notify the Commissioner for Labour of the construction work he undertakes if (i) “he has reasonable grounds for believing that the work will be completed in a period of less than 6 weeks”, or (ii) “not
more than 10 workmen are or will be employed on the work at any one time”. This implies that the Labour Department is usually not aware of the undertaking of many RMAA projects due to their minor scale. Consequently, as pointed out by Cheung (2005), many minor injuries in this sector are not likely to be reported to the Labour Department. It is not until some serious industrial accidents happen would such works come to the notice of the Labour Department. With significant under-reporting of minor injuries in the RMAA sector, it is difficult, if not impossible, to compare safety performance of RMAA projects with that of greenfield projects.

4.3.3 Lack of employment figures

The accident rate per 1,000 workers has been widely accepted as the primary indicator of safety performance of greenfield projects. However, no such information is available for the RMAA projects because of the lack of an accurate record of workers in this sector. It is well understood that the RMAA projects are usually undertaken by small-sized contractors with only a few workers hired. The project durations are usually short and the employment is highly unstable. It is hence very difficult for the C&SD to capture their employment figures or to enforce the contractors to report on such figures.

It has been advocated to compare their safety performances by the accident rate per value of construction output in each sector. However, the basis of this comparison is also questionable because different sectors may require different degrees of labour intensiveness. RMAA works tend to require far more workers than for the same amount of work done in greenfield projects.

All these potential deficiencies reveal that the RMAA sector is lacking in precise measurement of safety performance to enable inter-sector comparisons. To strive for continuous safety improvement of RMAA works, more effort should be devoted to the capturing of employment figures and raising of overall accident reporting level so as to derive more comparable safety statistics for this sector.

5. Conclusions

The increasing volume of RMAA projects will be likely to drive up the number of industrial accidents in this sector. This projected increase stimulates the need to exercise extra care to monitor the RMAA safety performance. Accident data is very important to industrial practitioners to enable them to measure such performance and to learn from past mistakes. As commented by Brace et al. (2009), a lack of proper accident data sets, whilst not an underlying cause in itself, could be a de-motivator and barrier to move things forward. Well compiled data, by contrast, will largely help the industry to inform intervention strategies as “national averages and sweeping generalizations can lead people down the wrong path for their particular problems” (Brace et al., 2009).

However, there is currently no employment figure available for the manual workers employed in RMAA projects. This makes it impossible to calculate the accident rate in this sector so as to enable an inter-sector comparison with greenfield projects. Worse still, there appears to be significant under-reporting of minor injuries in RMAA projects since these works are usually too dynamic and small in scale for the responsible authority to monitor. The weak awareness of the importance of accident
reporting and the traditional “blame culture” within the construction industry also contribute to this disturbing situation.

To strive for continuous safety improvement of RMAA works, comparable safety statistics should be compiled for this sector. More concerted efforts should be made to capture the employment figures in RMAA projects by making reporting mandatory. Meanwhile, more government inspections should be conducted and more stringent law enforcement should be imposed to raise the overall level of accident reporting. Individual workers and their employing companies should also be urged to take the issue of reporting accidents more seriously and efficiently.

Acknowledgements

The work described in this paper was fully supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (RGC Project No. PolyU 5103/07E). This study forms part of a research project entitled “Safety climate and its impacts on safety performance of repair, maintenance, minor alteration and addition (RMAA) works” from which other deliverables have been produced with different objectives/scope but sharing common background and methodology.

References


An Algorithm for Classifying Error Types of Front-Line Workers: A Case Study of Occupational Accidents in Construction Sites

Saurin, T.A.
Federal University of Rio Grande do Sul, Brazil
(email: saurin@ufrgs.br)

Costella, M.G.
Federal University of Rio Grande do Sul, Brazil
(email: maralucia35@gmail.com)

Abstract

The objective of this study is to propose improvements in an algorithm for classifying error types of front-line workers. The improvements have been identified on the basis of testing the algorithm on construction sites, an environment in which it had not yet been implemented. Thus, 19 occupational accidents which occurred in a small-sized construction company were investigated and the error types of both workers and crew members who had been injured were classified. The results indicated that there was no human error in 70.5% of the 34 times in which the algorithm was applied, providing evidence that the causes were strongly linked to work system design rather than specific behaviours of workers. Moreover, the study makes recommendations to facilitate the interpretation of questions that form part of the algorithm and proposes changes to some questions in comparison with earlier versions of this tool.

Keywords: accident investigation, human error, safety.
1. Introduction

The literature points out that each type of human error has certain causal patterns, which means that preventive actions should have different emphases for each type of error (Reason, 2008). For example, the use of error-proof devices is particularly recommended for tackling memory lapses and slips, since these types of errors occur when behaviours become automated and, such devices, by definition, operate independently of the operators' attention span. As to violations, characterized by deliberate deviations from safe working practices, they typically require improvements in procedures or improvements in safety culture (Saurin et al., 2008).

Therefore, knowledge of the most frequent error types, especially based on data which allow long-term trends to be identified, is important information for the design of health and safety at work (HSW) management systems. The classifications of error types are useful as they make it viable to organize data and as they contribute to our understanding of the modes through which errors are caused and how they can be prevented (Sanders and McCormick, 1993). However, the literature offers few methods to minimize the subjectivity involved in classifying an error. This might be a source of unreliability when human error data are analysed and tabulated (Grabowski et al., 2009).

Baker and Krokos (2007) also criticize the lack of methods for comparing different classifications, such a lack making it difficult to identify which are best for what purpose. Among the methods available for classifying errors, this study addresses the one put forward by Saurin et al. (2008), which was originally drawn up and tested in order to analyse accidents both in a factory making agricultural equipment and in a fuel distribution company. Basically, the method consists of an algorithm with a series of questions, with answers of the yes or no type, which allows the error types by frontline operators to be classified, based on the SRK (skill, rule and knowledge) classification put forward by Reason (1990) and Reason (1997). In this classification, the errors are differentiated according to the levels of cognitive performance at which they occur, thus providing a more abstract classification than those based on observable characteristics of behaviour (e.g. omissions and repetitions) as well as classifications that highlight local contextual factors, such as stress, interruptions and distractions (Reason, 2008).

It is against this background that this study sets out to make recommendations to facilitate the application and interpretation of questions of the algorithm, since studies conducted hitherto have indicated difficulties of this nature. Improvements in the algorithm were identified based on applying them to the investigation of occupational accidents in the construction industry, an environment in which they had not hitherto been tested.

Moreover, unlike the previous applications, the researchers were able to interview all the workers who had been injured, while what were not used were reports of investigations by the company, as no investigations had taken place. Thus, the context of applying the tool was clearly different from the earlier studies, which contributed to identifying opportunities for improvement. Moreover, applying the algorithm generated exploratory data, which are scarce in the literature, on the most frequent error types among construction workers.
2. Definition of human error and classification of error types adopted in this study

In this study, it is considered that a human error has one or both of the following characteristics: (a) there was a deviation with regard to the correct method of execution, assuming that those who were performing the task had the resources available to carry out the correct method; or (b) a wrong decision was taken, assuming that resources for making the correct decision were available. It is worth noting that the definition adopted does not necessarily mean that a human error leads to undesirable results, since chance can lead to good results even if there were faults in planning or implementation. As previously mentioned, this study adopts the SRK classification proposed by Reason (1990) and Reason (1997), which divides errors into three categories:

(a) skill-based errors (SB): at this level, the operator uses automatic and routine behaviours, with a low level of awareness. The errors typically involve failures of execution, lapses and slips being the most common. While lapses generally involve failures of memory, slips are associated with failures to recognize signs and disturbances of any kind that disrupt automatic behaviours. Lapses or slips occur prior to the detection of a problem;

(b) rule-based errors (RB): at this level, operators raise their awareness in order to apply familiar rules to deviations which are also familiar in routine situations. Three basic types of failures may occur at the RB level: application of a bad rule; application of a good rule, but inappropriate to the situation in question; non-application of a good rule. In this study, only this latter type of RB failure is considered as one type of error of front-line operators, it being designated by the term violation. It is assumed that the application of bad rules, or the application of a good rule inappropriate to the context, are types of errors that should be allocated to more senior levels in the hierarchy who are responsible for conceiving of the rules;

(c) knowledge-based errors (KB): at this level the operator acts at a high level of awareness to solve problems for which there are no rules. Errors are very likely when the operator is required to operate at this level, because, among other reasons, there are usually organizational pressures that limit the time and resources for decision making.

3. Algorithm for classifying error types

The algorithm proposed by Saurin et al. (2008) consists of ten questions, which can lead to five types of final answers (Figure 1): slips, memory lapses, violations, knowledge-based errors, and there was no worker error. Question 1 was expressed as follows: "was the worker aware of the procedures content and/or was he/she trained?" If the answer to Question 1 is no, Question 9 should be asked ("was the worker assigned by his/her superior to carry out this task?") which may lead to an end result either of a violation or of absence of operator error.
When the answer to question 1 is yes, Question 2 should be asked to check if the procedure and/or training were adequate and applicable for the task during which the accident occurred. If they are not adequate and applicable, the algorithm indicates that the final answer should be there was "no worker error." On the other hand, if the answer is yes, Question 3 should be asked: "was the procedure and/or training followed?" This question opens up two main branches in the algorithm. If the answer is positive, it should be asked if there was a technical failure (Question 4), which, if confirmed, indicates that there was no operator error. If a technical fault did not occur, the question should be posed of whether the problem occurred in the context of an unforeseen situation (Question 5). If it was unforeseen, it is characterized as an error that occurred when the worker was operating at the level of knowledge (KB error). If a routine situation, it is characterized as a slip.

As to a negative answer to Question 3, this opens a new line of questioning that begins with Question 6 ("if the procedure and/or training had been followed, would the incident happen?"). If the answer is positive, this indicates that the causes of the event were not linked either to the quality of the procedures or to compliance with them, which leads to the answer "no worker error." Should the answer be no, Question 7 should be asked, which Reason (1997) deems as a substitution test ("would
another worker behave the same way in a same situation?"'). If the conclusion is that other workers would act in the same way, the algorithm indicates that there was "no worker error."

Should the answer be no, Question 8 should be asked ("was the error intentional?"). If the behaviour was not intentional, it is characterised as a memory lapse. Otherwise, it is characterised as a violation. It is worth emphasizing that, after obtaining the conclusion about which type of error occurred, or obtaining the conclusion that no error occurred, the last question of the algorithm should always be asked ("was there any other worker involved?"). This question was introduced to emphasize that the algorithm should be applied to everyone who formed part of the team of operators involved at the scene of the accident, rather than just the victim.

It is also worth stressing that the result "no worker error" means that there was no error of front-line workers. Indeed, in such cases there may have been an error by someone else (e.g. management).

4. Research method

In order to identify opportunities for improving the algorithm, it was applied in the analysis of accidents that had occurred in a small construction company in Brazil, which dealt with both residential and commercial projects. During the period when this study was conducted, the company employed 70 workers on their construction sites (none of which were contracted out), besides 3 civil engineers and 1 architect. The main criterion for choosing this company was the ease of access that the researchers had to data. HSW management is characterized by the attempt to comply with legislation, with no use being made of any practice linked to excellence in performance in HSW in civil construction, such as those identified by Hinze (2002). The company had no procedure to guide the investigation of accidents, nor were there documented records of accidents that had occurred.

Thus, it was necessary for a member of the research team to visit the company's three construction sites that were in progress during the research study. They asked the 70 employees individually if they had experienced or witnessed an accident at work in the company studied. Based on these questions, 26 accidents were identified. However, only 19 events were selected for inclusion in this study, given that, in the other cases, the workers who had suffered injuries and who, therefore, could have added important information, were no longer employees of the company.

In the next stage of the research, interviews were conducted with the following stakeholders and in the following sequence: (a) with the workers who had been injured, (b) with the workers who were on the team in which the victim had worked, (c) with the company’s three engineers. These interviews aimed to clarify the context in which each event occurred, to underpin the understanding of its causes and to obtain support for applying the algorithm. With regard to the workers (31 interviews in all), the interviews lasted on average for about 30 minutes and were not tape-recorded in order to minimize embarrassment or inhibitions. Interviews with workers were in three stages:

(a) Initially, they were asked to provide information which allowed a basic characterization of their profile and the severity of the event to be made, such as their length of working service in the
company; education; age; position; years the event occurred; length of time they were laid off as a result of the event;

(b) Next, the researcher asked the interviewee to give his version of the accident so as to, based on this, recount the story back to him in order to check if the researcher had correctly understood what had really happened;

(c) In the last stage, questions were asked based on a script drawn up by Dekker (2002) to support the understanding of the organizational context that led to the human errors. This script gave rise to other questions during the interview and included questions such as: has a similar situation happened before? Were you trained to deal with this situation or was it a new or unforeseen situation? What safety rules or work performance rules clearly apply in this work situation? Were these rules followed? Was the task carried out under pressures of time, cost or other such ones? Do you think another colleague would do the same thing you did or would he do it differently?

As to the interviews with the engineers, they were held to clarify technical aspects related to each event, such as checking whether the work performance procedures used at the time of the accident had been the ones usually used in the company. In addition, photographic records were made of the environment in which each event occurred. It should be stressed that the possibility of conducting interviews with the workers and engineers, as well as unrestricted access to the construction sites, allowed the event to be described with a relative wealth of detail, especially in comparison to earlier studies that applied the algorithm, and which were based on the reports at hand in the companies themselves. In general, these reports were superficial.

After the interviews, a detailed description of each accident was written up and the algorithm was applied from the perspective of each of the workers who had been injured and from the perspective of each team member. However, in this first round of applications, the researchers noted difficulties in interpreting the questions, and sometimes the result was inconsistent with the context of the event. Thus, some modifications were made to the algorithm, such that the results presented in this article reflect how the modified version of the tool was applied.

5. Results

5.1 Recommendations on how to apply the algorithm

This item presents recommendations for applying the algorithm which were not explained in the earlier studies. These recommendations are illustrated by drawing on the accidents investigated:

(a) Recommendation 1: before starting to use the algorithm, what should be identified, using the description of the accident, are episodes that may serve as a reference for analysing the types of errors. Such episodes can be both decisions taken by operators and the actions they took. In the field study, the need to adopt this systematic approach became clear in the events in which, in addition to an action having occurred which immediately triggered the accident, the worker, moreover, did not
use the necessary personal protective equipment (PPE). In these situations, the algorithm was applied once more to analyze the action and yet again to analyze the decision not to wear the PPE.

As examples, two similar accidents can be cited in which labourers, not wearing gloves, had had their fingers jammed between the cable of the cart carrying concrete and the door frames. Taking into account the action of pushing the cart which culminated with the impact against the door, the application of the algorithm followed the sequence 1-2-3-4-5-10, which characterises a slip. It is worth mentioning that in Question 3, all that was evaluated was if the proper procedure for pushing the cart had been followed, but what was not assessed was the procedure that required the use of gloves;

(b) Recommendation 2: in case of doubts about the answer to a question, a good practice is to test different alternatives in order to check if the end result will be the same or not. As an example, the case may be cited in which, while a steel bar was being cut in the saw, a spark from the cutting disc hit the eye of the operator, who was wearing safety glasses with side shields. Both using the hypothesis of considering that the procedure was incorrect because the glasses were not of the appropriate model (sequence 1-2-10), and using the hypothesis of considering that the glasses were adequate, but perhaps they were damaged (sequence 1-2-3-4-10), the conclusions are that there was no error by the worker;

(c) Recommendation 3: based on recommendation 1, we see that it is possible, even without the application of the algorithm, to conclude that there was no error by the workers involved. Such cases include situations in which there was no action or decision by the workers who serve as references for the application of the algorithm. For example, mention may be made of the accident in which the shoring of a foundation trench did not support the loads and a worker was partially buried. In this case, although the application of the algorithm was unnecessary, it was nevertheless used (sequence 1-2-3-4-10) in order to validate it for such scenarios;

(d) Recommendation 4: the implementation of the algorithm should be undertaken by a team and include the participation of members with experience of the domain in question. In fact, two of the three authors of this study are civil engineers, one of whom is also an engineer of the company investigated, which facilitated understanding the events, their causes and corrective actions.

5.2 Modifications in the algorithm and recommendations as to interpreting the questions

This item presents seven modifications or recommendations for interpreting the questions of the algorithm, mainly targeting its being adapted to the context of construction sites:

(a) Modification or recommendation 1: the interpretation of Question 2 ("was the procedure and/or training adequate and applicable?") can be difficult when there are no documented procedures that specify the steps and rules applicable to the task, as was the case in the construction company investigated. In this case, it is proposed that the procedure adopted as a reference should be the one described in regulations or the one that is tacitly accepted as correct by workers and managers.
If it becomes evident from interviews that there is no consensus about what the procedure tacitly accepted as correct is, the answer to Question 2 should be no. This situation can be illustrated by an accident while the tower of the hoist was being dismounted. In that incident, a worker who was inside the building receiving the elements of the tower (each with a size of 1m x 2 m) broke a finger when his hand was squashed between the piece being received and the structure of the tower. The sequence in the algorithm of the investigation was 1-2-10, for all team members, making it clear that the procedure was inadequate. In fact, there was no consensus either about how many people should remove the pieces, or about whether or not to use gloves for this task, or about what the responsibilities of the employees involved should be. Although there is an intrinsic risk of something falling from a height in this task, it is likely that the lack of consensus arises from the fact that this operation is usually performed only once during the life-cycle of a construction site;

(b) Modification or recommendation 2: since the previous proposal is taken into account, it is unnecessary to make mention of the word training in Questions 2, 3 and 6. If the word ‘procedure’ incorporates those that are tacit, this implies that it also covers situations where the operator knows the procedures only through training, whether these are formal or informal occasions based on learning from more experienced colleagues;

(c) Modification or recommendation 3: Question 1 ("was the worker aware of the procedures content and/or was he/she trained?") was difficult to interpret when there were no documented procedures and when the term ‘procedure’ was interpreted according to proposal (a) as put forward above. Thus, it is proposed that Question 1 be replaced with the following question: was it a routine and/or habitual task for the worker? As an example of using this question, an accident can be cited in which a worker, without protective goggles, was splashed in the eye with concrete while it was being poured. Although he did not know the ideal procedure for this situation (wearing glasses), nor had received formal training to do so, the activity was routine. Thus, in this case, the answer to Question 1 was yes.

It is worth mentioning that in the version of the algorithm shown in Figure 1, the researcher could be induced to give a negative answer to Question 1. This would imply the assumption of an improper job assignment for that specific worker, which does not match the context of the example cited;

(d) Modification or recommendation 4: it is proposed that in Question 6 ("if the procedure and/or training had been followed, would the incident happen?") be added the expression “with the same severity”. The need for this change is illustrated by analysing the decision not to wear gloves in the accidents already commented on, and in which the workers had their fingers crushed against the frame of a door when they were pushing a wheelbarrow. If the algorithm were to be used in its original form, this decision would be analysed according to the sequence 1-2-3-6-10 (there was no worker error).

However, although using gloves would not avoid the occurrence of an accident, it is likely their use would minimize its consequences, which is sufficient justification for their use. Thus, according to this proposal, the analysis of the decision not to wear gloves leads the algorithm to the sequence 1-2-3-6-7-8-10 (violation), the option which was considered in the tabulation of the results. These
accidents also indicated, as an opportunity for improvement, that the design of the carts should be re-assessed in order to facilitate their passage through the doors.

(e) Modification or recommendation 5: Question 3 ("was the procedure and/or training followed?") should be answered from the perspective of everyone involved in the team who performed the task, rather than just in terms of the worker to whom the algorithm is being applied. This means that, should any member of the team not have followed the procedure, the answer to Question 3 should be no. Two similar incidents illustrate the need for this recommendation. They involve events in which workers had their feet pierced by nails that were protruding from pieces of wood scattered on the floor. If the proposed recommendation is adopted, the sequence of applying the algorithm is 1-2-3-6-7-10 (there was no worker error), given that other team members did not follow the procedure of removing the nails from the bits of wood and storing them in piles, in an organized manner;

(f) Modification or recommendation 6: the case study indicated that Question 7 ("would another worker behave in the same way in the same situation?") remains subjective even when it is possible to compare a worker’s performance with that of his teammates. In fact, when there is a team involved, subjectivity still persists to the extent that the performance of different teams should be compared to it. Thus, it is proposed that, if in doubt, a supporting question be used as a subsidiary one in order to answer Question 7 (it is suggested that this question should not be included in the graphical representation of the algorithm): were resources for applying the procedure available, without there being any dependence on others? This question aims to make explicit one of the main reasons that can lead to the breach of an ostensibly proper procedure, namely the lack of the resources (e.g. material or human resources) needed to apply it. If the answer is yes (the resources were available), this probably means that other workers would not act in the same way. If the answer is no, this probably indicates that other workers would act in the same way, thus characterizing the absence of error.

Four examples are cited which justify the contribution of the support question, it being the case that the first two resulted in violations and the last two in the absence of error. The first example refers to an accident during the transport of steel bars by three workers. During loading, the bundle of bars spilled open and a worker had his hand squashed between the irons. However, this worker was the only one of the three who was not wearing leather safety gloves, which, according to the investigation were available. Therefore, given his decision not to wear gloves, the application of the algorithm for the injured worker had the sequence 1-2-3-6-7-8-10 (violation).

As to the second example, unlike the previous one, this illustrates a situation in which all team members acted in the same way. In this case, three workers were preparing a cement mixer to be manhandled over a short distance, without having set a safety lever that would have maintained its loader fixed on top of the mixer. However, one of the team members crossed in front of the mixer (the tacit rule was always to cross behind the mixer, since the loader could only fall forwards) at the same moment as the loader fell, hitting him in the back. In this case, the resources to perform the correct action were available (the lever was in good condition and was accessible) and the application of the rule was immediate, depending only on the workers' action. In applying the algorithm, the decision not to set the safety lever was counted as three violations, one for each team member.
Nevertheless, other accidents revealed situations in which resources were not available and the procedure was not easy to apply. In one such case, the worker used a portable ladder as a support to nail the mould for a beam, and probably due to losing his balance, fractured his finger after hitting it with a hammer. In another case, in order to get down from a suspended scaffold, a worker jumped from a height of 1.50 m to reach the ground, lost his balance and broke an arm. In both accidents, the algorithm indicated the sequence 1-2-3-6-7-10 (there was no error). In fact, the procedures set out in Brazilian regulations and good practices in the industry recommend the use of scaffolding as a means to get access to the beams and to use a ladder to descend from scaffolding. However, such resources (scaffold and ladder) were not made available, which made the choices the workers made necessary and regarded as normal.

Modification or recommendation 7: the original version of Question 8 ("was the error intentional?") was replaced with the following one: was the action and/or decision intentional? The purpose of this change is to make explicit the concept of error presented in item 2 of this article.

If all the proposals presented are taken into consideration, one can arrive at a new version of the algorithm which is appropriate for the context of construction sites (Figure 2).

Figure 2: New version of the algorithm - shadowing highlights changes in comparison with the version presented in Figure 1.
5.3 Error types in the accidents investigated

The 19 accidents investigated made it possible to apply the algorithm 34 times, with 22 of these applications referring to the points of view of the workers who had been injured and 12 referring to those of their team-mates. From the perspective of those who had been injured, the number of applications of the algorithm was greater than the number of workers involved. In fact, whereas 19 workers had been injured, the algorithm was applied 22 times to them, given that, in some events, there was more than one action or decision that served as a reference for the application. Table 1 summarizes the types of errors for all the workers, only for those injured and only for their team-mates.

Table 1: Error types in the accidents investigated at construction sites

<table>
<thead>
<tr>
<th></th>
<th>Applications for all the workers (n = 34)</th>
<th>Applications for the workers injured (n = 22)</th>
<th>Applications for their team-mates (n = 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>There was no error</td>
<td>24 (70.5%)</td>
<td>15 (68.2%)</td>
<td>9 (75%)</td>
</tr>
<tr>
<td>Violations</td>
<td>8 (23.5%)</td>
<td>5 (22.7%)</td>
<td>3 (25%)</td>
</tr>
<tr>
<td>Slips</td>
<td>2 (5.9%)</td>
<td>2 (9.1%)</td>
<td>0 (0.0%)</td>
</tr>
</tbody>
</table>

Based on Table 1, it can be seen that, whatever the perspective, the category of “no worker error” was predominant. In particular, team-mates played a passive and reactive role in most events. Although they committed only 3 violations, they did not contribute to warning colleagues of the hazards. Such data may indicate that teams lack skills in perceiving risk, of communication and of coordination, which are not normally emphasized in the training of construction workers. It is also important to note that two categories of errors were not associated with any application of the algorithm. Regarding the absence of errors at the level of knowledge, this is compatible with the nature of the tasks performed on the building sites of the company investigated, such tasks being relatively repetitive and predictable. On the other hand, these kinds of tasks are susceptible to memory lapses, especially in dynamic environments such as building sites, where there tend to be several interruptions in routine activities that give rise to lapses. The absence of lapses can mean either that their consequences have not been strong enough to contribute to an accident, so much so that such errors are difficult to identify because they generally lead to the omission of some activity, which in turn makes it difficult to observe the error.

Considering the results of table 1, in the context of the construction company investigated, there is evidence that the greatest potential for advances in HSW lies in tackling latent conditions rather than active failures of workers. In fact, this indicates that regardless of being a human error investigation tool, the proposed algorithm does not adopt a person model of accident causation (Reason, 2008). It induces the investigation of the context in which errors happened (a feature of system models of accident causation) which allow the identification of contributing factors that are temporally and physically distant from the accident scenario.
6. Conclusions

The main objective of this study was to identify opportunities for enhancing an algorithm for classifying types of human errors, based on its application to the investigation of accidents on building sites. Thus, this study resulted in a new version of the algorithm, adapted to the context of building sites. The need for this new version arose from the difficulties of interpreting the questions in an environment that did not possess formal procedures and in which the breach of good HSW practices appeared to be the rule. It is worth stressing the fact that 70.5% of the applications have indicated the absence of error is strongly indicative that HSW actions should be primarily targeted on the management of the enterprise, rather than being focused on the behaviours of the workers.

References


Designing for Safety – Applications for the Construction Industry

Lew, J.J.
Purdue University
(email: lewj@purdue.edu)
Lentz, T.J.
National Institute for Occupational Safety and Health, USA
(email: tlentz@cdc.gov)

Abstract

While the rate of serious injuries and fatalities for construction workers in the United States has been improving as indicated by some statistics, there are major challenges in construction safety towards meeting a long-term goal of zero injuries. To achieve that goal, a variety of different approaches to safety should be considered and implemented. This paper will examine one such approach which involves designing for safety with consideration given to the safety of construction workers in particular. The paper will explore a current designing for safety initiative known as Prevention through Design (PtD) which seeks to implement design solutions to address hazards in construction along the lifecycle safety continuum for a construction project, beginning in the conceptual design phase and continuing through to completion. The paper describes the activities that are educating the broad construction audience (owners, designers, and contractors) and the efforts to increase partnership involvement in designing for construction safety. The objective of designing for construction safety is to eliminate the construction hazards with deliberate assessment of potential hazards and incorporation of design solutions within the project. The paper will describe this approach, and will provide examples of the application of designing for safety such as: structural design layout to reduce exposure to falls and the use of value engineering in the preliminary project phase.

Keywords: preliminary design phase, education, hazards, Prevention through Design (PtD)
1. Introduction and background

1.1 Hazards and their consequences in the construction industry

In the United States, the construction industry employs roughly 7.5% of the nation’s workforce yet accounts for over 20% of the nation’s occupational related deaths. Despite the fact that morbidity and mortality statistics mark a steady improvement in safety conditions for the construction industry, the records serve as reminder of the need to address hazards and provide for the safety and health of construction workers. In a little over a decade, the fatality rate has decreased from 14.7 per 100,000 workers in 1995 (Toscano and Windau, 1996) to 10.5 per 100,000 workers in 2007 (BLS, 2008). However, each year more than 1000 workers are killed in the construction industry, and the industry accounts for a disproportionate percentage of all workplace fatalities compared to employment across all industries.

Workers in the construction industry are involved in trades that are inherently dangerous because of the potential for exposures to multiple hazards. Despite the existence of well-characterized and effective solutions to these hazards, many known for decades, too frequently they are insufficiently implemented. It is estimated that 7 - 10% of the global workforce works in the construction industry, but the sector counts for at least 60,000 fatal accidents or 30 – 40% of all fatal accidents (Murie 2007; ILO 2005). Given these realities, and building upon a wealth of research characterizing hazards and proven solutions, an approach for anticipating, evaluating, and minimizing or removing the hazards prior to initiating work is warranted. This approach begins with the recognition that influence over the safety and health environment of the construction industry and its workers extends much broader than historically acknowledged.

1.2 Responsibility for safety in construction

Traditionally, safety was widely viewed as the responsibility of the contractor. Yet, the goal of zero injuries is not compatible with this view. Rather, the inclusion of owners, designers, and all parties involved in construction projects from planning to completion, is required to ensure that hazards are eliminated and workers are protected. A key component to reducing construction accidents through design and planning is the involvement of construction users and project owners. There are owners who recognize this possibility as an effective method to reduce accidents and accident producing situations, as evidenced when consideration is given to the lifecycle system of a construction project from the conceptual phase to completion. Who influences the safety of construction workers? There is no single influence, as the safety of the worker is influenced by other workers, supervisors, contractors, subcontractors, owners, and designers. Recognizing this string of influences is essential for impacting construction safety, and includes involvement of designers and engineers.

Previous research in Europe in the area of designing for safety has led many European Union (EU) countries to adopt legislation requiring architects and design engineers to implement design for
construction safety (ILO, 1985; European Foundation for the Improvement of Living and Working Conditions, 1991). The effect of these European Directives on safety and health conditions in the construction industry has recently been studied and publicized elsewhere (Aires, Gámez, and Gibb 2010); that study indicates that in a little more than a decade since the Directives were implemented, at least 10 EU countries have experienced significant reductions (~10%) in workplace accident rates. The study authors acknowledge the need for the next phase of the study to evaluate the extent to which reductions can be traced to better planning and design. In the United States construction worker safety is solely the responsibility of construction firms and is reinforced by the Occupational Safety and Health Administration (OSHA) standards and contracts specifications.

Among the pioneers in this effort, the National Safety Council Institute for Safety Through Design established in 1995 sought to advance workplace safety and health in its core mission: To reduce the risk of injury, illness, and environmental damage by integrating decisions affecting safety and health, and the environment in all stages of the design process (Christenson and Manuele, 1999). Within that mission statement are elements of issues that remain relevant and timely – sustainability, occupational safety and health, and the influence of design. Another noteworthy development in efforts to explore and promote discussion about this topic occurred in September 2003, with the convening of a symposium entitled Designing for Safety and Health in Construction. That event represented a “broad collaboration involving scholars and practitioners; the multiple disciplines involved in construction, design, and workplace safety and health; and different countries and continents (Hecker, Gambatese, and Weinstein, 2004).”

2. Prevention through Design (PtD)

2.1 Making the case for design solutions

It starts with planning, and as with any project, this is the stage at which safety and health issues can be addressed most efficiently. Consequently, NIOSH and its partners have created a National initiative, known as Prevention through Design or PtD, to prevent or reduce occupational injuries, illnesses, and fatalities by including prevention considerations into all designs that impact workers. One of the best ways to prevent and control occupational injuries, illnesses, and fatalities is to "design out" or minimize hazards and risks early in the design process.

Many examples of design solutions for challenges such as these exist, and many more remain to be discovered. The objectives of PtD are to promote this concept and its application in all industries, highlighting its importance in all business decisions. (Please refer to http://www.cdc.gov/niosh/topics/PtD/) One construction specialty area with possible applications of this approach relates to the increased emphasis of Green buildings and sustainable resources. The use of specialty roofing materials, insulation, and even installation of solar panels and skylights could all be associated with attendant hazards, in particular working at heights and risk of falls. Based upon the common recognition of this hazard, adopting safer work practices and modifying activities to protect
workers could be achieved through better coordination between manufacturers, facility designers, building owners, roofer, and construction engineers to

- determine the best designs for addressing fall hazards
- provide barriers or appropriate anchor points for fall protection
- design skylights to provide greater strength and durability or include metal coverings to prevent falls through them
- limit exposures to hazardous energy sources during installation and maintenance of solar panels (Lentz et al. 2009).

In particular, falls through skylights can be a significant hazard for roofer, other construction workers, and facility maintenance engineers. The occurrence of such events indicates a need to increase hazard awareness and introduce designs to control fall hazards. Possible design solutions include:

- skylight screens capable of safely supporting the greater of 400 pounds or twice the weight of the employee plus his equipment and materials
- guardrails around the skylight at least 45 inches in height with a top rail and mid rail which should be half way between the bottom surface and top rail. The rails should be able to withstand a live load of 20 pounds per square foot.

In some cases it is realized that these design solutions are not feasible, and consequently other options including personal fall protection should be utilized. A personal fall protection system consists of a body harness, lanyard and anchor points.

Another example of planning to avoid hazards involves structural design layout that affects erection and hoisting such that the sequence of erection could reduce exposure to falls when connections are made. Increased communication between designers, engineers, project owners, and construction project managers is essential for performing a safety constructability review during preliminary project phases.

Architects and designers are able to prepare plans with greater accuracy, efficiency and speed utilizing computer-aided-design (CAD) systems. A recently introduced technique and movement in design and construction is Building Information Modelling (BIM). BIM provides a vehicle whereby continuous learning is possible throughout all phases of a construction project, from conception to completion. CAD permits the visualizing of conflicts of building components. BIM has the potential during early design phases and during construction to reveal situations that involve risk management attention. There are case examples of BIM that show applications for planning, scheduling, improved conflict control, and hazard recognition in buildings (Ku et al., 2008). BIM then provides the possibility for designers to conceive hazard recognition during design and provide this information to constructors.
2.2 Harmonizing national PtD efforts

The interest in and knowledge of the role of design for workplace safety and health predate efforts and activities today. Yet the two related initiatives described here are intended to guide national efforts in the United States: the Prevention through Design (PtD) National initiative developed by the National Institute for Occupational Safety and Health and promoted through the National Occupational Research Agenda (NORA); and the NORA Construction Hazards Prevention through Design (CHPtD) objectives. Although these efforts are harmonized, the former has a scope which encompasses all industry sectors and work practices, while the latter is more focused on unique characteristics of the construction industry.

It should also be noted that many of the concepts and objectives related to PtD and CHPtD are not exclusive to these programs; rather they may include elements which have evolved either as a continuation of earlier efforts or objectives being pursued in concert with other groups based on a common recognition of their importance. Education can have a broad impact for informing designers, owners, and engineers about construction worker safety and how to develop and promote safe design solutions.

To catalyze and harmonize efforts to explore and promote the role of design in the broad field of occupational safety and health, NIOSH and its partners convened the first PtD Workshop in Washington, DC in July 2007. The intent was to launch a National Initiative aimed at eliminating occupational hazards and controlling risks to workers “at the source” or as early as possible in the life cycle of items or workplaces. PtD includes the design of work premises, structures, tools, plants, equipment, machinery, substances, work methods, and systems of work. The workshop attracted approximately 225 participants from diverse industry sectors and disciplines. Viewed as a collaborative endeavour, initial partners included the American Industrial Hygiene Association, the American Society of Safety Engineers, the Center to Protect Workers’ Rights, Kaiser Permanente, Liberty Mutual, the National Safety Council, the Occupational Safety and Health Administration, ORC Worldwide, and the Regenstrief Center for Healthcare Engineering. Others have joined and continue to do so since.

The central tenet of this initiative is as follows:

Addressing occupational safety and health needs in the design process to prevent or minimize the work-related hazards and risks associated with the construction, manufacture, use, maintenance, and disposal of facilities, materials, and equipment (NORA, 2008).

The approach to develop and implement the PtD National Initiatives framed by industry sector and within four functional areas: Research, Education, Practice, and Policy. Goals for each of these areas, and an additional focus area of small businesses, were established at a subsequent meeting of the NORA PtD Council in September 2008. The education goal for the National PtD Initiative is:
For designers, engineers, health and safety professionals, and business leaders to understand principles of PtD and apply knowledge in the design and re-design of facilities, processes, equipment, tools and organization of work (with 5 sub goals).

A comprehensive description of the PtD initiative is documented in an issue of the *Journal of Safety Research* (Volume 39, Number 2, 2008) dedicated to proceedings of the 2007 PtD National Workshop.

**2.3 NORA Construction Hazards Prevention through Design (CHPtD) goals**

The NORA Construction Sector Council was formed in 2006, and is comprised of invited stakeholders and subject matter experts from government, academia, industry groups, organized labor, and private consulting. During its initial face-to-face meetings, the Construction Sector Council identified priority topic areas through a series of discussions and multi-voting processes. Among the resulting topic areas identified, safety by design, later renamed Construction Hazards Prevention through Design (CHPtD) for harmonization and consistency with the broader PtD initiative, was determined to be a priority area for assessing research needs as well as the translation and dissemination of best practices for preventing hazards in construction through design and engineering solutions. A core CHPtD workgroup was formed from volunteers on the Sector Council with interest and experience in this topic area. Additional corresponding members were recruited through the Sector Council in February 2008.

To apply the concept of designing for safety to the construction industry the NORA Construction CHPtD workgroup was given the task of providing leadership to develop goals and priorities. The main idea was to utilize engineering strategies in the design phase of projects to reduce accident producing situations. This is to be accomplished by the formation of partnerships, coordination of efforts, and facilitating networking between the construction industry and associated groups of design organizations.

These activities were performed through a series of facilitated discussions, face-to-face meetings, and multiple teleconferences throughout a three-year period (2006-2008). An overall strategic goal (Goal 13) was established for the CHPtD topic:

*Strategic Goal 13* – Increase the use of “prevention through design (PtD)” approaches to prevent or reduce safety and health hazards in construction.

*Performance Measure* – Increase the use of CHPtD by 33% over the next 10 years.

The intermediate goals and associated performance measures were established to support the strategic goal and describe specific research or research-to-practice (r2p) activities identified as priority activities for this topic area. The draft goals, first disseminated in February 2008, were later revised
### 2.4 Outcomes and early indications of PtD implementation

Since the establishment of the vision and motivation for PtD, activities have started to accelerate. A PtD plan for the National Initiative was established by NIOSH and stakeholders in April 2009 (see [http://www.cdc.gov/niosh/programs/PtDesign/pdfs/PtDStrategicPlan2009.pdf](http://www.cdc.gov/niosh/programs/PtDesign/pdfs/PtDStrategicPlan2009.pdf)). The American Society of Safety Engineers (ASSE) recently published a technical paper and will begin developing a standard for the American National Standards Institute (ANSI) dedicated to addressing occupational risks in design and redesign processes (ASSE 2009). Further, in December 2009, the Acting Assistant Secretary of Labor at OSHA addressed the Advisory Committee for Construction Safety and Health (ACCSH), the advisory body established by statute that provides advice and assistance in construction standards and policy matters to OSHA. He specifically charged the ACCSH Roll-Over Protection work group to include Prevention Though Design issues in its approach to considering hazards. The intent is for ACCSH to provide OSHA with assistance developing products that will make design industries more aware of the value of design decisions that can help reduce hazards to construction workers. Another of the ACCSH workgroups has been formed and given a related task: to consider Green Jobs in Construction and how the roles of engineering, design, and planning can help prevent hazards. These activities will continue to build upon the already mature efforts of the OSHA Alliance Program Construction Roundtable and its Design for Safety work group. Among the guidance developed by the latter were construction Design for Safety training materials, web-based guidance, and design solution case studies for fall protection in construction.

### 2.5 Conclusions

The impact of addressing challenges related to design, and conducting additional research and evaluation, will ultimately be judged against measures that translate into fewer injuries and fatalities by eliminating or mitigating hazards. A reduction in the occurrence of accidents and injuries will not only save lives and improve the quality of life for workers, it can also result in lower workers’ compensation claims and other financial expenditures for contractors and owners of construction projects. In order to recognize hazards that can be eliminated before construction commences a need exists for additional tools in the form of PtD. As with the experience in the EU stemming from the establishment of preventive measures and guidance to address construction hazards, the increased recognition, validation, and dissemination of design solutions for the U.S. construction industry is expected to impact the safety and health conditions during construction activities. Disclaimer

The findings and conclusions in this paper have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be construed to represent any agency determination or policy.
2.6 Acknowledgements

The authors wish to acknowledge the members of the NORA PtD National Initiative and the NORA CHPtD councils for their participation in the development of the framework and priority topic goals. The authors also wish to acknowledge the other groups and individuals who have been and continue to be key proponents of PtD research and innovation.

References


Integration of Safety in the Building Delivery System

Jørgensen, K.
The Technical University of Denmark
(email: kirj@man.dtu.dk)
Sander, D.
NIRAS
(email: dsa@niras.dk)
Staghej, A.
Ankerhus a/s
(email: aage@Ankerhus.dk)

Abstract

It is important to see safety and health in construction as an integrated part of the way in which designers, architects, constructors, engineers and others carry out their consulting services. The philosophy is simple – if the demands for safety and health are incorporated early in the solving of a building assignment, then it becomes much easier to organise the construction site in a safety wise responsible way. In Denmark a report has been drawn up which illustrates how this could be done. The method for implementing this illustration is based on the lean construction model, which is the method recommended as the most suitable for a construction process, since it ensures that considerations for health and safety at work do not conflict with considerations for economical, efficiency wise, quality wise and architectural objectives. The goal is to have the considerations for health and safety at work become a natural part of the construction process and thereby also have them incorporated into the detailed design process. The practical value of the concept depends on how you manage and organise the detailed design process. Keeping health and safety at work in mind through all phases of the construction process will ensure due considerations with regard to organisation, demands for the outcome, analysing and fulfilling demands for buildability and thereby incorporating the demands for health and safety at work into the project material.

Keywords: lean construction, safety and health, design, buildability.
1. Introduction

It is a well known fact, both nationally and internationally, that the construction industry is a generally risky business (Work and Health in the EU – A Statistical Portrait 1994-2002, Eurostat; Jørgensen, 2008; Gambatese et al, 2008; Smallwood, 1996; Toole et al, 2006; Behm, 2005). The EU has documented that 1/3 of the comparatively many and serious occupational accidents are a result of flaws and defects in the client’s and the consultant’s detailed design, and 1/3 are a result of flaws and defects in the contractor’s planning (The European Foundation for the Improvement of living and Working Conditions, 1991). A series of research projects likewise demonstrate that the design forms the basis for safety (Gambatese et al, 2008; Smallwood, 1996; Toole et al, 2006; Behm, 2005). The necessity of incorporating the question of safety into the construction process early on has been a recurring theme through the last 20 years. The ideal situation for the safety of the construction workers is to make this an important parameter for the planners and designers of the conceptual and preliminary design phase (Szymberski, 1997; Gambatese et al, 2008). This served as the basis for the EU directive of 92 (Council Directive 92/57/EEC of 24 June 1992) concerning minimum demands for health and safety at temporary construction sites, where the role of the building planner, be it the client as well as the architect and consultants, is emphasized as having the responsibility for drawing up a plan for health and safety during the execution of the construction project.

The nature of the construction project presents a barrier in itself when wanting to implement both safety and quality into the building process (Loushine et al, 2006). The construction industry is a project based industry which exists in a dynamic and ever changing environment (Lindgard and Rowlinson, 2005). The tenderers’ focus on price instead of e.g. safety often makes the contractors leave out the cost for health and safety from their bids (Brooks, 1993). And even though it is required to include health and safety in the pricing this is not incorporated as well as it should be into the preliminary work on the construction project (Oluwoye and MacLennan, 1994). These circumstances strongly indicate how the work environment during the execution phase depends on the previous planning and on considerations for health and safety in the planning phase. They also indicate a need for clarifying the requirement of incorporating the demands for health and safety into contracts and tendering materials. Research, publications and guidelines on safety and problems with the work environment in the construction industry primarily focus on contractors and the work environment during the execution phase. Traditionally it has been the sole responsibility of the contractors who employ the construction workers, and the working environment legislation supports this (Gambatese & Hinze, 1999; Hinze and Wiegand, 1992). A series of research analyses give examples on how designers and planners generally do not see it as their responsibility to consider the safety of the construction workers. The analyses report statements such as the following: “An architectural firm rarely gets involved in the design of safety issues – we do not make decisions that pertain to construction worker safety. We are a structural firm and as such only responsible for the final product” (Hinze and Wiegand, 1992); "Traditional in the construction sector safety on the construction site is the responsibility of the contractors” (Gambatese et al, 2008); “The Engineers Joint Contract Documents Committee clearly state that designers have no responsibilities for means and methods affecting the safety of construction workers (Toole, 2002); “The initial premise is that clients and designers have been slow in taking up their responsibilities. Construction work covers many activities, techniques, materials and hazards and it is this diversity that increases the
probabilities of accidents occurring” (Baxendale et al, 2000); "Clients have a positive role to play in lowering injury rates and influencing contracts” (Smallwood, 1998).

In a series of research and development projects terms like “safety design” and "total safety management in construction” have gained a footing. In these projects it is pointed out how much the designers actually influence the safety during the construction phase and how decisions, design and construction has a direct impact on the safety of the construction workers (Hinze and Wiegand, 1992; Gambatese & Hinze, 1999). Safe design is defined as the deliberate decisions concerning the safety during construction which have been made during the design phase with the purpose of reducing the risks facing the construction workers’ (Toole et al, 2006). As mentioned earlier, several studies show a clear connection between the designers’ decisions and safety during construction (Hecker et al, 2005; Gambatese et al, 2008; Weinstein et al, 2005; Trethewy and Atkinson, 2003). Since the considerations for health and safety at work were already ensured during the detailed design phase, as well as during the preparation of the construction phase, it is safe to assume that the risk of accidents and other work-related injuries are reduced – including psychological injuries and work-related musculoskeletal disorders (WMSDs). The objective has to be to clarify how the construction workers can easily set up and carry out their work in a safe and healthy environment (Szymberski, 1997; Gambatese et al, 2005; Gambatese et al, 2008). But there also seems to be a need for formulating a best practise in which the designers, planners and contractors can seek inspiration for their attempt to minimize the risks of the construction process. This is thought necessary because the personnel at the consulting architects and engineers have very limited knowledge of how they can take the safety of the construction workers into consideration (Gambatese et al, 2005; Gambatese & Hinze, 1999). When asked what safe design or safe buildability is a series of different ideas were offered which are generally concerned with purely technical directions, but also with planning methods (Toole et al, 2006). An example of this could be, among others: "Tools for Construction Safety Design” (The Construction Industry Institute, 2009) containing over 400 design proposals. England has extensive material on The Health and Safety Executive’s homepage (UK HSE, 2009) and in Australia they recommend a special design review form called CHAIR (Workcover, 2001).

The fundamental principles of safe buildability are among others described in the following manner (Baxendale, 2000):

- Safety has to be considered systematically step by step from te very beginning of a project
- Everyone who influences safety are to participate
- Good planning and coordination must be implemented from the beginning of the project
- Health and safety should be handled by competent personnel
- Communication and the sharing of information between all parties should be included
- A formal record of safety information for future use should be made
The philosophy behind improving health and safety management begins with establishing a team with competencies and resources to manage the project in a way which incorporates safety. The planning supervisor for safety should be appointed as early as possible and is the client’s central responsibility (Baxendale et al, 2000).

2. Model for implementation

Illustration of how to create safe design

A Danish research project has accepted the challenge and attempted to illustrate to designers and planners how safe design could be obtained in more specific terms. The method for this illustration follows the model for "The Lean Project Delivery System", which is described by the fathers of lean constructions – Ballard (2000) and Koskela (2002), and is shown in figure 1. The illustration only includes the first 3 steps or the first 7 phases from programme to preparation of construction.

Figure 1: The basic concept for drawing up the illustration for how health and safety at work can be implemented into the construction project’s design and planning phases, Ballard (2000) and Koskela (2002).

Lean construction has two governing principles: "Maximise value and minimise cost" (Ballard, 2000; Koskela et al, 2002). This happens by emphasizing flow, simplicity and manageability, and planning production according to necessity, in this case the client’s wishes (Kamp et al, 2005). When looking at themes such as quality, safety and economy, a concept based on these principles can be especially interesting. In this context you can view accidents and illnesses as a special form of waste of human
resources. It is the practical experiences of the authors’ with applying this concept that you can create good health and safety conditions for construction projects that do indeed work.

3. Workshops as method for creating value

Planning the phases can be supported by workshops where as many stakeholders as possible are represented. A basic concept of the lean idea is that all involved parties are included in the entire construction process from beginning to end. This entails that the contractors participate early in the planning process and that the planners are involved well into the execution period. The workshop method is proposed for securing this involvement and participation in the process, but other forms can also be used as long as the process and participation of all involved parties is secured throughout the build. This calls for a continuous project manager and a well structured meeting schedule.

4. Project definition, value and needs

The values of the construction are laid down during the first 2-3 phases of the construction process both regarding the end product as well as the construction process. All following phases must necessarily be based on the decisions, strategies and framework determined during these first phases. This also applies to health and safety, where the conditions during construction are totally dependant on how much health and safety is incorporated into the design process and overall requirements for e.g. buildability, materials, planning et al. Of course the main objective is not to limit the possibilities of the construction, but by incorporating health and safety from the beginning as an outcome influencing parameter you could reach new solutions that comply with both the wishes of the client and at the same time enables a safer and healthier construction process. The client leads the way in the opening phases. He can state his terms for the finished construction as well as for the construction process. The degree to which the client is able to formulate his/hers demands for health and safety and to demonstrate his prioritization of this during the opening phases will influence the entire construction process and the realisation of the values.

The construction estimating contains the client’s basic ideas and requirements and the architect’s design which forms the basis for the rest of the construction process. The foundation stone is laid down for that which you wish to build and at what cost, the time frame, quality and health and safety at work including the safety and health for the construction workers.

The programme must contain goals and values for the construction, which means that the client determines the basic values for the construction with regard to: function of the construction i.e. size, location, quality, economy, time frame et al. It is important at this stage that the client sets a definite level for the health and safety of the construction since it affects the choice of collaborators, contracts, suppliers, organisation et al.

Two significant areas influence this stage – the formulation of the vision and strategy of the construction project and the formulation of the plan for carrying out the construction process.
A vision expresses what the client desires for the construction in terms of character and values. This could be expressed as in the following:

- The construction is to be a model project wherein the managerial values, including health and safety at work, are communicated to the collaborators during the entire construction process.

- That health and safety at work is a joint responsibility for all parties involved in the construction process, possibly in an alliance where all parties have well defined duties and tasks aimed at improving health and safety at work.

The strategy is an expression of the way in which the client wishes to fulfil his/hers vision. This could be expressed as in the following:

- That the construction process is to focus on the time frame as well as economy, quality and health and safety at work. This includes minimizing health and safety risks as much as possible during the design and planning phase and is to take place as a purposeful planning of the health and safety process during construction.

- That an objective and measurable goals are set up for the project considering health and safety during construction, and that risks are prevented by identifying them and planning to avoid them early on in the construction process.

- That an organisation is set up managed by e.g. the client’s health and safety coordinator and the head of design and planning. They are to ensure information and knowledge for everyone involved so these can take responsibility and act with regard to the vision for health and safety at work including continuous collection of reports on discrepancies, accidents and near accidents as well as carry out supervision and control e.g. during an audit.

- That everyone involved are motivated towards fulfilling the clients vision for health and safety at work through contracts, bonuses and consequences when the requirements are not met or when they are excellently complied with. This could be carried out by the client’s health and safety coordinator.

**The design criteria** contains the general design criteria, but should still be drawn up in such an explicit way that the following processes understand what it is they are to include in their considerations. The conceptual design can even contain very precise information on what is included in the stated goals and values. When considering health and safety at work it could be expressed as in the following:

- Building components must be manageable in order to minimize heavy lifting. As an alternative, in cases where heavy lifts can not be avoided, suitable lifting tackle is to always be made available.
• Substances and materials that might present a nuisance to the ones working with them are not to be used. As an alternative, in cases where use of these substances or materials can not be avoided, necessary safety equipment is to always be made available.

• The sites and means of access are to provide room enough for the construction workers to apply good work postures. As an alternative, in cases where this is not possible, a special work place evaluation is to be carried out for the assignment with regard to health and safety.

• Traffic roads and transport forms on the construction site are to be designed in such a way that they create a high level of safety for those who move around and work at the site. Areas for walking and driving could e.g. be kept separate. As an alternative, in cases where this is not possible, a work place evaluation is to be carried out and necessary safety precautions are to be taken for when unsafe transportation takes place on the construction site.

It is thought that the health and safety requirements only should be written down in a set of a few general rules that refers to the law of working environment. However experiences show that if this is the method then health and safety considerations are not incorporated into the design and planning of the construction. If only the client explicitly states his demands there are possibilities of creating changes in this area.

5. Lean design

During the phases from ”design concepts” to ”process design and pre project” to ”the main project” planning moves from the overall parameters to a more specific definition of how to solve the minor and major details of the construction. When these phases have been completed there is only a small possibility of changing the conditions under which the construction will take place. Therefore it is important to incorporate considerations for health and safety into these phases. When the client has drawn up specific values and goals for health and safety, they will be reflected in the detailed decisions and solutions made during the process from the design concepts to main project just like the clients other values – and thereby they ensure that health and safety at work is in fact considered in accordance with the requirements.

The lean design largely contains the planning work based on the design concept.

The method signals that the design concept is also an integrated part of the planning and that it can adapt to and be altered within the process.

Because of this the lean design forms the more detailed part of the construction planning consisting of many different elements. The finished construction is the focus of this phase: How it is going to look, which elements it is to consist of, the construction, installations etc. But this is also where the more precise decisions are made on what is to be built and how.
The design concepts establishes what the building is going to look like, its outer appearance, floor plan, choosing the structural engineering principle, choosing materials and installations. This includes identifying the risks that can create difficulties and which are to be a part of considering the choice of construction, materials etc. The deliberations ought to evolve around whether there are alternative solutions which can minimize the need for specific safety requirements later in the process.

Furthermore procedures for communication and cooperation between the involved parties throughout the construction process could be established here. This could e.g. be a decision stating: that the construction process is to be carried out as a lean project; how coordinating health and safety is to take place et al.

Furthermore the architect puts forward demands for how the clients goals, values and specifications from the programme are to be met. This also includes how to handle the requirements for health and safety at work during both construction and during use and maintenance of the building.

This is also the most suitable time for determining and describing structural elements as basis for drawing up control charts for quality assurance and similar control charts for health and safety evaluations.

The process design and pre-project includes documentation from pilot studies and possibly of new methods which are to be applied if possible and clarification of specifications, testing materials and inquiring on possibilities and needs with those involved e.g. end users and authorities. Acceptances are obtained from the authorities, it might be investigated what is possible in areas which have not been clarified and the main project is defined. Moreover this includes the first rough sketch of a plan for health and safety and a specification of which actual risks are to be corrected in the main project. In the process design and pre-project the designer’s demands are transformed into concrete actions and the overall solutions are determined. Moreover the operational action plans for the execution of the construction project are determined.

To a wide extent this is where the final lines are determined for health and safety. Therefore it is important that the plans for product and process with regard to requirements and choices in relation to which consequences it might have on health and safety during both construction and later maintenance of the building are thoroughly looked through during this phase. All structural elements must be scrutinized at this stage ex. the ground, the materials, the building site etc. which have been sketched or decided on. Every part of the construction project is looked through in order to assess the risks concerning health and safety at work based on the safety list for structural elements. There is a definite need of defining buildability and especially safe buildability during this phase and therefore it is necessary to get into a dialogue with the entrepreneurs, who are going to make the construction. The demands stated in the design criteria that may not have been fulfilled in the design concept are to be incorporated in the planning at this point and solutions must be found. The process design very much includes managing and operating the processes – both vertically and horizontally in relation to the entire chain of deliverables being both planning element deliverables and detailed planning deliverables as well as product and material deliverables and output in the form of e.g. the execution of a task.
The overall lines for the process during the execution of the project are added to the demands for the process to be plan able via e.g. lean methods.

6. Lean supply

During the phases from "the main project" to "the supplier project" and to "production preparation" the construction project is planned and defined in detail and the execution of the construction is prepared. Furthermore it is determined which minor and major structural element deliverables are to be agreed upon with which suppliers. The transition and hand over of objectives, decisions knowledge and solutions are based on written and verbal forms of communication where particularly the workshop method and involving the contractors can ease this process. However the final decisions and agreements must always exist in written form.

It is important that the contracts and agreements entered into with both contractors and suppliers contain information on those health and safety risks to which a solution has not been found as well as those demands and requirements for health and safety that were formulated from the beginning by the client and have been incorporated into the design and planning.

Thereby a plan for health and safety becomes a visible product of the considerations and decisions made by the client’s health and safety coordinator during the planning phase in collaboration with the project manager.

In principle the project consists of planning the construction and organising the execution of the construction project. This is usually carried out so that the contractors need only carry out the final detailed planning, which usually takes place during the construction period with the planners, the suppliers and with the construction workers.

The project includes timetables, logistics, agreements, contracts, staffing, detailed plans etc., and among these the construction site plans, the plan for health and safety during the build, the workplace evaluation, the drawings and work sections.

Today the suppliers constitute a more and more significant part of the construction process by delivering system solutions, finished factory-made solutions et al. Because of this part of the planning and preparation of a construction depends on what the product in question consists of and which information, technical materials and mounting instructions those constructing the building need to receive. This makes the suppliers an equally important partner to include in the dialogue on how to solve engineering questions concerning health and safety as well as quality and efficiency.

**The main project – product design** includes the detailed description of how to solve and carry out the construction assignment. During this stage, the main plan, general drawings, building component drawings, detail drawings and detailed descriptions explaining the demands for materials and for carrying out the tasks are drawn up. This is also the phase during which the final plans for health and safety on the construction site are determined as well as the basis for those workplace evaluations that
are to be carried out by the ones working on the project regarding risks that have not been addressed during the design and planning phase.

In connection with the main project the construction has to be scrutinized with regard to buildability and execution.

Detail drawings and detailed descriptions are drawn up in which links between the various building components and mounting details, including their function and buildability, are specified, controlled and determined. In connection with this it has to be evaluated which risks it has not been possible to eliminate during the design and planning phase, and which therefore have to be addressed through precautionary measures during the execution of the construction project. The evaluation will result in requirements for the ones involved in the project to implement the identified measures. The risk assessment will include the client’s values e.g. time frame, price, quality and health and safety at work. This, in combination with Lean Construction’s 7 preconditions for a healthy activity, ensures that obstacles do not arise during the execution of the construction project.

The purpose of the supplier project and detail engineering is to determine which materials, outputs and possible prefabricated building components that are to be delivered by who and when. Choices have to be made concerning choice of product, choice of suppliers and thoughts on delivery times, mounting sequence and mounting method.

This also includes thoughts on the risks possibly connected with handling and processing before mounting and a demand for the suppliers to be a part of the on-site work because of their specialized knowledge about the products.

A series of analyses show that the suppliers are the primary source of new information on products and materials for others involved in the projects. The suppliers are responsible for the set-up and content of the products, and the suppliers are also responsible for providing the product buyers with satisfactory and uniform information on the products such as statutory manufacturer’s manual.

The purpose of the production preparation is to ensure that all goals, requirements and specifications are fulfilled in the material describing what is to be built. The project material must be evaluated in order to assess the buildability and to determine the actual methods for executing the construction project. This is also the stage at which the collaboration between the client’s health and safety coordinator, the planning manager, the construction manager and the contractors is developed. They are to coordinate and communicate the health and safety measures during the build. The client’s health and safety coordinator for design and planning is to hand over the process to the health and safety coordinator for the build. It may be the same person who carries on the work, but often it will be two different health and safety coordinators, since the coordinator for design and planning needs to possess special competencies within planning and the coordinator for the construction needs competencies within executing the construction process. Furthermore the health and safety coordinator for the construction needs to possess special skills in facilitating cooperation and motivation among everyone employed at the construction site.
**Workshop based process planning** has presented good results with regard to collaboration between the building trades and the mutual communication and coordination within the construction process which are vital to complying with the timetables, plans for quality and plans for health and safety at work.

Included in this are planning kickoff meetings and time-outs throughout the construction period, organising foreman meetings, continuous and dynamic planning, arranging introduction meetings for new site employees and involving the construction workers in quality and safety procedures.

### 7. Conclusion

A general theme in literature on the subject is that the construction industry brings along major safety costs for the construction workers worldwide and that occupational injury or fatalities are rather common. Another general theme is that architects, designers and planners have not seen it as their responsibility to provide safety during the execution of the construction projects. They have passed on this responsibility to be solely in the hands of the contractors.

This is given since the employer is responsible for the safety of the employees with reference to the health and safety at work act.

But at the same time the importance of incorporating health and safety into the planning from the very beginning is pointed out, which has led to a legislation which orders the client to make sure that health and safety is handled during the construction design and planning phase.

On the other hand the literature points out again and again that the designers and planners do not possess the knowledge necessary to incorporate health and safety into their work. This is a problem which the Danish report on integrating health and safety in the design and planning phase tries to compensate for. But it is to be considered as a small step on the way and it will not suffice on its own. There is a need for developing methods and gaining experiences and good examples which can form the basis for a development. This development needs to happen fast, if further accidental deaths in the construction industry are to be prevented.

### References


Eurostat data (1994-2002) ”Work and health in the EU – a statistical portrait”.


The European Foundation for the Improvement of Living and Working Conditions (1991) “From Drawing Board to Building Site”.


Identifying Potential Health and Safety Risks at the Pre-Construction Stage

Gangolells, M.
Department of Construction Engineering, Technical University of Catalonia and Group of Construction Research and Innovation, Spain
(email: marta.gangolells@upc.edu)

Casals, M.
Department of Construction Engineering, Technical University of Catalonia and Group of Construction Research and Innovation, Spain
(email: miquel.casals@upc.edu)

Forcada, N.
Department of Construction Engineering, Technical University of Catalonia and Group of Construction Research and Innovation, Spain
(email: nuria.forcada@upc.edu)

Roca, X.
Department of Construction Engineering, Technical University of Catalonia and Group of Construction Research and Innovation, Spain
(email: xavier.roca@upc.edu)

Fuertes, A.
Department of Construction Engineering, Technical University of Catalonia and Group of Construction Research and Innovation, Spain
(email: alba.fuertes@upc.edu)

Macarulla, M.
Department of Construction Engineering, Technical University of Catalonia and Group of Construction Research and Innovation, Spain
(email: marcel.macarulla@upc.edu)

Vilella, Q.
Department of Construction Engineering, Technical University of Catalonia and Group of Construction Research and Innovation, Spain
(email: quirze.vilella@upc.edu)

Abstract

Previous researches have demonstrated that decisions made during the pre-construction stage have a big influence on the construction worker safety. This paper introduces a systematic approach for dealing with health and safety risks during the pre-construction stage. The developed methodology helps designers to calculate the safety-related performance of their residential construction designs, providing a consistent basis for comparisons between them. In order to avoid a typical shortcoming in the evaluation of health and safety risks, indicators are based on quantitative data available in the
project documents. Significance limits are statistically obtained with the analysis of 25 new-start construction projects.

**Keywords:** construction hazards prevention through design, health and safety management, risk assessment, building, construction process.
1. Introduction

Compared to other industries, the construction sector is one of the most hazardous (Carter and Smith, 2006; Wang et al., 2006; Camino et al., 2008), killing approximately 350 employees per year in Spain (Ministerio de Trabajo e Inmigración, Subsecretaría de Trabajo y Asuntos Sociales, 2006). Construction accidents not only cause human tragedy, but also delay project progress, increase costs and damage the reputation of the contractors (Wang et al., 2006).

Designers, architects, engineers and contractors have an influence on the health and safety of building site employees (Gambatese and Hinze, 1999; Behm, 2005; Frijters and Swusste, 2008; Gambatese et al. 2008; Toole and Gambatese, 2008). Since the adoption of the Royal Decree 1627/1997 (transposition of Directive 92/57/EEC), Spanish building designers are legally required to consider health and safety in their designs. However, previous studies have shown that designers in general – not just in the construction industry- fall short of satisfying this obligation (Behm, 2005; Fadier and De la Garza, 2006; Frijters and Swuste, 2008). In addition, most contractors often neglect the implementation of their health and safety plans (Wang et al., 2006; Saurin et al., 2008).

During recent years, the concept of Construction Hazards Prevention through Design (CHPtD) has been widespread, in order to consider construction safety during the design phase. However, the literature has not yet addressed the technical principles underlying CHPtD in order to help designers better perform CHPtD (Toole and Gambatese, 2008). Additional tools and processes are needed in order to assist architects and design engineers with hazard recognition and design optimization (Gambatese, 2008).

2. Aim

The main objective of this paper is to develop a methodological framework to evaluate the safety-related performance of construction designs in order to reduce potential on-site health and safety risks.

The methodology facilitates the identification and quantification of health and safety risks related to the construction process of residential buildings during the design stage. Thus, health and safety risks related to the construction design are predicted before the building construction starts and therefore it will be possible to provide a range of on-site safety measures to avoid accidents at the construction site. The methodology is also able to provide the safety risk level of a building project, which can be used when comparing the safety performance of different construction companies and construction sites.

3. Development of the methodology

In order to calculate the safety risk level of a construction project, the first step is to identify specific health and safety risks related to the construction process. Assessing construction safety risks is the
second step of this methodology, which includes: (1) development of indicators, (2) formulation of
the significance limits and (3) determination of the overall safety risk level of a construction project.

3.1 Identification of safety risks related to the construction process

3.1.1 Process-oriented approach

The first step of the methodology is to identify safety risks related to the construction process. OHSAS 18001:2007 suggests using reports of incidents and accidents that have occurred in other organizations. In this case, guidance provided by the Occupational Accident Report Form of the Spanish National Institute of Safety and Hygiene at Work was used to initially identify general safety risks. However, safety risks coming from INSHT had to be customized to the construction process and for this reason an exhaustive preliminary analysis with a process-oriented approach was carried out. Safety risks provided by INSHT (Spanish National Institute of Safety and Hygiene at Work) were analysed for each construction process.

According to Gangolells et al. (2009a) and Gangolells et al. (2009b), construction processes initially considered were (1) earthworks, (2) foundations, (3) structures, (4) roofs, (5) partitions and closures, (6) impermeable membranes, (7) insulations, (8) coatings, (9) pavements and (10) door and window closures. Each of these main processes was separated into smaller process steps, so that finally a total of 219 stages were considered in this initial review.

3.1.2 Preliminary assessment of generic safety risks in each construction stage

According to OHSAS 18001:2007, risk is the combination of probability of occurrence and the severity of the injury or ill. In fact, consideration of risks in terms of the probability of their occurrence and the severity of their consequences provides the general rationale behind safety risks assessments (Carter and Smith, 2006). Probability (P) is defined as the likelihood of a hazard’s potential being realized and initiating an incident or series of incidents that could result in harm or damage. Severity of consequences (C) is defined as the extent of harm or damage that could result from a hazard-related incident (Manuele, 2006). Both criteria are not dependent on the project, so they could be used in this early stage. Probability of Occurrence was defined ranging from improbable to very likely and Severity of Consequences was defined ranging from none to catastrophic. These grade scales were converted into a numerical scale so as to calculate the significance of a safety risk in a specific construction stage (Table 1).

The significance rating of a safety risk in a particular construction stage ($S_{Gi}$) was obtained by multiplying these components of significance. A safety risk was considered to be significant for a particular construction stage if its $S_{Gi}$ was equal or greater than 3. The resultant matrix allowed us to distinguish potential safety risks for each construction stage. In order to make future assessments controllable and effective, most of construction risks were aggregated with the help of experts.
Table 1: Scoring system for Probability of Occurrence (Pi) and Severity of Consequences (S).

<table>
<thead>
<tr>
<th>Probability of Occurrence (Pi)</th>
<th>Severity of Consequences (S)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improbable</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Not very likely</td>
<td>Minor</td>
<td>1</td>
</tr>
<tr>
<td>Likely</td>
<td>Major</td>
<td>2</td>
</tr>
<tr>
<td>Very likely</td>
<td>Catastrophic</td>
<td>3</td>
</tr>
</tbody>
</table>

3.1.3 Health and safety risks related to the construction process

As a result of the process-oriented approach, 90 significant health and safety risks for construction activities were obtained and 22 categories of construction safety risks were proposed (Table 2).

3.2 Assessment of safety risks related to the construction process

Immediate causes of accidents include unsafe conditions and unsafe acts (Jannadi and Assaf, 1998; Fang et al., 2004). Unsafe conditions are physically conditions likely to produce an accident. Unsafe acts cannot be assessed during the pre-construction stage of the construction project and therefore they are not considered in this paper.

Unsafe conditions were evaluated by means of exposure, which assesses the frequency of occurrence of the hazard-event (Fine and Kinney, 1971) or the quantitative estimation of potentially hazardous situations to which workers are exposed during the construction process.

3.2.1 Determining indicators

In order to assess the risk exposure, specific indicators were developed. These indicators represent the variable that was being measured. They can be obtained from the information of construction project documents, since the proposed methodology is developed to assess health and safety risks during the design stage. Table 2 shows the corresponding indicators for each health and safety risk.

Table 2: Safety risks related to the construction process –obtained by means of a process-oriented approach- and corresponding safety indicators.

<table>
<thead>
<tr>
<th>CONSTRUCTION SAFETY RISKS</th>
<th>INDICATOR [P]</th>
</tr>
</thead>
<tbody>
<tr>
<td>FALLS BETWEEN DIFFERENT LEVELS</td>
<td></td>
</tr>
<tr>
<td>FH-1</td>
<td>During small demolition operations, earthworks and foundation work.</td>
</tr>
<tr>
<td>FH-2</td>
<td>During structural work.</td>
</tr>
<tr>
<td>CONSTRUCTION SAFETY RISKS</td>
<td>INDICATOR [P]</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>FH-3 During roof work.</td>
<td>Roof perimeter without boundary walls plus perimeter of holes measuring more than 0.40 m² per m² of roof area [m/m²].</td>
</tr>
<tr>
<td>FH-4 During work on facades, partition walls and vertical coatings.</td>
<td>Total area of partition walls plus total area of cladding on them (parging, plastering, tiling, painting, etc.) [m²].</td>
</tr>
<tr>
<td>FH-5 During floor work.</td>
<td>Total perimeter of holes measuring more than 0.40 m² plus total perimeter of balconies without boundary walls per m² of floor area [m/m²].</td>
</tr>
<tr>
<td>FH-6 During work on door and window closures.</td>
<td>Number of balconies without boundary walls and windows in the building [units].</td>
</tr>
<tr>
<td>FH-7 During work on false ceilings and ceiling coatings.</td>
<td>Total area of cladding of structural floors plus total area of false ceilings plus total area of cladding on them (parging, plastering, painting, etc.) [m²].</td>
</tr>
<tr>
<td>FALLS AT THE SAME LEVEL</td>
<td></td>
</tr>
<tr>
<td>FS-1 During small demolition operations and earthworks.</td>
<td>Site occupation [m²].</td>
</tr>
<tr>
<td>FS-2 During reinforcement work.</td>
<td>Weight of reinforcing bars [kg]. Site occupation [m²].</td>
</tr>
<tr>
<td>FS-3 During roof work.</td>
<td>Total area of roof [m²].</td>
</tr>
<tr>
<td>FS-4 During work on partition walls and vertical coatings.</td>
<td>Total area of partition walls plus total area of cladding on them (parging, plastering, tiling, painting, etc.) [m²].</td>
</tr>
<tr>
<td>INJURIES FROM FALLING OBJECTS DUE TO CRUMBLE OR COLLAPSE</td>
<td></td>
</tr>
<tr>
<td>FOC-1 During earthworks.</td>
<td>Volume of excavated and/or filled material [m³].</td>
</tr>
<tr>
<td>FOC-2 Due to the use of in-situ concrete.</td>
<td>Volume of in-situ concrete [m³].</td>
</tr>
<tr>
<td>FOC-3 During cladding work on facades.</td>
<td>Area of discontinuous cladding in facades [m²].</td>
</tr>
<tr>
<td>FOC-4 During cladding work on partition walls.</td>
<td>Area of discontinuous cladding in partition walls [m²].</td>
</tr>
<tr>
<td>FOC-5 During false ceiling work.</td>
<td>False ceiling area [m²].</td>
</tr>
<tr>
<td>INJURIES FROM FALLING OBJECTS DURING HANDLING</td>
<td></td>
</tr>
<tr>
<td>FOH-1 During materials and waste management operations.</td>
<td>Weight of structural floors, foundations, facades, partition walls, floors and roofs [kg].</td>
</tr>
<tr>
<td>FOH-2 During handling in prefabricated structure assembly.</td>
<td>In case of prefabricated structures: floor area [m²].</td>
</tr>
<tr>
<td>FOH-3 During handling in cladding work.</td>
<td>Presence of heavy claddings.</td>
</tr>
<tr>
<td>FOH-4 During handling in work on door and window closures.</td>
<td>Size of window closures [m].</td>
</tr>
<tr>
<td>INJURIES FROM OBJECTS FALLING FROM ABOVE</td>
<td></td>
</tr>
<tr>
<td>OF-1 During materials and waste management operations.</td>
<td>Weight of structural floors, foundations, facades, partition walls, floors and roofs per m² of floor area [kg/m²].</td>
</tr>
<tr>
<td>CONSTRUCTION SAFETY RISKS</td>
<td>INDICATOR [P]</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>OF-2 During earthworks.</td>
<td>Volume of excavated and/or filled material per m² of site occupation [m³/m²].</td>
</tr>
<tr>
<td>OF-3 During structural work.</td>
<td>Volume of in-situ concrete structures per m² of floor area [m³/m²].</td>
</tr>
<tr>
<td>OF-4 During roof work.</td>
<td>Total roof perimeter without boundary walls plus total perimeter of holes in the roof measuring more than 0.40 m² per m² of roof area [m/m²].</td>
</tr>
<tr>
<td>OF-5 During work on facades and vertical coatings.</td>
<td>Total area of facades plus total area of cladding on them (parging, coating, painting, etc.) [m²].</td>
</tr>
<tr>
<td>OF-6 During work on partition walls and vertical coatings.</td>
<td>Total area of partition walls plus total area of cladding on them (parging, plastering, tiling, painting, etc.) [m²].</td>
</tr>
<tr>
<td>OF-7 During false ceiling work.</td>
<td>False ceiling area [m²].</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INJURIES FROM STEPPING ON OBJECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO-1 During small demolition operations.</td>
</tr>
<tr>
<td>SO-2 During removal of garden elements.</td>
</tr>
<tr>
<td>SO-3 Injuries from stepping on reinforcing bars, screws or nails.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INJURIES FROM HITTING STATIONARY OBJECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS-1 In provisional on-site facilities and storage areas.</td>
</tr>
<tr>
<td>HS-2 During small demolition operations.</td>
</tr>
<tr>
<td>HS-3 During removal of garden elements.</td>
</tr>
<tr>
<td>HS-4 During structural work.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INJURIES FROM HITTING MOVING OBJECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>HM-1 During materials and waste management operations.</td>
</tr>
<tr>
<td>HM-2 During earthworks.</td>
</tr>
<tr>
<td>HM-3 During foundation work.</td>
</tr>
<tr>
<td>HM-4 During structural work.</td>
</tr>
<tr>
<td>HM-5 During work on concrete foundations and floors.</td>
</tr>
<tr>
<td><strong>CONSTRUCTION SAFETY RISKS</strong></td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td><strong>INJURIES FROM CUTS OR BLOWS FROM OBJECTS AND TOOLS</strong></td>
</tr>
<tr>
<td>CS-1</td>
</tr>
<tr>
<td>CS-2</td>
</tr>
<tr>
<td>CS-3</td>
</tr>
<tr>
<td>CS-4</td>
</tr>
<tr>
<td>CS-5</td>
</tr>
<tr>
<td>CS-6</td>
</tr>
<tr>
<td><strong>INJURIES FROM PROJECTION OF FRAGMENTS AND PARTICLES</strong></td>
</tr>
<tr>
<td>FF-1</td>
</tr>
<tr>
<td>FF-2</td>
</tr>
<tr>
<td>FF-3</td>
</tr>
<tr>
<td><strong>INJURIES FROM BECOMING CAUGHT IN OR BETWEEN OBJECTS</strong></td>
</tr>
<tr>
<td>CO-1</td>
</tr>
<tr>
<td>CO-2</td>
</tr>
<tr>
<td>CO-3</td>
</tr>
<tr>
<td>CO-4</td>
</tr>
<tr>
<td>CO-5</td>
</tr>
<tr>
<td>CO-6</td>
</tr>
<tr>
<td>CO-7</td>
</tr>
<tr>
<td><strong>INJURIES FROM BECOMING CAUGHT IN DUMPED VEHICLES OR MACHINES</strong></td>
</tr>
<tr>
<td>CV-1</td>
</tr>
<tr>
<td>CV-2</td>
</tr>
<tr>
<td>CV-3</td>
</tr>
<tr>
<td>CV-4</td>
</tr>
<tr>
<td><strong>CONSTRUCTION SAFETY RISKS</strong></td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>CV-5</td>
</tr>
<tr>
<td>OX-1</td>
</tr>
<tr>
<td>ET-1</td>
</tr>
<tr>
<td>TC-1</td>
</tr>
<tr>
<td>TC-2</td>
</tr>
<tr>
<td>EC-1</td>
</tr>
<tr>
<td>EC-2</td>
</tr>
<tr>
<td>EC-3</td>
</tr>
<tr>
<td>EC-4</td>
</tr>
<tr>
<td>EH-1</td>
</tr>
<tr>
<td>EH-2</td>
</tr>
<tr>
<td>EH-3</td>
</tr>
<tr>
<td>EH-4</td>
</tr>
<tr>
<td>EH-5</td>
</tr>
<tr>
<td>EH-6</td>
</tr>
<tr>
<td>CC-1</td>
</tr>
<tr>
<td>CC-2</td>
</tr>
<tr>
<td>CC-3</td>
</tr>
<tr>
<td>ER-1</td>
</tr>
</tbody>
</table>
## CONSTRUCTION SAFETY RISKS

### INDICATOR [P]

#### INJURIES FROM FIRES AND EXPLOSIONS

| AC-1 | Injuries from fires in areas for storing flammable and combustible substances. | Floor area [m²]. |
| AC-2 | Injuries from breakage of underground pipes (electric power cables, telephone lines, water pipes, or liquid or gaseous hydrocarbon pipes). | Site occupation per m² of floor area [m²/m²]. |
| AC-3 | Breakage of receptacles with harmful substances. Storage tanks for dangerous products. | Floor area [m²]. |
| AC-4 | Injuries from fires due to specific welds. | Type of structure. |

#### INJURIES FROM BEING HIT OR RUN OVER BY VEHICLES

| HV-1 | During material transport operations. | Weight of structural floors, foundations, facades, partition walls, floors and roofs per m² of site occupation [kg/m²]. |
| HV-2 | During earthworks. | Volume of excavated and/or filled material per m² of site occupation [m³/m²]. |
| HV-3 | During foundation work. | Volume of in-situ concrete in foundations per m² of site occupation [m³/m²]. |
| HV-4 | In prefabricated structure assembly. | In case of prefabricated structure: floor area [m²]. |

#### INJURIES FROM TRAFFIC ACCIDENTS

| TA-1 | Injuries from external or internal traffic accidents. | Volume of excavated and/or filled material per m² of site occupation [m³/m²]. |
|      | Weight of structural floors, foundations, facades, partition walls, floors and roofs per m² of site occupation [kg/m²]. |

#### INJURIES FROM CONTACT WITH CHEMICAL AGENTS

| L-1 | Dust generation in activities involving construction machinery or transport. | Volume of excavated material per m² of floor area [m³/m²]. |
| L-2 | Dust generation in earthworks and stockpiles. | Volume of excavated material per m² of floor area [m³/m²]. |
| L-3 | Dust generation in activities with cutting operations. | % of facing brick closure. |
|      | % of the floor area having discontinuous ceramic and/or stone surfaces. |

#### INJURIES FROM CONTACT WITH PHYSICAL AGENTS

| L-5 | Generation of noise and vibrations due to site activities. | Time of activity, use of special machinery (road roller, graders and compactors, etc.) |

In order to make the outcome of the process independent on the people who conduct the assessment, most of the developed indicators are objectively quantifiable. Indicators are expressed in absolute...
terms (when a particular health and safety risk is directly related to the volume of work), or in relative terms (measuring the density of hazards or as a percentage of a total amount).

So as to assess health and safety risks exposure (EX), a four-interval scale was developed. Numerical scores for risk exposure were assigned as shown in Table 3.

<table>
<thead>
<tr>
<th>Risk exposure (EXj)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>No exposure</td>
<td>0</td>
</tr>
<tr>
<td>Low exposure</td>
<td>1</td>
</tr>
<tr>
<td>Significant exposure</td>
<td>9</td>
</tr>
<tr>
<td>High exposure</td>
<td>25</td>
</tr>
</tbody>
</table>

### 3.2.2 Obtaining significance limits

In order to establish numerical limits between the different exposure levels, 25 new-start construction projects were analysed. They ranged in size from a small block of two dwellings with a total floor area of 371 m² to a property development of 93 dwellings and a floor area of 12 681 m². They also ranged from three to seven levels above ground and from zero to two levels below ground.

So as to establish lower and upper limits for a significant exposure, a 68% interval confidence was calculated. Thus, if an indicator was lower than \([\mu-\sigma]\) for a particular construction project, the exposure to the corresponding safety risk was considered low. On the contrary, if it was higher than \([\mu+\sigma]\), the exposure to the corresponding risk was considered high. Indicators within \([\mu-\sigma, \mu+\sigma]\) were considered as significant. Significance limits for each construction safety risk can be consulted on Gangolells et al. (2009b).

If after conducting the assessment, any construction safety risk is found to be unacceptable (EX>9), actions to eliminate or reduce that risk must be applied. In addition, if the documents of a construction project lack the information needed to make a satisfactory appraisal, high exposure is automatically assumed (EXj=25).

### 3.3 Determining the overall health and safety risk level of a construction project

The methodology sets to assess the overall safety risk level of a construction project as shown in (1).

\[
R = \sum_{j=1}^{n} EX_j
\]  

(1)
Where $R =$ overall safety risk level of a construction project; $EX_j =$ exposure corresponding to a safety risk $j$.

Obviously, the construction project with the highest sum is the project with the lowest safety level.

4. Case studies

The methodology has been applied to the design process of a particular construction project: an isolated four-storey building with one underground car park floor. Lots of design decisions may have an effect on the final health and safety risk level, such as the choice between an in-situ concrete structure or a precast concrete structure, the choice of the roof type, the choice of the balconies, or even the size of the windows. Obviously, each design alternative tends to provide different benefits and to have different safety implications.

Analysing the choice between designing an in-situ concrete structure or a precast concrete structure, the methodology highlights that a precast concrete structure reduces risks FS-2 (falls between the same level during reinforcement work), FOC-2 (injuries from falling objects due to crumble or collapse due to use of in-situ concrete), OF-3 (injuries from objects falling from above during structural work), SO-3 (injuries from stepping on reinforcing bars, screws or nails), HS-4 (injuries from hitting stationary objects during structural work), HM-4 (injuries from hitting moving parts of machinery during structural work), CS-2 (injuries from cuts or blows from objects and tools during work on foundation and structure), CO-6 (injuries from becoming caught in or between objects in forming and shoring operations), EH-3 (injuries from exposure to harmful or toxic substances due to the use of concrete release agents at the construction site) and CC-1 (injuries from contact with caustic or corrosive substances during work on foundations and in-situ concrete structures). However, designing a precast concrete structure instead of an in-situ concrete structure causes two other safety risks: FOH-2 (injuries from falling objects during handling in prefabricated structure assembly) and HV-4 (injuries from being hit or run over by vehicles in prefabricated structure assembly). Thus, the safety risk level of designing an in-situ concrete structure was found to be 36, whereas the safety risk level of designing a precast concrete structure was found to be 18.

In the case of choosing a roof type (a trafficable roof with boundary walls or a slate gable roof with a slope of 45% and windows for ventilation), it was found that a trafficable roof with boundary walls reduces the construction safety risks FH-3 (falls between different levels during the roof work) and FS-3 (falls at the same level during roof work. Safety risks OF-4 (injuries from objects falling above during roof work) and CS-3 (injuries from cuts or blows from objects and tools during finishing work on roofs) are also reduced as a result of this alternative.

In any case, designers may assume different safety risk levels in the final design and implement on-site measures at the construction site in order to eliminate or reduce these risks.
5. Conclusions

This paper has presented a methodology for predicting and assessing health and safety risks associated with the construction of new residential buildings. In this way, the methodology is able to highlight how changing design decisions may affect the significance of a particular risk and, therefore, the overall safety risk level of the construction project. However, the methodology does not provide a list of design improvements because it could be seen by designers as an intrusion on their creative process.

This study represents a step forward to encourage smaller construction and design firms to adopt de CHPtD concept. The methodology not only ranks the significance of the safety risks in a specific construction design, but also compares the absolute importance of a particular safety risk in different construction projects. The methodology is especially worthwhile for those less-experienced designers who lack the skills and knowledge required to recognize hazards and develop optimal designs. Designers can compare different construction alternatives during the design phase and determine the corresponding safety risk level without their creative talents being restricted.

The strength of the methodology lies in the fact that it helps designers to explicitly consider construction worker safety during the design process. The developed methodology also highlights significant health and safety risks in advance. Thus, it will be possible to provide a range of on-site safety measures to avoid accidents at the construction site. Proactive hazard elimination is safer and more cost-effective than reactive hazard management.

Risk assessment has traditionally been a qualitative process and therefore subjective judgments often influence its accuracy. In this case, when assessing the safety risk level of a construction project using the suggested methodology, no subjective judgements have to be made, so that the outcome of the process is not dependant on the people conducting the assessment.

6. Further research

Further research is needed in order to consider contributing causes of accidents. Manageable factors for promoting workplace safety performance should be taken into account when a potential safety risk is assessed during the pre-construction stage. Moreover, and in order to better estimate the overall safety risk level of a construction design, future studies should explore the possibility of introducing a weighting system.

Besides these developments, further research is also needed to implement the methodology in a web-based information and knowledge management system with databases in it. Thus, it could be possible to reuse indicator calculations to the assessment of each design. In addition, data collected in previous assessments could be reused to refine the methodology, especially regarding the significance limits of health and safety risks.
7. Acknowledgements

This study was carried out as part of project number 2004/44 of the Spanish Ministry of Public Works (funded under the Spanish R+D Program).

References


Construction Management Health and Safety (H&S)
Course Content: towards the Optimum

Smallwood, J.
Nelson Mandela Metropolitan University
(email: john.smallwood@nmmu.ac.za)

Abstract

Although H&S education is both essential and a pre-requisite for management commitment, South African construction management programs address H&S to varying degrees. Those that do so to a lesser degree invariably focus on legislation and do not address procurement and other dynamic issues of H&S. However, no particular H&S curriculum should be viewed as optimum, as new management strategies, systems, processes and research findings amplify the need for amendment and improvement of a curriculum. Given the aforementioned, a postal survey was conducted among a group of ‘H&S better practice’ general contractors (GCs) to determine the important issues relative to a construction H&S curriculum. Findings of the survey include: construction management predominates in terms of the importance of the inclusion of construction H&S in the tertiary education programs of nine built environment disciplines; construction H&S should be included as a separate subject and as module in various subjects; all twenty-four subject areas are important, and ‘management of SCs’, ‘role of management’, ‘worker participation’, and the ‘OH&S Act’ predominate among construction management H&S curricula subject areas. Conclusions include that the inclusion of a holistic construction H&S course in a construction management programme is essential due to a practicing construction manager’s responsibilities for human and other resources, legislation, and the catalytic role of H&S relative to productivity, quality and schedule, and ultimately, cost. Recommendations include, inter alia, ideally, construction H&S should be included in a construction management programme as a separate subject.

Keywords: construction management, health and safety, education
1. Introduction

Construction management programmes are invariably structured to prepare graduates to fulfil a range of functions in terms of the built environment. These include, inter alia, construction management, project management for clients, property development and administration, management consulting and materials manufacturing. However, regardless of the function fulfilled, construction H&S competencies are essential.

Construction is a multi-stakeholder process undertaken by generally four teams: design; construction; client, and financial. In general, design, which precedes and which influences construction, is separated there from. Research conducted worldwide indicates that clients, project managers, designers, quantity surveyors, construction managers, workers and unions all influence, and have a role to play in H&S.

According to Al-Mufti (1999) civil engineers have a pivotal role in ensuring the H&S of construction workers, which is challenging at the best of times, but more so given that young graduates may be faced with major responsibilities for considerable human and material resources, without necessarily having the full experience and competency at the early stages of their careers. Consequently, it is necessary that they be provided with adequate H&S knowledge during their degree studies. This contention applies equally to construction management.

The non-improvement in the UK construction industry accident rate is attributed to seven factors by Anderson (1999), inter alia, lack of education and training. Anderson maintains that management education and training, particularly that provided by tertiary institutions, “fails to give the necessary emphasis to the subject, and those new to the industry have to fall back on ‘learning on the job’ as opposed to gaining experience on the job.”

Carpenter et al. (2001) recommend that academia embraces H&S risk management as an integral and intellectual component part of the curriculum equivalent in all respects to the study of other risk management aspects of the construction process.

Given the aforementioned the objectives of this study are to determine:

- The importance of H&S to the discipline of construction management;
- The preferred subject areas for a construction management H&S programme, and
- The extent to which construction management programmes address H&S and the subject areas included in such programmes.
2. Review of the literature

2.1 The role and importance of H&S in construction

A study conducted by Smallwood (1996) among construction project managers investigated, *inter alia*, the extent to which inadequate or the lack of H&S negatively affects other project parameters. Table 1 indicates that with the exception of schedule, identified by more than half of the respondents, all the parameters were identified by the majority of respondents. It is notable that productivity and quality predominate, both also having a cost implication, cost itself being ranked third.

Table 1: Extent to which inadequate or the lack of health and safety negatively affects other project parameters (Smallwood, 1996).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Response (%)</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>87.2</td>
<td>1</td>
</tr>
<tr>
<td>Quality</td>
<td>80.8</td>
<td>2</td>
</tr>
<tr>
<td>Cost</td>
<td>72.3</td>
<td>3</td>
</tr>
<tr>
<td>Client perception</td>
<td>68.1</td>
<td>4</td>
</tr>
<tr>
<td>Environment</td>
<td>66.0</td>
<td>5</td>
</tr>
<tr>
<td>Schedule</td>
<td>57.4</td>
<td>6</td>
</tr>
</tbody>
</table>

95.8% of project managers also stated that inadequate or the lack of H&S increases overall project risk. Risk increases as a result of increased variability of resources.

2.2 The role of education and training

Table 2 presents the upstream → downstream sequence postulated by Krause (1993). Culture is at the upstream end, and influences management system, which in turn influences exposure, which may or may not result in incidents at the end point of the sequence. Education and training is an integral activity relative to management system – that is, within the context of managing construction H&S within a construction business and on projects. However, a pre-requisite in terms of H&S culture is optimum tertiary construction management H&S education. The issue being that construction managers need to understand and appreciate the role and importance of H&S in construction, and have an appropriate H&S culture and positive disposition to H&S. Furthermore, Table 2 also informs in terms of likely subject areas that should be addressed in a construction management programme.

This sequence graphically portrays the link between H&S culture and H&S performance.
2.3 Issues relative to H&S

According to Lakanen (1999) the main developments and key issues arising from studies conducted in construction H&S relative to programme content are: new regulations; the level of musculoskeletal injuries; new approaches to H&S; occupational health; accidents; work experience; rehabilitation; promotion of employment; need for development in the work environment, and new H&S measures.

The promulgation of the EU Construction Directive 92/57/EEC on the implementation of minimum H&S requirements at temporary or mobile construction sites, required development of knowledge and skills with respect to the participation of clients and designers in H&S, and the integration of design and construction in terms of H&S.

Ergonomic interventions have major potential to mitigate the high number of musculoskeletal injuries. Physical training also contributes to the mitigation of such injuries.

A holistic approach requires the integrated development of work organisation, physical environment and rehabilitation. Work organisation and physical environment requires an appreciation and understanding of the role of planning and pre-planning of H&S to realise optimum ergonomics. Rehabilitation forms an integral part of H&S and needs to be integrated with other interventions to ensure feedback. Relative to H&S, the role of programmes, awareness in the form of information, motivation and goal setting, training, campaigns, audits and enhanced vocational education in H&S performance, amplify the need for the inclusion of such subject areas in a tertiary programme.
The risk of occupational diseases amplifies the need for related education. The need for expertise related to induction and other forms of training is reinforced by the incidence of accidents involving new workers. The disproportionate number of accidents involving falls indicates a need for expertise relative to accident prevention. Similarly, inadequate housekeeping indicates a need for expertise relative to planning, pre-planning, systems, and audits.

### 2.4 Course content

Research conducted by Smith and Arnold (1999) among GCs in the USA to investigate the optimum H&S course content for construction students at Pennsylvania State University determined the following to be the significant skills required of employees with between one and five years experience: pre-project hazard analysis; preparation of accident reports; conducting tool box talks; participating in project H&S meetings; performing hazard analysis; recognising common hazards; conducting H&S audits; maintaining material safety data sheet (MSDS) files, and the managing of permits. The experience modification rating (EMR), incident ratings, and the cost of accidents (CoA), in particular the indirect CoA, were also considered to be important.

### 2.5 Form of presentation

A study conducted in the USA among Colleges and Universities determined that 45% of curricula included a subject wholly devoted to construction H&S. The remaining 55% of Colleges and Universities either addressed H&S in a generalised manner in other subjects, or a certain group of subjects addressed H&S relative to the subject material (Coble et al., 1999). According to Suckarieh and Diamantes (1995) only about 50% of construction management programmes in the USA have courses that are dedicated to H&S. However, Coble et al. (1999) recommend that all construction management programmes seriously consider specifically addressing H&S in their curricula.

### 3. Research

#### 3.1 Sample frame, methodology and analysis

The questionnaire is virtually a replica of the questionnaire administered in a previous study (Smallwood, 2002).

The sample stratum consisted of 29 general contractors (GCs), which had achieved a first, second, or third place in the then Building Industries Federation South Africa (BIFSA) and currently the Master Builders South Africa (MBSA) National Health and Safety (H&S) Competition and, or a BIFSA / MBSA 4 or 5-Star H&S grading on one or more of their projects. A four-question questionnaire consisting of 36 sub-questions was mailed to 29 GCs, of which 9 responded, 1 questionnaire was returned to the researcher undelivered, which represents a net response rate of 32.1% [9 / (29-1)].
3.2 Findings

Given that the mean scores (MSs) are all > 3.00, the midpoint of the MS range, the GCs can be deemed to perceive the inclusion of construction H&S in the tertiary education programs of the various built environment disciplines as more than important, as opposed to less than important (Table 3). Construction management is ranked first, followed closely by civil engineering, electrical engineering, and project management. However, it is notable that the top four ranked disciplines, mechanical engineering, and architecture have MSs > 4.20 ≤ 5.00, which indicates that the inclusion of construction H&S in such programs can be deemed to be between more than important to very important / very important. Furthermore, given that the MSs of interior design and landscape architecture are > 3.40 ≤ 4.20, the inclusion of construction H&S in such programs can be deemed to be between important to more than important / more than important. In the case of quantity surveying, the MS falls within the range > 2.60 ≤ 3.40 and therefore the inclusion of construction H&S in such a program can be deemed to be less than important to important / important.

Table 3: Degree of importance of the inclusion of construction H&S in the tertiary education programs of various built environment disciplines

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Response (%)</th>
<th>MS</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unsure</td>
<td>Hardly.......................... Very</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Construction management</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Civil engineering</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Electrical engineering</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Project management</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Mechanical engineering</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Architecture</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Interior design</td>
<td>0.0</td>
<td>0.0</td>
<td>11.1</td>
</tr>
<tr>
<td>Landscape architecture</td>
<td>0.0</td>
<td>0.0</td>
<td>11.1</td>
</tr>
<tr>
<td>Quantity surveying</td>
<td>11.1</td>
<td>0.0</td>
<td>11.1</td>
</tr>
</tbody>
</table>

Table 4 indicates that in terms of the form in which construction H&S should be included in a construction management program, GCs are in favour of a separate subject (100%), as opposed to a component of a subject such as construction management (62.5%). However, the universal support for the inclusion of construction H&S as a module in various subjects such as building construction, indicates that the relevance of H&S should be addressed in all subjects. Doing so will also contribute to the raising of the level of awareness of H&S and the inculcation of an H&S culture.
Table 4: Form in which construction H&S should be included in a construction management program

<table>
<thead>
<tr>
<th>Form</th>
<th>Response (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separate subject</td>
<td>100.0</td>
</tr>
<tr>
<td>Component of a subject e.g. construction management</td>
<td>62.5</td>
</tr>
<tr>
<td>Module in various subjects e.g. building construction</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Respondents were requested to indicate the degree of importance of the inclusion of twenty-four subject areas relative to construction H&S in a construction management program (Table 5).

It is notable that all the MSs are above 3.00, the midpoint of the MS range, which indicates that the GCs can be deemed to perceive the inclusion of all subject areas to be more than important as opposed to less than important.

However, it is significant that twenty-one of the twenty-four subject areas have MSs > 4.20 ≤ 5.00, which indicates that the inclusion of such subject areas can be deemed to be between more than important to very important / very important. The top four ranked subject areas all have a MS of 4.89. First ranked ‘management of subcontractors (SCs)’ is possibly attributable to the fact that SCs invariably undertake the greater percentage of work on construction projects, coordinating and integrating the contributions of SCs is important in terms of H&S, and SCs have varying H&S cultures. Second ranked ‘role of construction management’, and third ranked ‘worker participation’ constitute the ‘two pillars’ of any H&S programme / process. The ‘OH&S Act and Regulations’, ranked fourth, provide the framework within which H&S occurs, or does not occur, and effectively constitute a template which contractors can use.

The subject areas ranked fifth to eighth all have a MS of 4.78. Fifth ranked ‘H&S / Productivity / Quality’ indicates the importance of addressing synergy, which is the optimum basis for the promotion of H&S. Furthermore, many of the respective related actions are common. Sixth ranked ‘H&S pre-planning’ is important as H&S needs to be facilitated in the early phases of projects - ‘best practice’ H&S requires that both designers and contractors need to engender and focus on the pre-planning of H&S. Given that invariably H&S courses and tertiary education curricula primarily address ‘H&S programs’, the ranking of seventh is notable. However, such programs address the ‘mechanics’ of H&S, which is important in terms of managing the construction process and activities. Safety, ranked eighth, was uncoupled from health and hygiene to determine whether there is a difference in importance between the two components of H&S.

The subject areas ranked ninth to eleventh all have a MS of 4.67. Ninth ranked ‘H&S education and training’ is important as graduates need to be sensitive to the role of H&S education and training, the various types, and their respective importance. Furthermore, international research indicates there to be an inverse relationship between education and training, and the occurrence of incidents. Tenth ranked ‘role of project managers’ is ranked ahead of thirteenth ranked ‘role of clients’, and fourteenth
The role of project managers is important in terms of H&S as project managers manage design delivery, integrate design and construction, and oversee construction, all three activities being critical in terms of H&S. Furthermore, construction management is the ‘gateway’ qualification for project managers in South Africa. ‘H&S plans’, ranked eleventh, are important, as in terms of the South African Construction Regulations, contractors are required to submit such H&S plans to clients before commencement of construction work. H&S plans must respond to the H&S issues identified in H&S specifications provided by clients to contractors.

The subject areas ranked twelfth to fourteenth all have a MS of 4.56. Twelfth ranked ‘health and hygiene’ is concerned with workers’ occupational health (OH) and to a degree, primary health, as many occupational and primary health issues are inter-related. In reality, the OH issues exceed the safety issues. Furthermore, the health of workers impacts on attendance and absenteeism, productivity, and also quality. Thirteenth ranked ‘role of clients’ is important as both construction managers and project managers need to be sensitive thereto. Construction managers should interface with clients, particularly ‘better practice H&S’ clients to optimize their H&S performance. Project managers in turn, should facilitate H&S contributions by clients. Fourteenth ranked ‘role of designers’ is equally important as both construction managers and project managers should understand and appreciate the role of designers in H&S. The importance is underscored relative to project managers as they manage design delivery and integrate design and construction, and the integration of design and construction is important in terms of H&S. Fifteenth ranked ‘H&S culture’ has a MS of 4.50, is important as it is at the upstream end of the ‘upstream / downstream’ sequence: culture → management system → exposure → incidents i.e. a optimum H&S culture is a pre-requisite for realising a healthy and safe project and, or an improvement in H&S performance.

The subject areas ranked sixteenth to nineteenth all have a MS of 4.33. An understanding and appreciation of sixteenth ranked ‘economics of H&S’ is important as H&S is essentially a ‘profit centre’, and H&S can be promoted on such a basis as opposed to reference to H&S legislation. Stating the business case relative to H&S is likely to be more convincing than citing sections of H&S legislation. Seventeenth ranked ‘role of the media and awareness’ is important as H&S can be promoted or marginalised by the media, and awareness contributes to the maintenance of a healthy H&S culture and H&S climate. Eighteenth ranked ‘environment’ is important as environment and H&S issues are interrelated and the environment is viewed as a project parameter. Nineteenth ranked ‘measurement and statistics’ is important as it is an integral aspect of management system. However, measurement should include both performance and outcome indicators. Twentieth ranked ‘role of the unions’ and twenty-first ranked ‘Compensation for Occupational Injuries and Diseases (COID) Act (workers compensation)’ both have a MS of 4.22. Given that unions are concerned with the well being of the workers they represent, they address H&S. Construction management should integrate unions into the construction process in terms of H&S.

Two subject areas have MSs > 3.40 ≤ 4.20, which indicates that the inclusion of such subject areas can be deemed to be between important to more than important / more than important. Twenty-second ranked ‘ergonomics’ is concerned with the relationship between workers and their workplace. Ergonomics, which is related to H&S, has a direct impact on workers’ health and well being, but
indirectly affects productivity, quality, and time. Twenty-third ranked ‘Influence of procurement’ is important as it should address H&S through, *inter alia*, the inclusion of H&S as a pre-qualification criterion.

Twenty-fourth ranked ‘role of quantity surveyors’ has a MS > 2.60 ≤ 3.40, which indicates that the inclusion of such a subject area can be deemed to be between less than important to important / important. Quantity surveyors have a critical role to play as they should ensure that H&S is budgeted for by affording contractors the opportunity to do so when tendering.

**Table 5: Importance of the inclusion of subject areas relative to construction H&S in a construction management program**

<table>
<thead>
<tr>
<th>Subject area</th>
<th>Response (%)</th>
<th>MS</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manage...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Role of...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Worker participation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OH&amp;S Act &amp; Regulations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H&amp;S / Productivity / Quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H&amp;S pre-planning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H&amp;S programs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H&amp;S education &amp; training</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Role of project managers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H&amp;S plans</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health &amp; hygiene</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Role of clients</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Role of designers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H&amp;S culture e.g. values, vision, goals, &amp; mission</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economics of</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Subject area</th>
<th>Response (%)</th>
<th>MS</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management of subcontractors</td>
<td>0.0</td>
<td>0.0</td>
<td>1</td>
</tr>
<tr>
<td>Role of construction management</td>
<td>0.0</td>
<td>0.0</td>
<td>2</td>
</tr>
<tr>
<td>Worker participation</td>
<td>0.0</td>
<td>0.0</td>
<td>3</td>
</tr>
<tr>
<td>OH&amp;S Act &amp; Regulations</td>
<td>0.0</td>
<td>0.0</td>
<td>4</td>
</tr>
<tr>
<td>H&amp;S / Productivity / Quality</td>
<td>0.0</td>
<td>0.0</td>
<td>5</td>
</tr>
<tr>
<td>H&amp;S pre-planning</td>
<td>0.0</td>
<td>0.0</td>
<td>6</td>
</tr>
<tr>
<td>H&amp;S programs</td>
<td>0.0</td>
<td>0.0</td>
<td>7</td>
</tr>
<tr>
<td>Safety</td>
<td>0.0</td>
<td>0.0</td>
<td>8</td>
</tr>
<tr>
<td>H&amp;S education &amp; training</td>
<td>0.0</td>
<td>0.0</td>
<td>9</td>
</tr>
<tr>
<td>Role of project managers</td>
<td>0.0</td>
<td>0.0</td>
<td>10</td>
</tr>
<tr>
<td>H&amp;S plans</td>
<td>0.0</td>
<td>0.0</td>
<td>11</td>
</tr>
<tr>
<td>Health &amp; hygiene</td>
<td>0.0</td>
<td>0.0</td>
<td>12</td>
</tr>
<tr>
<td>Role of clients</td>
<td>0.0</td>
<td>0.0</td>
<td>13</td>
</tr>
<tr>
<td>Role of designers</td>
<td>0.0</td>
<td>0.0</td>
<td>14</td>
</tr>
<tr>
<td>H&amp;S culture e.g. values, vision, goals, &amp; mission</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economics of</td>
<td>0.0</td>
<td>0.0</td>
<td>16</td>
</tr>
</tbody>
</table>
4. Conclusions

The inclusion of construction H&S in a construction management programme is essential due to a practicing construction manager’s responsibilities for human and other resources, legislation, and the catalytic role of H&S relative to productivity, quality and schedule, and ultimately, cost.

All subject areas presented to the respondents are deemed to be important and therefore it can be concluded that a holistic approach to the presentation of construction H&S at honours level is required, as opposed to merely addressing H&S. The rankings achieved by ‘management of SCs’ and ‘H&S / Productivity / Quality’, reinforces the critical role of H&S in overall project performance. The ranking of ‘management of SCs’ reinforces the increased role of SCs due to increased: specialisation; labour only subcontracting; pyramid subcontracting, and use of alternative procurement systems. The rankings of the ‘role of management’ and ‘worker participation’ amplify the need for management commitment and a participatory management style, which should optimise worker participation. The mean score achieved by ‘H&S culture’ reinforces the critical role of H&S culture in H&S performance. The low level of emphasis on ‘ergonomics’, ‘influence of procurement’, and the ‘role of quantity surveyors’, is possibly attributable to a lack of appreciation thereof.

5. Recommendations

Ideally, construction H&S should be included in a construction management programme as a separate subject, if not, then at least as an identifiable component of a subject such as construction management. This will ensure that construction H&S is afforded the requisite status. However, construction H&S should also be included as a module in various subjects such as building construction.
Given the influence of all stakeholders on construction H&S, and that construction management graduates invariably fulfil a range of roles in industry, the requisite subject areas should be included in a final year honours level programme.

**References**


Utility Risk Management Education for Engineers

Jeffrey J. Lew
Purdue University
(email: lewj@purdue.edu)

James H. Anspach
J. H. Anspach Consulting
(email: jhanspach@aol.com)

Abstract
There are an estimated 20 million miles of underground utility lines in the United States; worldwide this estimate must be a staggering number. Good risk decisions on design and construction cannot be made without knowledge of where these systems are, how they are constructed, and design constraints for relocation or construction in their vicinity. As evidence of a lack of knowledge, utilities are cited as the number one cause of delays to highway projects in the United States. Additionally, excavation activities accidentally cut these lines over 600,000 times a year. These results can and have been catastrophic. Subsurface Utility Engineering (SUE) has emerged as a comprehensive practice of civil engineering to manage these risks, but educational opportunities for this new discipline are few. Previous publications have studied potential ideas for developing SUE curricula within existing educational framework based on the best practices within the SUE industry. Recent national research efforts have substantiated this lack of educational and training opportunities in utility issues. This paper will explore, explain and recommend educational and training needs as presented in recent research studies with interviews conducted with designers and utility companies. These studies were performed under the auspices of the National Academies’ Transportation Research Board, the National Cooperative Highway Research Program, and the American Association of State Highway and Transportation Officials.

Keywords: subsurface utility engineering, SUE, utilities, curriculum, utility locating
1. Introduction

Overhead utility lines are becoming a thing of the past except in rural areas. Underground space in corridors is becoming more congested; the urban underground increasingly resembles a spider web of utility lines, including phones, electricity, gas, cable television, fiber optics, traffic signals, street lighting circuits, drainage and flood control facilities, water mains, and wastewater pipes. The deregulation of utility services is adding to the problem, as multiple service providers seek to place their networks underground. (SHRPII R-15 2009) The increasing installation, maintenance, rehabilitation, or replacement activities related to underground utilities are matched by the increasing need for urban street and highway projects to extend highway networks, reduce congestion and carry out maintenance and renovation projects. (SHRPII R-01) There are an estimated 20 million miles of active and abandoned underground utility lines in the United States; worldwide this estimate must be a staggering number. Good risk decisions on design and construction cannot be made without knowledge of where these systems are, how they are constructed, and what design constraints are for relocation or construction in their vicinity.

2. Background indicating the need for utility knowledge

The technical complexity of utility systems has increased, but the educational opportunities have not kept pace. There is a general shortage of experienced designers and the engineering shortage in the U.S. continues to increase. Additionally, since the utility network is typically in public rights of way, an additional design and construction coordination requirement with other engineers is necessary. Utility relocation engineers employed by utilities have little formal training in transportation system design and construction. This absence of technical knowledge is an obstacle to coordination.

There are a lot of involved utility stakeholders in any particular project. For example, a typical large highway project in the U.S. may involve the following persons:

- State DOT utility engineer
- State DOT survey section personnel
- State DOT Property Department
- Railroad Companies
- DOT traffic Department
- Design or Planning Consultant hired by the state
• Survey consultant hired by the state

• State One-Call Center

• Utility company records personnel

• Utility company engineering personnel

• State DOT maintenance personnel

• Utility company “locators”

• Utility company “contract locators”

• Private industry “private utility locators”

• State construction inspectors

• Utility company construction inspectors

• State consultants for construction inspection

• Utility company consultants for relocation design

• State utility design or relocation designers

• Municipal engineers or their consultants

• Municipal GIS departments

• Federal Aviation Administration (FAA), Corps of Engineers, military, industrial, and other utility owners

• Federal Highway Administration (FHWA)

• Subsurface utility engineering consultants
With this many parties involved in the process, there is a need to clearly identify responsibilities, scopes of work, and timing sufficiently to address all the parties and the means to get utility information delineated on plans. However, educational opportunities regarding utilities are limited to traditional generic engineering courses, on-the-job training, and trade organization courses.

3. Subsurface Utility Engineering

Up until the 1980s, utility issues related to design, coordination, and location and characterization were addressed mainly through a DOT employee working directly with a utility company representative. In 1989, a new branch of civil engineering was introduced at the National Highway Utility Conference, hosted by the FHWA in Cleveland, OH. Subsurface utility engineering (SUE) has emerged in the past three decades as a means to better characterize the quality of subsurface utility information and to manage the risks associated with the project development and construction process that may affect existing subsurface utilities. It combines traditional civil engineering practices of utility data collection and depiction with new technologies and new concepts for defining utility information quality. SUE is defined as a branch of engineering practice that involves managing certain risks associated with utility mapping at appropriate quality levels, utility coordination, utility relocation design and coordination, utility condition assessment, communication of utility data to concerned parties, utility relocation cost estimates, implementation of utility accommodation policies, and utility design. (ASCE 38-02, 2002)

The basic premise of SUE is that utility location data as shown on plans can come from various sources, e.g. records, surface geophysical imaging, determinations based upon physical visible features, and conversations with reliable (or not) parties. Knowing the genesis of this data, and the processes used to collect and interpret it, leads to the ability to classify the utility data as to its reliability. Reliability is defined through four “Utility Quality Levels (QL).” QL A, QL B, QL C, and QL D all have rigorous protocols to follow in order to ascribe these quality levels to data. Perhaps the most important aspect is that in order to have a quality level associated with utility data, that utility data must be collected and depicted under the direct responsible charge of an appropriately registered professional. These collection and depiction protocols are standardized in an ASCE Standard Guideline (CI/ASCE 38-02). The ASCE has developed and holds educational classes in this standard, but other aspects of SUE are not included.

Utility-related problems are a leading cause of delays for highway construction projects, according to a recent National Cooperative Highway Research Program study conducted through the Federal Highway Administration (FHWA). (tfhrc. 2002) To alleviate this delay problem the FHWA has been encouraging the use of SUE on Federal-aid and Federal Lands Highway projects as an integral part of the preliminary engineering process. The proper and successful use of SUE benefits both highway departments and impacted utilities as described in the following paragraph:

Unnecessary utility relocations are avoided. Accurate utility information is available to the highway designers early enough in the development of a project to design around many potential conflicts. This
significantly reduces costly relocations normally necessitated by highway construction projects. Also, project delays caused by waiting for utility work to be completed so that highway construction can begin are reduced. Unexpected conflicts with utilities are eliminated since the exact location of virtually all utilities can be determined and accurately shown on the construction plans. Consequently delays caused by redesign when construction cannot follow the original design due to utility conflicts are reduced. In addition, contractor claims for delays resulting from unexpected encounters with utilities are reduced. Finally safety is enhanced when excavation or grading work can be shifted away from existing utilities; there is less possibility of damage to a utility that might result in personal injury, property damage, and releases of harmful products into the environment.

4. Utility characterization

The term “Utility Characterization” is used to describe the determination of the characteristics of a utility other than location. These characteristics include utility type, owner, size, material type, age, usage status (inactive, abandoned, out-of-service, active), pressures, voltages, capacity, and condition. Condition can be further subdivided by cathodic state (for metallic utilities), pipe-wall thickness, corrosion (inside and outside of the pipe), wrapping and coating integrity, and physical condition (breaks, tears, and gouges). There is no standardization within the locating industry for this data collection and little standardization among or within the various utility agencies. Oil and gas pipelines that are required to be regularly inspected and for which reporting standards have been established by PHMSA or related agencies have probably advanced the furthest both in technologies applied and in the analysis and use of characterization data to avoid future pipeline failures and to implement effective life cycle management practices. Quite a few universities have developed instruction in utility characterization techniques, mostly through their “trenchless technology” classes and centers.

5. Studies related to Utility Risk management

The National Academies in the U.S. and its sponsors such as FHWA and AASHTO have funded several research projects related to utility risk factors as delineated in the SUE definition. Three such recent projects were SHRPII R-01 (Encouraging Innovation in Locating and Characterizing Utilities), SHRPII R-15 (Dot-Utility Coordination: Understanding Key Aspects of the Problem and Opportunities for Improvement), and NCHRP 40-04 (Utility Location and Highway Design). Each of these projects has recognized the lack of training and education available to engineers in the areas of utility location and characterization, coordination, and design. These areas can be considered a three-legged stool. When any of the three legs is not addressed, the result is instability.

Interviews with A/E firms, utility owners, agency designers were conducted during the R-15 study. There was a general consensus that many designers are not sufficiently knowledgeable of the utility relocation process (and technical issues) and suggested that training programs be held in order to educate them. High turnover rates at DOTs have led to inexperienced people doing design. Utility networks can be very
complex. There is a feeling in the utility industry that if DOT designers understood the complexity of some utility systems, a greater effort would be made to avoid utility relocation during highway design. Advancements in technology are also being made, providing new information that could be utilized in the design and relocation process. Training must be done in order to get designers and UCs to utilize this information correctly. To improve the efficiency of highway renewal effort there is a need to develop a core curriculum in utility relocation engineering that can be applied in various educational and training settings.

The R-01 study states that limited efforts have been made to introduce pipeline related courses and utility asset management instruction into engineering curricula but this introduction is difficult because of the press of other growing education and training needs for each branch of engineering. Utility locating and characterization is, practically speaking, not treated at all in the vast majority of engineering curricula in which transportation design project personnel are educated. The topic is most closely related in scientific or engineering curricula to the study of geophysics. Geophysicists are the ones most likely to be involved in new locating and characterization equipment development. Use of general purpose locating equipment is likely to fall to general construction personnel with varying levels of training on how to use the equipment and the physical phenomena affecting the output of the equipment.

6. Recommendations

The vast majority of persons that end up with job duties dealing with utilities receive no formal training at all. The FHWA recognized this fact and developed and sponsored the National Highway Utility Conference, which was held on an annual basis from 1991 through 2000. The AASHTO subcommittee on Right-of-Way and Utilities has made an effort to fill the void created when the National Highway Utility Conferences ended in 2000. This annual AASHTO meeting is mostly attended only by DOT ROW or Utility Section personnel and consultants. Consultant designers do attend, and it has allowed an exchange of knowledge for consultant designers, who are familiar with aspects of highway design, with DOT utility personnel.

The National Highway Institute (NHI) developed a course in 2000 called the Highway / Utility Issues Course. It is a two day course designed to bring DOT utility personnel together with utility personnel to develop awareness of each other’s issues. This course is slated to be re-designed in the next few years.

Utility Organizations do develop and conduct specific utility design courses for their constituents. The Electric Power Research Institute (www.EPRI.com), Gas Technology Institute (www.gastechnology.org), American Water Works Association (www.awwa.org), and others hold courses, webinars, and sessions at conferences relating to the design of specific utilities.

The R-15 study proposed the following path forward as a start of a necessary educational and training process.
• Identify core competencies and indicated learning needs of DOT transportation designers with regard to utility relocation engineering.

• Develop specific learning objectives.

• Develop a model educational and training curriculum. The curriculum should include a clear designation of learning objectives, and an organizational structure designating instructional modules and sequencing. Each module should be fully developed including selection of teaching method, instructional materials and methods for assessing student learning. Additionally, a methodology for curriculum evaluation and a plan for a test pilot should be developed.

• Conduct the Pilot training program, including evaluation of the model curriculum. Address lessons learned and make appropriate revisions to the curriculum.

• Develop guidelines for implementing the curriculum. The guidelines will describe how to use the curriculum for a variety of learning settings. These settings may include, but are not limited to, distance learning, workshops, short courses, and university courses. Also, describe how the curriculum can be deployed for educational purposes such as certificate programs, degree programs, and on-the-job-training (e.g., federal, state, and local governments and the private sector).

Lew and Anspach also outlined SUE-related educational needs in a previous CIB paper. (CIB 2004)

Table 1: SUE-related Educational Needs (Lew and Anspach 2003)

<table>
<thead>
<tr>
<th>1. Utility system design and construction practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Surface geophysical techniques for imaging utilities</td>
</tr>
<tr>
<td>3. Survey practices / engineering surveys / control surveys</td>
</tr>
<tr>
<td>4. CADD platforms / GIS and data management / mapping</td>
</tr>
<tr>
<td>5. Economic issues for utility relocations</td>
</tr>
<tr>
<td>6. Right-of-way issues / national accommodation policies</td>
</tr>
<tr>
<td>7. Utility damage prevention laws, construction site safety</td>
</tr>
<tr>
<td>8. Traffic control, management, scheduling</td>
</tr>
<tr>
<td>9. Contract law, indemnification / insurance / liability issues</td>
</tr>
<tr>
<td>10. Communication skills, existing standards / best practices</td>
</tr>
<tr>
<td>11. Utility condition assessment, repair vs. replacement economics</td>
</tr>
<tr>
<td>12. Highway design / structure design / hydraulic design</td>
</tr>
</tbody>
</table>
7. Conclusions

Subsurface utility engineering is a proven discipline using rigorous methodologies to reduce construction risks due to underground utility locations. A cornerstone of SUE is the classification of the accuracy and reliability of the location of existing subsurface utilities. Several community colleges and private schools have begun providing training in utility “locating” but this provides just a small piece of the needed education.

In spite of the educational opportunities outlined in the above paragraphs, there is no coordinated effort to produce a curriculum and educational venue that meets the broad needs of the subsurface utility engineer. It is unlikely that an engineering undergraduate student will receive any exposure to utilities. A graduate student may receive isolated opportunities, mostly related to utility characterization methods. A practitioner may search out and find several avenues for information, but they are unlikely to be structured, and placed in context with each other.

It is unlikely that progress in meeting these educational needs in a coordinated setting can be accomplished through traditional engineering programs. Yet, there is a growing need and opportunities as utility risks continue to increase. It is more likely that a “Utility Institute” similar to the “Transportation Institutes” of several US universities or the Trenchless Technology Center of Louisiana Tech University, would be a viable venue.

References


http://www.tfhrc.gov/focus/june02/utility.htm


The Role of Health and Safety Coordinator in Sweden and Italy Construction Industry

Aulin, R.
Division of Construction Management, Faculty of Engineering, Lund University
(email: radhlinah.aulin@construction.lth.se)
Capone, P.
Department of Civil & Environmental Engineering, University of Florence
(email: pcapone@dipolo.dicea.unifi.it)

Abstract

Despite rigorous efforts to improve the construction working environment in the European Union, the fatal accident rate is approximately 13 workers per 100,000 as against 5 per 100,000 for the all sectors average. Although the accident rates have declined steadily and steeply since 1994, it still remains unacceptably high. Thousands of construction workers still suffer severe injury and even death every year that otherwise may have been preventable. Hislop (1995) argued that one factor that provides the most effective and positive impact on a site is the definition of accountability and responsibility. Defining the line of accountability and responsibility on site is complex and often fuzzy. Debate on transferring the accountability and responsibility for safety to others are high on the main agenda. Therefore only by clearly defining the accountability and authorising responsibilities can injuries and other accident-related losses be controlled. One of the key players on site is the health and safety coordinator (HSC) whose duty is to coordinate and manage health and safety from the planning through to the completion stage. Since both Sweden and Italy are bounded by the European Union Framework Directive (89/391/EEC) and the Construction Site Directive (CSD) (92/57/EEC), therefore it would be beneficial to examine how both countries define and interpret the roles of HSC on site. Since the directive is legally binding, the members had transposed this directive into their national law. In Sweden the appointment of HSC is stipulated in the Working Environment Act (AML 1/1 2009) while in Italy is established in Dlgs 81/08. This paper will examine and compare the role of HSC on site according to the legislation from both Sweden and Italy while simultaneously defining the responsibilities and establishing accountabilities. Results demonstrate how these two countries had transposed the CSD 92/57/EEC diligently into the national law and provisions. Both countries defined the responsibilities of HSC for two stages of construction project: during the planning and project preparation stage and during project execution stage.

Keywords: health and safety coordinator, legislation, planning stage, construction stage
1. Introduction

In many countries, construction industry continues to be one of the sectors with high accident rates. Some of the common contributing factors are obvious such as transient nature of the industry, constantly changing hazards as the projects is constructed, tight schedule, multiple operation and others. However non-direct factors such as pre-planning, inadequate selection of sub-contractor and poor coordination of various actors on the working site have often been overlooked. Furthermore, the nature of the project that involves multiple players such as designers, contractors, subcontractors, consultants has increased the complexity of coordinating health and safety on worksite. Therefore, by having a means in place, hazards can be identified and effectively controlled and safe work practices promoted (Hislop 1995). This function can be performed by coordinating various roles in ensuring health and safety at workplace through a health and safety coordinator.

Jha and Iyer (2006) had stated examples of projects that were successful with proper coordination and examples of failed projects that are without one. Generally, coordination means unifying, harmonising and integrating different agencies involved in any industry with multiple objectives (Jha and Iyer, 2006). In the construction industry, the central problem of coordination is due to the fact that the basic relationship between the parties to a construction project has the character of ‘interdependent autonomy’ where there is lack of match between technical interdependence and the organisational interdependence (Saram and Ahmed, 2001). Some authors even claimed that the function of coordination is ambiguous due to low tangibility of both the process and the results (Saram and Ahmed, 2001).

The European Union (EU) spelled out the role of coordination through appointed health and safety coordinators (HSC) as stipulated by the Construction Sites Directive (CSD) (92/57/EEC). The CSD 92/57/EEC was transposed into national law in most member countries of the EU with minor changes in the management or personnel structure and/or the safety measures advanced by the original Directive (Usmen et.al. 2001). Some countries worked this Directive creating the mechanism and means for an effective implementation, while other countries have made simple transposition with a few adaptations creating some ambiguity in interpreting the requirements (Alves Dias 2004). In Sweden the appointment of HSC is stipulated in the Working Environment Act (AML 1/1 2009) while in Italy is established in Dlgs 81/08. By examining these two countries will be able to demonstrate how clear the implementation by each country is.

This aim of this paper is to discuss how two member countries, Sweden and Italy translate and define the roles and responsibilities of HSC as stipulated in CSD 92/57/EEC into their working environment. The paper will also examine the similarities and differences in the defining the roles of HSC between these two countries.

2. European Union construction health and safety

Generally all workers within the EU are bounded by the Council Directive 89/391/EEC - Introduction of Measures to Encourage Improvements in the Safety and Health of Workers at Work or better known as the Framework Directive. This Directive introduces measures to encourage improvements in
the safety and health of workers at work; contains general principles concerning the prevention and elimination of occupational risks, the informing, consultation and training of workers; contains minimum rules regarding the safety and health of workers at work. However due to the recognition that the construction industry is a high hazardous industry, has lead the EU to publish in 1992 a special directive changing the way health and safety is being considered (Alves Dias, 2004). The CSD 92/57/EEC requires the construction sector to make efforts towards a continuous and sustained reduction of occupational accidents and diseases. The CSD 92/57/EEC was designed to guarantee the safety and health of workers on construction sites in the European Community whenever building or civil engineering works were carried out. The Commission recognised that large number of accidents resulted from poor coordination especially where various undertakings worked simultaneously or in the succession on the same construction site. Article 3-6 of the CSD 92/57/EEC introduced the new concept of safety and health coordination based on a new chain of responsibilities (including the owner and the designer), new safety and health documents (the prior notice, the safety and health plan, and the safety and health file) and new safety and health stakeholders (the safety and health coordinators for the design phase and for the construction phase) (Hughes and Ferrett, 2007; Alves Dias, 2004). In particular, these requirements must be taken into account as early as possible during the project namely the preparation stage.

This recognition represented a major paradigm shift where previously all responsibility for health and safety were borne upon by the contractors. The CSD 92/57/EEC brings about a cultural change prevalent within the industry (Usmen et.al. 2001). The introduction of the CSD 92/57/EEC had caused architects, in particular, across Europe to feel uncomfortable with this change in responsibility from the contractor to the client, who was required to take appropriate steps with respect to safety and health in the planning and execution of construction project. Furthermore, concerns are growing about the additional costs to implement the revised structure embodied in the provisions of the CSD 92/57/EEC (Usmen et.al. 2001). This cost has been estimated to range between 0.2 – 2% of the total project cost distributed on the basis of 35% for coordination during the project preparation phase and 65% during the project execution phase (Usmen et.al. 2001). There is also confusion in some counties about the need for the health and safety documents content till example the safety and health plan. A final concern revolves around the poorly defined competence and qualification requirements of the safety coordinator with mutual recognition of training and development programs and qualifications (Usmen et.al. 2001).

### 3. Role of construction health and safety coordinators

#### 3.1 Sweden

The function of coordination is stipulated in both the old and new versions of the Work Environment Act - AML 1997:1160 and AML 1/1 2009. The older version (AML 1997:1160) defines the function of coordination in Chapter 3 Section 7 ambiguously. It states that the client is responsible for coordination measures for the prevention of ill-health and accidents on a common worksite for the activity. The coordination function may be transferred to some other company or employer carrying on activities on the common worksite and usually it’s the main developer or the building contractor. Nevertheless, the client is never legally free from his responsibility on health and safety on the project.
The person responsible for the coordination (mainly during the execution stage) function shall ensure that: the work of preventing risks of ill-health or accidents are coordinated at the common worksite; work is planned accordingly to avert risk of ill-health or accidents due to different activities being in progress at the worksite; general safety devices are established and maintained and general safety regulations for the worksite issued; responsibility for the special safety devices which may be needed for a particular job or jobs is made clear, and personnel facilities and sanitary devices are established at the worksite satisfactorily.

However, in April 2006, the European Commission has some criticism against the Swedish implementation of the CSD (92/57/EEC). Among the critique is about the accident statistic, definition of construction works, the role of the client and the coordination measures. Therefore the Swedish Work Environment Authority had taken these criticisms and reformulated the existing AML and the related provisions which came in force in January 2009. The changes concerning the coordination measures are discussed below are for both the AML 1/1 2009 and the applicable provision that is the Building and Civil Engineering Works Provisions 2008:16 (older version is 1999:3).

**Client’s coordination responsibility**

The client alone is responsible for the overall initial planning and project preparation and project execution. He/she must take into considerations the issues of health and safety for the workers performing the work and also the users of the finished building/product. This overall planning differs from such planning which normally belongs to the job’s execution as stipulated in the older version where all involved during this stage must take into consideration of other on-going activities themselves (Prevent, 2009). The changes mean that the consideration for health and safety must be accounted for as early as possible right during the planning stage and through the execution of construction work (Andersson et. al, 2009).

The client shall appoint a suitable HSC for planning and project preparation stage as well as for the execution stage. The HSC can be the client himself/herself. There is no formal requisition in order to appoint someone as HSC. It must on the other hand a conscious and qualified decision by the client. (Prevent, 2009).

The appointments of HSC by the client must be for two stages: HSC for the planning and project preparation stage (HSC-P) and HSC for the execution stage (HSC-E). These appointments are valid for projects that have high risk activities as stipulated in Section 12a in AFS 2008:16 which basically cover main construction activities. These appointments are not bounded contractually but rather a normal appointment of an employee with specific task concerning health and safety (Prevent, 2009).

**Transferring the health and safety responsibility**

As mentioned above, the client is never free from his/her responsible for health and safety of the worksite. In such case, the client can surrogate the responsibility to an independent employee (uppdragstagare). This person will take over the client’s health and safety legal responsibility and information in accordance with Capital 3 Section 7c in AML. In order to legalize the transfer, two conditions must be fulfilled that are: the independent employee bear total responsibility for either the whole construction process (planning and project preparation and project execution) or only during the
execution stage and the agreement must be made in writing. This can be applicable to turnkey project where the independent employee is the main turnkey contractor (planning and project preparation and project execution) and to a traditional project where the independent employee is the main contractor (project execution). It is important to remember that only the full co-ordination responsibility at the entire common worksite can be transferred. If only a part of the responsibility is transferred this transfer is not valid and consequently null and void. Then the responsibility falls on the client’s shoulder.

HSC

Since the HSC is a new role being introduced at the construction worksite, the Work Environment Authority has drawn out the specific requirements for the appointment of such person. HSC can either be a legal person or a natural person that has the right qualifications, competencies and experiences to perform the specified duties for each role. When a legal person is appointed as a HSC, it usually means the company bears the health and safety responsibilities and not the individual. The coordination responsibility for HSC does not only apply for a common worksite where there are many contractors working simultaneously but also for worksites where only one contractor running the show.

HSC-P must be involved during the planning and managing of project preparation. Besides that he/she must coordinate with various actors, prepare a health and safety plan and other necessary documentation on building operation, repair works, renovation and demolition. On the other hand HSC-E must coordinate the work with preventing risks for ill-health and accidents on the worksite and implement the coordination of the application of relevant health and safety rules when technical or organisational questions about the planning of building operations which shall be executed at the same time or after each other and when the time allocation should be accounted for. Furthermore, HSC-E shall coordinate the application of relevant health and safety rules in order to ensure that workers operating the activities at the worksite apply these rules in a systematic way as well as following the work environment plan, coordinate measures to supervise the execution of the building or construction work with respect to health and safety in a correct manner, take necessary measures to ensure that only authorised persons have access to the worksite, and organise information for workers. During this stage he/she must update the health and safety plan when any changes have been made. HSC-E must also check that all technical equipment are inspected and tested.

3.2 Italy

Italy has the highest rate of workplace accidents and deaths of any European Union (EU) country. According to Giaccone M (2009), the reported work-related accidents for manufacturing and construction sector for the year 2008 is 367,132 cases. Despite the large figure, the work-related accidents declined by a quarter in comparison to the year 2000. The fatal accidents statistic shows a stronger decline for the same sector where 554 cases reported in 2008 in comparison to 766 cases in 2000. Giaccone (2009) claimed that these figures do not include work-related accidents among undeclared workers, who account for 13.4% of the total labour force which would contribute to a much higher figure.
The development of safety and health at work Italian laws

The first rules regarding safety and health were issued in 1942 within the Civil Code (Codice Civile), whereas the first specific laws are of the ‘50s and in particular the most important are the Decreto del Presidente della Repubblica (D.P.R.) 1955 n. 547 a general act for all kind of working situation and il D.P.R. 1956 n. 164 a specific act for construction. These laws were really well conceived and detailed, but unfortunately they were insufficiently applied and practically unconsidered. The adaptation of the EU Directive has started a period of a big issues and changes of acts and laws on the matter. The first general act Dlgs (Decreto Legislativo) 626/94 prescribes measures for the improvement for the protection of health and safety of workers at work while the D.lgs 494/1996 took in the Construction Site Directive 92/56/EEC through the framework legislation on the implementation of minimum safety and health requirements on temporary or mobile construction sites. According to this regulation, clients, project supervisors, employers, individual contractors and self-employed persons all have responsibilities to ensure safety (Baldacconi and Santis, 2000).

The proxy to the government for the enactment of the Act on the protection of health and safety at works considers both the reorganization of the law, and the reform of the provisions existing before decree 626. At this point, the situation was complex due to the numerous laws issued without continuity even with the European provision guiding as a base. Therefore, it was necessary to rearrange the matter, to be implemented in full compliance with the European provision and the balance of powers between state and regions, ensuring, at the same time, the uniformity of protection throughout the country. Italy drops the former Act 626, better known as the law on occupational safety. The Council of Ministers approved a decree giving effect to the Act concerning the protection of health and safety in the workplace. The Act D.lgs 81/08 covers 12 titles and over 300 articles. This was a lengthy and complex matter that reorders and innovated in terms of prevention, training, enhancement and coordination of supervision and the role of social partners and representatives of workers for the safety and security, ensuring a balanced system of sanctions.

The client and the responsible of the works

The client is defined as the person on whose behalf the work is done. In the case of public work, the client is the subject of decision making and spending on the management of the contract. The responsible of the works instead is the person charged, by the client to monitor the realization of the works and in the case of a private work to delegate his own duties and responsibilities. This subject may also coincide with the designer on the design phase and with the director of the works on the execution phase. The client or the responsible of the works, in the design phase of the work, and in particular at the time of the technical choices, during the implementation of the project and organising the operations of the worksite, shall comply with the principles and general measures to protect Article 15 through the risk analysis, prevention programming, etc. In order to allow the planning of execution in safety of the works or stages of work that have to be realised simultaneously or successively with one another, the client or the responsible of the works includes in the project the duration of the works or stages of works. The client is relieved from responsibility for payment of the obligations conferred only upon the controller of the works. In any case, the assignment of responsibility for the work shall not relieve the developer from responsibility for verification of the compliance of the obligations listed above.
The coordinator that controls for safety and health during the project preparation (HSC-P) is referred to as the coordinator for the design phase. He is the person charged by the client or from the responsible for the works, of the following tasks: prepare the safety and health plan and coordinate the contents of which are within the addendum XV and prepare a dossier containing useful information for prevention and protection from the risks to which workers are exposed during maintenance work, taking into account the specific rules of good technique. The file is not in the case of routine maintenance work.

HSC-P works closely with the designer in order to integrate design choices and the setting of the site that concerns the health and the safety on the worksite. The coordinator of safety at the execution stage (HSC-E) is the person responsible of excursions of the tasks. The coordinator can not be identified with the employer or with one of his employees or by the service of prevention and protection (RSPP) appointed by him. Such role is essential and so it is important that the client makes a conscious and qualified decision. In the first place he will have to verify the compliance with the security plans, operational plans (to be considered as a detailed plan of the security plan and coordination) and the correct procedures on the part of businesses and independent employed, making any changes in relation to the evolution of work with evaluating proposals from contractors. He organises among employers, including the independent ones, cooperation and coordination of activities and their mutual information. He suggests the client and the responsible for the suspension of the works, removal of business by the worksite or the termination of the contract in case there are serious deficiencies in terms of safety. In cases where the client or the responsible of the works does not take any action on the report, without providing adequate justification, the coordinator for implementation of such will give communication to the company local health units and to the direction of the provincial work territorially competent.
4. Discussions

Table 1 compares the implementation of the directive between these two countries against the EU Construction Site Directive 92/57/EEC.

Table 1: A comparative analysis on the role of HSC between Sweden and Italy as stipulated in Construction Site Directive 92/57/EEC

<table>
<thead>
<tr>
<th>Factors</th>
<th>EU</th>
<th>Sweden</th>
<th>Italy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statutory requirements</td>
<td>Construction Site Directives 92/57/EEC</td>
<td>AML 1/1 2009, AFS 2008:16</td>
<td>D.Lgs 81/08 (framework law), Title IV- Temporary and mobile, Chapter 1- measures for health and safety at temporary or mobile</td>
</tr>
<tr>
<td>Client’s role</td>
<td>Article 3: Appoint one or more coordinator for h&amp;s matters, Submit a prior notice before work begins to competent authority</td>
<td>AML cap 3 sec 6, AFS 2008:16 Sec 4-5 &amp; 7, Responsible for h&amp;s during every stage of the project, Select a suitable HSC for p&amp;p and design, Select a suitable HSC for execution, Can select oneself as the HSC, Submit a prior notice before work begins to competent authority</td>
<td>Article 90, In the design phase - assessing of the plan and evaluate the security coordination and the technical file prepared by the coordinator for security, Appoint coordinators for safety for the design and for work execution, To verify the suitability of the technical-professional carer, the contractors and the self-employed according to the functions or work to be entrusted, Submit a prior notice before the work start</td>
</tr>
</tbody>
</table>
| Transfer of responsibility | No special mention except in the definition of project supervisor in Article 2 which states that the person can act on behalf of the client during p&p and/or during the execution stage | AML cap 3 sec 7c  
Transfer to an independent employee who bears total responsibility for either the whole construction process (p&p and project execution) or only during the execution stage and the agreement must be made in writing. | No specific mention about transfer of responsibility |
|----------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| Who can be HSC             | No special mention except in the definition of HSC in Article 2e and 2f that HSC can be either a natural or legal person | AFS 2008:16 sec 6  
HSC can either be a legal or a natural person | Not mention except in Article 89 (e) that HSC must be appointed by the client |
| Qualifications of HSC      | Not mentioned                                                                                   | AFS 2008:16 sec 6  
Knowledgeable, competent, experience to perform the HSC tasks according to AML and all relevant Provisions. | Article 91  
Degree in engineering, architecture, geology, agriculture or forestry with at least one year experience  
A recognised university degree in engineering or architecture as well as at least two years work experience  
Qualified surveyor or valuer, or industrial or agricultural expert agronomic with at least three years experience  
Apart from the formal education, the coordinators are expected to attend specific courses organised by the regions in the field of prevention and training.  
The costs must be borne by the participants. |
| HSC-P duties and responsibilities | Article 5  
Coordinate when architectural, technical & organisational aspects are decided and time estimation for work or work stages  
Draw up a h&s plan  
Prepare a file containing relevant h&s information for future use. | AFS 2008:16 sec 9 & 11-12  
Participate in the planning and lead the preparation and design of project.  
Coordinate the preparation and design of project with regard to h&s to allow participants involved during this stage to take into consideration each other planning and solutions.  
The coordination should lead to the execution of different parts of the project together with the construction, installation and others that occurs at different time and stage of the project where the risk of ill-health and accident could arise.  
Draw up a h&s plan if it is required before the site is set-up.  
Compile a file. This shall be completed when the works are concluded. It shall describe the design and construction of the object together with the building products used, to the extent material to safety and health in connection with work on the operation, maintenance, repair, alteration and demolition of the object. | Article 91  
Establish a security plan and coordination of high risk work  
Prepare a dossier containing useful information for the prevention from the hazards faced by the workers. |
<table>
<thead>
<tr>
<th>HSC-E duties and responsibilities</th>
<th>Article 6</th>
<th>AFS 2008:16 sec 1315</th>
<th>Article 92</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate implementation of general principles of prevention of safety</td>
<td>Participate in the planning of the work and ensure that common safety and health conditions are being addressed when choosing working methods and material during coordinating of work and during planning of work schedule.</td>
<td>Check with proper coordination and control, the application by the party companies and self-employed with regard to security plan and coordinate work with high risk and its enforcement.</td>
<td></td>
</tr>
<tr>
<td>Coordinate implementation of relevant provisions for the protection of workers</td>
<td>Organise safety activities on construction sites. If there is more than one enterprise that performs the work activities on the construction sites, then the HSC shall organise a mutual safety activities with them.</td>
<td>Assessing the suitability of the Operational Safety Plan as a supplement to the detailed security plan</td>
<td></td>
</tr>
<tr>
<td>Update the h&amp;s plan and the files</td>
<td>Ensure that a h&amp;s plan is available at the worksite as soon as the site has been set-up.</td>
<td>Evaluating the proposal of the party companies to improve safety on site and verify that the sub-contractors adjust them accordingly to their plan and operations</td>
<td></td>
</tr>
<tr>
<td>Organise cooperation between employers, coordinating their activities to prevent accidents.</td>
<td>Make any adjustment to the h&amp;s plan if necessary to the progress of the work and any changes which may occur on site.</td>
<td>Organise among employers including self-employed cooperation and coordination of activities and their mutual information.</td>
<td></td>
</tr>
<tr>
<td>Ensure working procedures are being implemented accordingly</td>
<td>Ensure the suitability of the plan to suit the working methods that are being used on construction site or the condition sets to perform the work. Update working methods periodically. With every change that takes place to suit the conditions or h&amp;s conditions, adjustments must be made.</td>
<td>Verify the implementation of the provisions between the social partners to achieve coordination between the representatives of the security to improve safety on site.</td>
<td></td>
</tr>
<tr>
<td>Allow only authorise person on site</td>
<td>Update the file which may be needed according to the progress of the work and any changes occurring during the project execution stage.</td>
<td>Notify the client or project supervisor of any non-compliance and propose the suspension of work, remove companies or self-employed from the project or terminate the contract.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Supervise measures to verify that technical devices are duly inspected and tested and also that the operators have sufficient competence or whenever applicable requires permit.</td>
<td>If no action is taken by the client, the coordinator may report the failure to the local health authority and the Head of the department of Labour</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suspend any work in case of grave and imminent danger, directly observed the individual working to verify the adjustments made by the companies concerned.</td>
<td></td>
</tr>
<tr>
<td>Documents</td>
<td>Prior notification - Article 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On site where work is scheduled to last longer than 30 working days and &gt;20 persons are occupied simultaneously at any time or the volume of work is scheduled to exceed 500 person-days, the client/project supervisor must draw prior notice to competent authority before work begins.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Work environment plan – Article 5b**

The plan shall contain rules applicable to the construction site concerned, taking into account the industrial activities taking place including specific measures for high risk works.

**h&s file – Article 5c**

Prepare a file appropriate to the characteristic of the project containing relevant h&s information to be taken into account during any subsequent works.

<table>
<thead>
<tr>
<th>Prior notification AFS 2008:16 Sec 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notification to Authority before work begins on site where work is scheduled to last longer than 30 working days and &gt;20 persons are occupied simultaneously at any time or the volume of work is scheduled to exceed 500 person-days.</td>
</tr>
</tbody>
</table>

**Work environment plan AFS 2008:16 Sec 12**

The plan shall also contain a description of the h&s measures to be taken during the project execution stage including risk assessment for high risk works.

**h&s file – AFS 2008:16 Sec 9**

The file described the design and construction of the object together with the building product & material in connection to h&s with work in connection to operation, maintenance, repair, alteration and demolition of the object.

<table>
<thead>
<tr>
<th>Prior notification Article 99</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notification to Authority on a common worksite where the volume of work is scheduled to exceed 200 person-days.</td>
</tr>
</tbody>
</table>

**Work environment plan Article 100**

The plan shall also contain a description of the h&s measures to be taken during the project execution stage including risk assessment for high risks works.

**h&s file 91(b)**

The file described the design and construction of the object together with the building product & material in connection to h&s with work in connection to operation, maintenance, repair, alteration and demolition of the object.

<table>
<thead>
<tr>
<th>Others</th>
<th>Article 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>The appointments of HSC do not relieve the client of his responsibility for h&amp;s for the whole project.</td>
<td></td>
</tr>
</tbody>
</table>

**AML kap 3 sec 6**

The Client is never free from his/her responsible on h&s for the project.

**AFS2008:18 sec 16**

If HSC-E is unavailable on site, contact person(s) should be made available to disseminate required information.

<table>
<thead>
<tr>
<th>Article 157</th>
</tr>
</thead>
<tbody>
<tr>
<td>The client or the project supervisor upon violation of safety and security may be punished in the form of imprisonment or fines.</td>
</tr>
</tbody>
</table>

**Article 158**

The coordinator for the design and execution upon violation of safety and security may be punished in the form of imprisonment or fines.

**Legend:**

- h&s – health and safety
- p&p – planning and project preparation
5. Conclusions

Generally the noble idea of the introduction of HSC in Sweden is relatively new. One small study performed by Andersson et.al (2009) indicated that the new changes are accepted positively by both the clients and the project managers. Currently, all appointed HSCs need to attend at least a 50hr course to acquire the certificate to prove their competencies in health and safety. The question is that who should bear for the cost. Furthermore there is no rule about the provider of the courses being certified by the Swedish Work Environment Authorities. Till date, after a year of implementation, no studies have been made examining the implementation of HSCs on construction sites. On the other hand, the HSCs’ role in Italy has been well structured especially in specifying their qualifications, responsibilities and accountabilities. With the new legislation (D.Lgs 81/08) it is hope the accident statistic will decline and the safety situation will improve positively. Overall, Italy had transposed the CSD 92/57/EEC as early as in 1996 in adopting the HSC role. Contrary, Sweden despite having a good accident record had only transposed the CSD 92/57/EEC early 2009 and all these while had interpreted the importance of coordination ambiguously. No mention of accountability was written in either the law or the provisions. It is hope with these changes in both legislation in Sweden and Italy will contribute to a better health and safety work environment.

References


How Can We Prevent Construction Accidents?  
Outcomes from a Stakeholder Consultation: Project and Workplace Influences

Gibb, A.  
Loughborough University, UK  
(email: a.g.gibb@lboro.ac.uk)

Brace, C.  
Scott Wilson Ltd.  
(email: charlotte.brace@scottwilson.com)

Pendlebury, M.  
Loughborough University, UK  
(email: charlotte.brace@scottwilson.com)

Bust, P.D.  
Loughborough University, UK  
(email: p.d.bust@lboro.ac.uk)

Abstract

This paper presents some of the findings from a time-limited, independent research project that reviewed evidence about underlying causes of construction accidents and levers within and beyond health & safety systems to make further improvements. The triangulated method incorporated national and international expert consultations with a total of 72 participants from across the industry, plus a literature review. An initial ‘sounding out’ exercise was also undertaken to gather feedback on the practical strategies developed during the consultation process through the use of two focus groups. Perspectives on the underlying causes identified: broader societal and industry-wide influences (macro); project and process factors (mezzo); and worker/supervisor/workplace causes (micro). From these, a number of potential improvement strategies for reducing fatal and serious accidents were proposed, themed under three categories: enforcement and compliance; competency and training; and culture and mindset. These have been evaluated in terms of their likelihood to effect change and the likelihood of them being implemented, typically related to the cost and/or the difficulty expected to bring them to fruition. The highest priority compliance and enforcement strategy was the idea of increasing the number of supervisors. Other potentially important strategies for consideration, which need further research and evaluation, were identified as enhancing any connection between employment type and safety and organisations implementing licensing requirements. The most promising competency and training strategies included issues such as: developing strong organisational competency and maturity; conducting enhanced examination of accident and high potential incident data; conducting in-house evaluations of interventions; and, developing individual competency and understanding. The culture and mindset theme’s high priority strategies were to make subcontractors part of the team and to remove the ‘bonus payment’

Keywords: accidents, construction industry, causes, prevention strategies.
1. Introduction

The UK has a large and exciting construction industry, which contributes over £100 billion annually to the gross domestic product (HSE, 2009). The construction industry has been recognised internationally as one of the most dangerous industries in which to work, with the statistics often explained in terms of the industry’s inherently hazardous nature (Lingard & Rowlinson, 2005). There have been considerable efforts over many years directed at reducing the numbers of accidents and injuries through prevention. However, there is recognition that construction still has one of the highest rates of fatal and major injuries of all industries in the UK (HSE, 2009) and further improvement needs to be sought. In late 2008, the Secretary of State (SoS) at the Department for Work and Pensions (DWP) commissioned an inquiry into the underlying causes of construction fatal accidents. (The full findings of the inquiry can be found at: www.dwp.gov.uk/publications/policy-publications/fatal-accidents-inquiry.shtml and the details of the work presented in this paper can be found in Brace et al 2009). This paper presents findings from a time-limited, independent research project reviewing non-HSE (Health & Safety Executive) evidence about underlying causes of construction accidents and levers within and beyond health & safety systems that could be applied to make further improvements. The aims of this independent research were to explore the extent of complementary evidence about underlying or root causes of construction (fatal) accidents generated by parties outside HSE and to determine some practical strategies (levers) that might be adopted for accident reduction, based on industry needs and stakeholder feedback.

2. Approach

The triangulated method incorporated a literature review plus national and international expert consultations with a total of 72 participants from across the industry to gather:

- Stakeholder opinion on underlying causes of accidents and strategies for prevention based on their experience of fatal and serious construction accidents;

- Detail about existing accident investigation processes and approaches to learning from accidents; and

- Case study examples of good practice regarding accident investigation and prevention from the UK as well as a range of different countries.

The stakeholders consulted included: 27 UK senior construction industry expert stakeholders; 15 practitioners from the UK construction industry; 15 workers representing the UK’s very small, hard to reach organisations/sole-traders; and; 15 overseas construction industry expert stakeholders. The consultation combined face to face and telephone interviews, plus email correspondence. Consequently, the research team created a ‘list’ of possible strategies that arose during the preceding research process. These were organised into main topic groupings and feedback on the potential improvement strategies was gathered from 14 industry stakeholders (who were separate individuals to
those already involved in the research) via two focus groups. Upon completion of data gathering and feedback, based on researcher/stakeholder perceptions, the potential improvement strategies were given a rating of high, low or medium priority based on perceived impact, implementation and dependency. This paper focuses on summarizing some of the proposed intervention strategies that resulted from the research process.

3. Findings - causes of construction (fatal) accidents

There have been very few comprehensive studies reported in the literature on why or how construction accidents happen. Most studies on construction accidents focus on immediate causes, characteristics of accident victims or accident sequence. It is clear from the review that of the few studies examining the underlying causes and contributing factors to construction accidents, those that do have limitations. The underlying factors that have been documented in these studies (e.g. Whittington et al 1992; Suraji et al 2001; Arboleda & Abraham 2004; Behm 2005; Chi et al 2005; Haslam et al 2003; Haslam et al 2005; Chaplin 2006; Ling et al in press) include: workplace management and culture; worker training and competency; worker attitude and behaviour; equipment factors; inappropriate/non-compliant procedures; lack of safety regulations and legislation; environmental factors; industry structure and set up. It is not possible to quantify the extent to which each factor plays a role in accidents due to the discrepancies in reporting and in data collection itself.

As would be expected, based on the accident hierarchy, there do not appear to be any major differences between the causal/underlying factors reported to be contributing to fatal accidents, compared to those for all accident injury outcomes. The underlying factors reported were complex and inter-related and for the purposes of this work they were grouped into the themes of macro, mezzo, and micro (it is important not to confuse this use of ‘micro’ to refer to worker, workplace and supervisor issues with the use of the term ‘micro’ to refer to very small organisations). Perspectives on the underlying causes gathered via the stakeholder consultation exercises identified similar and broader: societal and industry-wide influences (macro factors); project and process factors (mezzo factors); and worker/supervisor/workplace causes (micro factors). These can be viewed as potential defences against accidents, in line with approaches by Reason (1990) and applications to construction accidents by Gibb and colleagues (Haslam et al 2003; Gibb et al 2006).

When active or latent failures at each level create holes in the defensive plates, accidents can occur, with the ‘chance’ element being represented by the chance of the holes in the various plates lining up to provide an opportunity for ‘accident trajectory’, Figure 1.
Figure 1: Schematic demonstrating the themes used to summarise the underlying causes of construction accidents (after Reason, 1990 and Gibb et al, 2006)

Considering influence and responsibility, these categories work in one direction. It is important to note that the responsibility of industry leaders and corporate managers extends beyond the macro to the mezzo and micro areas – actions of such leaders have a very significant impact on projects and on workers.

Amongst the stakeholder cohort, underlying causes of construction fatal accidents at the macro level were reported to include:

- Immature corporate systems, inappropriate enforcement, lack of proper accident data, lack of leadership from ‘Government’ as a key client and a lack of influence of trades unions in practice on most sites, especially for smaller projects.

Mezzo factors were identified as:

- Immature project systems and processes, inappropriate procurement and supply chain arrangements, lack of understanding and engagement by some of the design community, lack of proper accident investigation / data and consequently, a lack of organisational learning.

Micro factors were reported to include:

- A shortage of competent supervisors; a lack of individual competency and understanding of workers and supervisors; the ineffectiveness or lack of training and certification of competence; a lack of ownership, engagement and empowerment of, communication with and responsibility for workers and supervisors. These factors were also exacerbated by poor behaviour, cost pressures; poor equipment or misuse of equipment, including personal protective equipment; site hazards; poor employment practices; an itinerant workforce and inadequate management of and provision for vulnerable workers such as younger, older or migrant workers.
4. Findings - strategies for accident prevention

Within the literature, a number of strategies have been proposed for preventing construction fatal accidents, including those focused on the technical, organisational and human factors, with many prevention strategies focused on particular accident mechanisms, such as falls from height. The expert stakeholder cohort were surveyed to find out what interventions they had found successful in reducing accident rates and other more ‘futuristic’, ideal world methods that they felt could be adopted to reduce accidents and increase safety within the industry based on their experience and understanding. (Due to the relatively small number of fatal accidents that occur in the industry compared to serious and slight injury outcome accidents, stakeholders were asked to consider methods for preventing all accident outcomes.) After reviewing the findings from the literature and stakeholder consultation exercises, a number of potential improvement strategies for reducing fatal and serious accidents at the macro, mezzo and micro level were proposed. Table 1 presents the full set of potential improvement strategies proposed but this paper discusses only the potential mezzo and micro level improvement strategies. Another paper discusses the macro level improvement strategies (Brace et al, forthcoming 2010). These potential improvement strategies were themed under three categories: enforcement and compliance; competency and training; and culture and mindset, and are summarised in the following sub-sections, along with a rating of high, low or medium priority based on perceived impact, implementation and dependency (based on researcher/stakeholder perceptions). It should be noted that it is very unusual for (existing or former) interventions to be evaluated for their impact, which causes difficulty in determining their efficacy for reducing accidents improving safety.

Table 1: A summary of the strategies under each of the classification groupings and cross cutting themes)

<table>
<thead>
<tr>
<th>Macro Factors</th>
<th>Mezzo Factors</th>
<th>Micro Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Theme 1: Enforcement and Compliance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enhance enforcement activities;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ensure Government is an exemplar client;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Certify all construction organisations;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Link Building Control approval to health and safety;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focus on overall effective management systems;</td>
<td>Increase the number of supervisors;</td>
<td></td>
</tr>
<tr>
<td>Divide HSE;</td>
<td>Organisations to implement licensing requirements.</td>
<td></td>
</tr>
<tr>
<td>Consider the creation of a Government construction body.</td>
<td>Enhance any connection between employment type and safety.</td>
<td></td>
</tr>
</tbody>
</table>

**Theme 2: Competency and Training**

| | |
| --- | --- | --- |
| | | |

111
Provide free advice and training
Conduct finer analysis of accident data;
Consider advice/legislation for accident investigation and learning;
Conduct evaluations of interventions;
Implement competency standards;
Develop training and competency in the design community.

Develop strong organisational competency and maturity;
Conduct enhanced examination of accident and high potential incident data;
Conduct in-house evaluations of interventions.

Develop individual competency and understanding.

Theme 3: Culture and Mindset

Tackle safety from a consumer protection perspective;
Outlaw inappropriate tools and equipment;
Insurers to demand greater safety provision by organisations;
Change HSE approach;
Consider implementing an independent accident investigation board;

Make subcontractors part of the team;
Create a minimum time period before site work starts.
Remove the ‘bonus payment’;
Encourage and manage diversity in the industry.

Reduce poor employment practices.

4.1 Theme 1: enforcement and compliance

Enhance any connection between employment type and safety (Mezzo Factor; potentially High Priority) It was noted that there may be differences between employment types (e.g. directly employed labour vs. long chains of subcontractors) and levels of safety, e.g. management may have more control over directly employed labour and less control over staff employed via long subcontracting chains, suggesting that the industry should be moving away from labour only employment. However, it was also noted that safety is dependent on project level/site based culture and compliance. It was therefore proposed that the relationships between employment types and safety levels should be examined and the value of increasing the proportion of direct employees/reducing sub-subcontractor culture be evaluated.

Increase the number of site supervisors (Micro Factor; High Priority) Many issues were raised with regard to competency and unsafe behaviours amongst operatives and it was repeatedly stated that supervisors are ‘the first line of defence’ in preventing unsafe events and picking up on poor attitudes. Therefore, it was proposed that the number of qualified and competent supervisors should be increased across the industry. It was recognised that this imposes significant cost challenges for many companies, particularly at a time of financial problems, hence the implementation at this time may be
more difficult than anticipated. There may also be short-medium term issues regarding the lack of competent supervisors.

**Organisations to implement licensing requirements (Micro Factor; potentially High Priority)**

Many issues were raised with regard to competency and standards for individuals working in the construction industry. It was suggested that we should consider changing the method of employment/procurement, for example, instead of expecting sub-contractors to complete pre qualification questionnaires etc., change the ‘rules’ so that workers have to be licensed to work, raising competency levels. It was therefore proposed that an action is to investigate the value, feasibility, and impact on industry of the idea of licensing through a review and cost benefit analysis.

### 4.2 Theme 2: competency and training

**Develop strong organisational competency and maturity (Mezzo Factor; High Priority)**

Effective (health & safety) management systems and processes are essential for good health and safety. Good management systems are often already embedded into the larger, better managed construction organisations. However, it was recognised that despite good principles, aspects may be missing during practical implementation. It was also noted that strong organisational competency and maturity are likely to be missing from many (smaller, less well resourced) organisations. Examples of what is meant by this suggestion and how it can be developed included: make H&S part of the whole management system and interface it with people’s ‘day jobs’ so that it is not seen as a ‘bolt on’ – “good safety is good business”; ensure all safety staff are supportive and supported, with clear objectives and high level of authority and leadership from the top.

**Conduct enhanced examination of accident and HPI data (Mezzo Factor; High Priority)**

A detailed understanding of the ‘problems’ and underlying causes of accidents that occur within organisations is required in order to better target interventions. Therefore, as well as suggesting finer in-house analysis of accident data and investigations (Strategy 2.2), in order to enhance understanding of ‘near misses’ and opportunities for improvement based on additional relevant data, it was also suggested that there could be a focus on High Potential Incidents (HPIs).

**Conduct in-house evaluations of interventions (Mezzo Factor; High Priority)**

When interventions have been implemented in industry, there is limited evaluation of their efficacy. Therefore, it was proposed that (simple) evaluations of interventions should be managed to determine whether or not changes are having the desired effect and to better inform the organisation and the industry. It was noted that assistance would need to be provided to industry organisations on how to conduct worthwhile evaluations, e.g. including field workers to work with industry to ensure uptake and evaluation, and this is covered in Strategy 2.4.

**Develop individual competency and understanding (Micro Factor; High Priority)**

The primary issue for individual workers was the need to improve competency at all levels so that people know why things have to be done in certain ways and have the right ‘questioning’ attitude to work appropriately. Examples of how this might be achieved included training and development in the soft
skills of managers and supervisors, and revised training for supervisors to ensure they are adequately trained and fully supported in and aware of their responsibilities for creating engagement.

4.3 Theme 3: culture and mindset

Create a minimum time period before site work starts (Mezzo Factor; potentially Low Priority)
There is currently insufficient time for contractors to plan work properly prior to commencing site work, which can impact on site safety. Therefore, it was proposed that contractors should demand a minimum time period (risk based) before work starts, which is priced into all contracts, e.g. based as part of the standard conditions. However, it was also noted that any time provided under such a system would not necessarily be used for this purpose. Therefore, it was suggested that further work be conducted to explore the impact of this idea on safety practices.

Make subcontractors part of the team (Micro Factor; High Priority)
If employers’ attitudes to subcontractors could be changed so that they take responsibility and ownership for all of the workers, and subcontractors are treated as part of the ‘team’, this would have a positive impact on safety. A possible strategy to be explored for aiding cultural change included examining the revision of welfare provision, such as accident benefits, death benefits etc.

Remove the ‘bonus payment’ (Micro Factor; High Priority) When a bonus payment is offered for finishing by a certain time etc., this can create the temptation to cut corners to ‘get the job done’. It was therefore suggested that such bonus payments are removed or revised significantly to prevent this negative outcome.

Encourage and manage diversity in the industry (Micro Factor; Medium Priority) A diverse workplace, particularly one including a higher proportion of females and ethnic minority groups, was considered to create a safer environment by generating a less ‘macho’ culture. Therefore, it was proposed that methods for encouraging a more diverse workforce are re-examined and pursued, e.g. raising awareness of the opportunities in the construction industry within schools.

5. Conclusions

This work has provided an insight into current industry practices and thinking about the causes of accidents and levers and strategies that could be adopted to improve health and safety and reduced accidents in the construction industry. A number of strategies have been proposed in this paper and these have been attributed a priority rating based on perceived impact, implementation and dependency. However, there is an urgent need to evaluate interventions to establish their value in making the construction industry safer.

The rich data gathered during this work was largely subjective opinion as there are only very limited numbers of ‘hard facts’ concerning the underlying causes of accidents and the efficacy of interventions in the construction industry, in the UK or internationally. The tight time constraints (6
weeks for the data collection phase caused by the SoS deadline) meant that the work was very intense but focused and the research team were unable to explore in depth all avenues that were captured during the research process. Despite its limitations, this work provides a picture of the current practice of construction health and safety and evaluates opinion on the challenges and opportunities facing the construction industry in this regard.

The highest priority compliance and enforcement strategy was the idea of increasing the number of site supervisors. Other potentially important strategies for consideration, which need further research and evaluation, were identified as enhancing any connection between employment type and safety and organisations implementing licensing requirements. The most promising competency and training strategies included issues such as: developing strong organisational competency and maturity; conducting enhanced examination of accident and high potential incident data; conducting in-house evaluations of interventions; and, developing individual competency and understanding. The culture and mindset theme’s high priority strategies were to make subcontractors part of the team and to remove the ‘bonus payment’.

6. Acknowledgements

The work described in this paper was funded by the Health and Safety Executive (HSE). Its content, including any opinions and/or conclusions expressed are those of the authors alone and do not necessarily reflect HSE policy or the views of the Inquiry Chair, Rita Donaghy, CBE FRSA. The final report from the Inquiry including Rita Donaghy’s recommendations can be found at: www.dwp.gov.uk/publications/policy-publications/fatal-accidents-inquiry.shtml

References


4D-BIM for Construction Safety Planning

Sulankivi, K.
VTT Technical Research Center of Finland
e-mail: kristiina.sulankivi@vtt.fi
Kähkönen, K.
VTT Technical Research Center of Finland
e-mail: kalle.kahkonen@vtt.fi
Mäkelä, T.
Finnish Institute of Occupational Health
e-mail: tarja.makela@ttl.fi
Kiviniemi, M.
VTT Technical Research Center of Finland
e-mail: markku.kiviniemi@vtt.fi

Abstract

This paper explores the chances for having 4D-BIM (four-dimensional building information modelling) as a central technology for construction site safety related planning activities. The paper is grounded in the on-going research project called BIM Safety (BIM-based Safety management and Communication System). As an intermediate result of the research project, it is presented how four-dimensional site layout and safety related planning activities can be carried out by using the currently available BIM software. Besides of the tools and procedures, findings concerning potential safety related use-cases to be tested in the pilot projects will be presented, as well as expected challenges and benefits of utilization of 4D-BIM. BIM technology can be used as a starting point for safety planning and communication. The utilization of 4D-BIM technology can result in improved occupational safety by connecting the safety issues more closely to the construction planning, providing more illustrative site layout and safety plans, providing methods for managing and visualizing up-to-date plans and site status information, as well as by supporting safety communication in various situations, such as informing site staff about coming safety arrangements or warning about risks. The main objective of the BIM Safety research project is to develop procedures and use of BIM technology for safety planning, management, and communications, as part of the 4D-construction planning. Piloting BIM-based procedures in real on-going building projects is an essential development method that will be used in the research project. The project started at April 2009 and will be going on till April 2011.

Keywords: construction planning, safety planning, building information modelling, 4d, site planning
1. Introduction

BIM-based construction production planning and 4D simulation increases rapidly in Finland on the basis of building information models created in design and engineering phase. Nevertheless, even in the cases of most advanced construction process modelling the main focus is usually merely on the scheduling of parts of the building's frame, as well as planning and visualization of corresponding work tasks. Thus the site processes including safety and logistic aspects are practically ignored although some practical experience on BIM-based site layout or area planning exists.

Safety planning can be seen as a part or dimension of the construction production planning. In several other disciplines it has a key aspect position in the field of production planning. Safety planning has been carried out to a certain extent separately with other production planning and control and for example, a concrete falling protection plan is not created in all projects. Safety management related communication to the level of employee is challenging under the site circumstances. Partly for these reasons the construction accident rate has remained high compared to other industries. In Finland, one in four fatal occupational accidents takes place in the construction field. Several previous studies show that the problem of the high accident rate and hazardous activities on site has been identified in many countries, for example Vacharapoom & Sdhabhon 2009.

BIM Safety project continues the work started within the earlier TurvaBIM- research project (Building Information Model promoting safety in the construction site process, TurvaBIM 10/2007 - 2/2009). The main results of the TurvaBIM project were the three dimensional BIM-based site layout planning procedures and their testing. A static three-dimensional site layout plan was considered as a basic method for creating a BIM based site plan, in which case a site plan is created for various construction stages.

The on-going BIM Safety research project aims to develop and test solutions for the planning and management of construction site safety using more dynamic 4D site models. This means that construction schedules are linked with i) the building parts, ii) the temporary structures, and iii) site production equipment. BIM technology will be applied to safety planning, safety management and safety communications, and these activities will be integrated into the 4D-construction management (more information available at the project web-site http://www.vtt.fi/sites/bimsafety/).

2. Method

The BIM Safety research project encompasses action research approach where the piloting of designed BIM-based procedures in real on-going building projects will be the most important experimental task. At the first stage of the project, preparation work for piloting has been carried out including literature study, safety hazard record analysis, pilot planning, hands-on modelling testing, and tool development in co-operation with the research partners. Additionally, work concerning possible technologies for BIM-based or mobile safety communication at site has been started, a practical demonstration using available technology being a target.
Literature study and analysis of records of real safety hazards/accidents has been carried out to find out the major problems of occupational safety at construction. At the next stage the most promising opportunities to progress these safety problems with the help of 4D-BIM are to be tested in pilot-cases.

Generally, two main approaches for improving construction safety and security have been identified and used as starting points for this research:

1. **Proper Collaborative Planning.** Detailed construction site layout planning is perhaps the best practical example of this paradigm where site safety issues are proactively studied and communicated for creating working conditions where chances for accidents are minimised. It is important to take into account the need for incorporating all partners and their knowledge for the facilitation of high level committed safety securing activities.

2. **Sufficient Awareness.** This refers to continuous reviews of working conditions and relating potential hazards. Nowadays experienced site foremen and project managers are carrying out these activities intuitively. However, the advanced BIM technology based solutions encompass potential for reaching new performance level.

The Tekla Structures software package was selected to be the main research platform. Functionality tests concerning 4D-features in the selected modelling software Tekla have been carried out using Tekla structural model of a completed building project. Testing has been carried out to assure that the selected software can be used for safety planning and visualization in the coming pilot projects. This far there is real experience of use of the software related to planning, modelling and visualization of permanent construction assemblies of buildings only. As part of the modelling and visualization tests a set of suitable visualization rules were developed for temporarily used safety equipment. The rule set can be used and developed for different purposes in pilots. Additionally, availability of safety related custom components for the selected modelling software has been surveyed in the project, and needed missing site layout and safety planning components created in cooperation with the contractor.

At the next stage the usability and potential of BIM will be tested and studied in on-going building projects, and feedback collected concerning experience in the use of BIM for safety planning, management and communication. The development work has recently started in the first pilot project by supporting the safety planning. Construction work of the pilot project has started at January 2010 and is scheduled to be completed at January 2012. The second pilot is expected to be started during the second half of the year 2010.

### 3. **Recent research and developments on BIM based safety solutions**

Occupational health and safety management is a multi-dimensional field. The nature of its research, development and their results has a heterogeneous nature with links to the basic sciences such as psychology and medicine, and, besides of that it has strong links to the
applied sciences such as education, engineering and management. Current interest in BIM and more generally in new technology are gradually bringing ICT and its applications to the field of occupational health and safety management. This can result in solutions that can be characterised as engineering controls and health management system as part of business decision making. The need of such solutions has been discussed by Gibb (2006) and Williams (2006). The overall interest around BIM and its applications have created wide variety of attempts some of which have also addressed occupational safety issues. The identified categories of such research and development are presented on the following.

Education and training. Visualization technologies and facilities, interactive learning environments having BIM models as central units (Alshawi et al, 2007; Vries et al, 2004).

Analysis and anticipation of unsafe conditions. Rule based hazard identification from 4D CAD Model (Vacharapoom & Sdhabhon, 2009), Dynamics of different site operations causing safety risks to each other (Rozenfeld et al, 2009). Analytical procedures based 4D simulations to reveal potential safety threats (Hu et al, 2008).

Monitoring of conditions. Use of RFID, mobile and augmented reality technologies for obtaining real-time data from construction site and for comparing those to the plans (Sørensen et al, 2009; Hakkarainen et al, 2010; Golparvar-Fard & al, 2009).

Communication and collaboration. BIM centric practices have been found to have significantly beneficial to the industry (Mahalingam et al, 2009). BIM technologies are generally seen as means to facilitate communication in relation to safety aspects (Eastman et al, 2008; Suermann & Issa, 2007; Heesom & Mahdjoubi, 2002; Khanzode & Staub-French, 2006). Automated system approaches for getting good quality work instructions have been studied by Mourgues and Fischer (2010).

Recent advancements of BIM technologies are providing decent starting points for the development of solutions for pro-active site safety planning and management. This means that the user is not just a passive observer of potential problems but he/she has all necessary functions available as efficient solutions enablers for improving the working conditions. The research effort presented in this paper falls into the category of pro-active site safety planning and management solutions. Compared with the earlier research we consider that the selected research approach having collaborative safety planning and safety awareness building as starting points can result in novel contributions by combining safety management functions with appropriate BIM solutions.

4. Opportunity to promote safety with the help of 4D-BIM

Recent research concerning occupational deaths in Finnish construction concludes that the major safety problems are associated to falls, moving on site from one location to another as a part of work tasks and installations of prefabricated units (Lappalainen et al 2007). Inappropriate work planning
and supervising, insufficient communication between different partners and lack of safety training and practices were identified as key contributing factors behind the named accident types. Reasons of disability pensions of retired construction workers indicate that those individuals have suffered from sharp heavy load lifting. At the first stage the BIM Safety research focuses on these special major problems of occupational safety at construction sites in Finland.

BIM solutions include many attributes which offer several interesting opportunities to promote safety at construction sites. The visualization offers a totally new tool for risk assessment, planning, introduction, safety management etc. The use of visual BIM encourages other partners to involve both risk assessment and planning. These partners are designers, other contractors, safety specialists, occupational health care etc. Additionally 4D-BIM means improved chances to make alternative preliminary plans of different construction stages and tasks. It can also produce better safety while safety matters are included in this planning process.

5. Approach and tools for 4D-safety in the BIM Safety research project

The main target of the research project is to develop BIM-based solutions for construction site safety planning and management as part of the 4D-construction management. Safety planning procedures and particularly those by the contractors have been studied to find the planning tasks which could be supported by BIM. Construction events/tasks and the related necessary technical solutions including safety are to be modelled into the building's 4D production model, in which the structural model produced by the structural engineer is used to serve as the starting point. Safety planning is part of the whole construction planning, a perspective which will be taken into account in the methods developed. This complies also with the current safety management principles. The strength of using BIM-based tools is the opportunity to use building information models created in the design process as bases for BIM-based production models also. Additionally, use of BIM technology in real construction projects increases all the time and is a possibility to develop safety planning when it is integrated with BIM-based 4D construction planning process. According to Vacharapoom & Sdhabhon (2009), many previous international research studies have also addressed the lack of integration between construction and safety. They see various 4D CAD models as innovative tools to link construction design and planning, as well as incorporate safety related activities into the construction schedule.

In Finland building information modelling started in architectural design, but has become more common also in structural and HVAC engineering. The use of modelling has been characterized by the fact that the models created in the design and engineering process are tried to be advantaged for various purposes. Already in design process an architectural model has been used as a reference for engineering modelling and for quantity takeoff by contractors. Today use of models for construction planning and management including safety purposes is at the early stages. Models created in the design process can be developed to serve site and safety planning by adding the planned temporary site and safety arrangements to the model created in the architectural design or structural engineering stages. In some other countries, e.g. in USA and China, it’s more common that contractors has their
own CAD expert to create models, because BIM-based tools are not commonly used during design work and as a result there is no models available for contractors needs.

Several BIM-based software packages have nowadays well established positions and are used by design and construction professionals. Such tools form natural starting points also for BIM-based site layout and safety planning. Tekla Structures and Tekla Construction Management software were selected for testing and piloting tasks of the BIM Safety project. Tekla Structures is a structural engineering and modelling software and Tekla Construction Management is meant for use on site. Modelling software covers tools for steel, concrete and precast element structures modelling to the detailed level. Both software includes rather sophisticated 4D-tools, and especially those features important for site use are being developed further all the time. A special advantage of using Tekla software for safety planning is the opportunity to use the real structural model of the building project as a basis for safety planning. This model corresponds to the construction work at site including the assemblies like the building is designed to be built up. Nevertheless, development work has been needed to find the ways to apply the selected software for the proposed safety related purposes.

Beside Tekla Structures, other available BIM-based tools suitable for site and safety planning have been also studied. Examples of those are ArchiCAD and Revit. From the viewpoint of safety, the strengths of these software include suitable tool for landscape modelling and visually high level plans, and a weakness is lack or limitation of 4D-features. Google SketchUp has achieved a relatively high popularity of professional use, especially in architectural sketching, but in USA some contractors have also been using it for site planning and to support project communication (http://sketchup.google.com). Its popularity seems to be based on low cost, easiness of use, visually high level plans, and support to easily share 3D-components modelled by users with the help of Internet-based 3D Warehouse. Additionally, one special feature is the opportunity to place the 3D-models of buildings to Google Earth. BIM used on site can also be a combined model created e.g. by the help of Navis Works software. Navis Works does not include any modelling tools but can be used to combine models of various design parties to create combined models of rather small file size, to review these combined building designs, for clash checking and for creating 3D or 4D visualizations.

6. Piloting 4D-BIM for safety in the BIM Safety project

6.1 Developing 4D-BIM for safety purposes

Before the start of the actual piloting, functionality tests concerning 4D-tools in the selected modelling software Tekla Structures were carried out relating to the modelling and visualization of safety tasks and corresponding temporary equipment. The central tools at the software that supports the use of a BIM at construction phase are called model organizer, task manager and project visualization tools. Testing was needed to find out how the temporary safety related structures and equipment can be managed with the help of the selected software. This testing focused on 4D falling protection planning, especially scheduling and visualisation of safety railings. As a result of the testing, a BIM-based 4D safety railing demonstration has been created.
Technical 4D testing was carried out by VTT using Tekla Structures (version 15) modelling software and data from a completed residential building project called Mäntylinna (the developer and the contractor in this case is Skanska). The original Tekla structural model was created by the structural engineer Finnmap Consulting, and it served as a base for modelling safety tasks. Before actual safety planning, the surface of the site area was roughly modelled with the help of architectural modelling software ArchiCAD and combined into Tekla model as a reference model. Next safety railings were modelled to the edges of the intermediate floors and balconies with help of roughly modelled/semantic railing components. To create 4D-BIM, tasks corresponding erection of precast elements and related safety railings was created into a task list in the task manager -tool. After scheduling the tasks and linking them with the corresponding parts in the model, and creating suitable visualization rules, it became possible to visualize project status on any selected review-date on the planned time scale (Figure 1). This view describing current or planned status of the construction project on a specific date can be easily distributed to any project participant as a snapshot produced with one press of a button.

Figure 1: 4D safety railing visualization as part of precast element erection visualization.

4D visualization requires appropriate set of visualization rules, by which the software is told which parts are to be displayed and how. This far there is real experience of use of the software to permanent construction assemblies of a building only, and the new thing in the demonstration is including temporary safety railings in 4D planning and visualization. In the test, the following object groups and representation styles were defined for visualizing status of safety railings on any review date: railings to be assembled today (shown as red), other railings needed today, but installed earlier (colour by class, meaning displayed with the same colour as modelled), and railings taken away (shown as hidden). Parts of the model are filtered to each object group by rules relating to status of the corresponding task on the review date, and rules are set in object group dialog box (Figure 2). The rule set can be used and developed in different purposes in pilots.
Object and component libraries in various modelling software aim to provide ready-modelled 3D descriptions or structures to facilitate and accelerate modelling of building components that can be installed permanently into a building. However, the site equipment needed for example during precast unit installation, are temporary parts and circumstances for which the libraries do not offer ready 3D descriptions. In addition, libraries are software-specific, so that for example, GDL-objects used in ArchiCAD software cannot be directly used in other modelling software. (Sulankivi & al 2009)

The software used here has originally been developed for structural engineering and does not include customised components for site safety planning. Availability of safety related custom components for Tekla Structures in other sources was studied in the project, before starting to create needed site layout and safety planning components in cooperation with the contractor. The next figure presents some examples of custom components created for site layout planning (Figure 3). Custom components that correspond to the real safety railings planned to be used in the first pilot project are being developed.
At the next stage of the research project, the experience from 4D visualization test will be used for creating a real 4D falling protection plan for an on-going pilot construction project.

**6.2 Utilization of 4D-BIM in the first pilot project (planned testing)**

New office premises of Skanska corporation have been selected to be the first pilot project in BIM Safety research effort. This construction project is located in Helsinki Finland. BIM-based site layout and falling protection planning, as well as use of BIM for risk assessment, orientation guidance and safety communication are considered to be the development areas related to BIM and safety in this first pilot.

BIM-based site layout planning is under way by the contractor, and the development work related to BIM-based falling prevention planning has recently started. Research team has been carrying out preparation work for conducting 4D site layout and falling prevention plan in cooperation with the site organisation, by attending safety planning and modelling the railings planned to be used in the construction project. At the next stage a real BIM-based falling prevention plan will be created. That will be integrated with the real structural design and the scheduling of safety equipment will be based on the erection schedule of corresponding building assemblies. Consequently the target is to include a BIM-based falling prevention plan as part of the 4D-planning. This 4D model is aimed to be used to support safety planning, risk assessment, and safety communications, as well as for visualizing the project when introducing the project to site staff.

**6.3 Expected benefits and challenges**

Based on the first experiences concerning safety related tasks scheduling and 4D-visualisation using Tekla Structures, it seems that the temporary safety related parts can be included in 4D planning and visualization. Additionally, the user can define object representation and visualization rules quite flexibly to the purpose needed, e.g. by selecting which parts are showed and how (colour and visibility) in the visualization. However, some special features and requirements are related to BIM-based planning and 4D visualization of temporary structures, that have not needed to be taken into account when modelling and visualization has covered permanent building parts only. For example, if permanently installed building elements are modelled and scheduled, they will be visible in status-views of a 4D-visualization from the installation date forward. Temporary parts are to leave their position when they become unnecessary, or a permanent building part is to be installed at the same location.

In the first pilot project the target is e.g. to carry out more comprehensive BIM based falling prevention plan. That is expected to promote quality of planning and risk assessment, as well as support communication related to falling protection arrangements. As the safety railing modelling is implemented on the structural model it is possible to plan and manage also the details e.g. safety railing fixings. While all safety railing items are modelled the needed safety railing quantities can be calculated from the model.
The most significant weakness in tools identified so far is, that the time scale for visualizations is one calendar day (steps between review days), which seems to be too long time for ordinary building projects. That goes for scheduling tasks in task manager also, but possibility to define the assembly order of parts related to one task supports more detailed planning and information of installation sequence. Another identified problem is the lack of specific components for site planning, slowing down remarkable the utilization of the tool for site layout and safety planning in practice. When safety related components are created, it must be considered that they should be easy enough to model (insert to a BIM), and assemblies of parts in a component correspond to real installation and removing units at a construction site, to be able to carry out scheduling and visualization with help of 4D-tools. Additionally, it should be taken into account that pre-modelled components may be used as source of product and quantity information on construction site. Thus, there may be need to save specific product identifying codes or other information into the safety components, to be able to produce suitable quantity-reports.

7. Conclusions

BIM Safety project is revealing the special characteristics of safety oriented construction process planning. These special characteristics are requiring new functionalities that do not exist as such in the current BIM software. There are special requirements for modelling, scheduling and visualizing various temporary safety related structures if compared to those parts permanently installed into a building. Development work is needed for having workable and efficient site safety planning that would then fully capitalise the potential of BIM technologies and result in better accident prevention. In particular we see that the following functionalities should be in focus in the research and concerning development efforts by software companies.

- **Object and component libraries for site planning**: structural supports, site facilities (such as huts), large-scale temporary structures, main work equipment including safety equipment
- **Site planning functions**: Site layout planning with necessary spatial modelling functions, modelling land surface and temporary excavations, presence of detailed 4D simulations (time-steps < one day)
- **Safety analysis procedures**: space occupancy/realise by various resources, space usage clashes, analysis of transportation and movement routes, analysis of fixing and installation procedures, analysis of selecting safety equipment

From the process –view, one of the basic findings has been that detailed falling protection planning has traditionally not been carried out. A concrete falling protection plan is not created in all projects, and if it has been done, various safety guardrail types planned to be used, have been marked usually to a 2D-plan only symbolic by different colours. BIM-based safety railing planning requires more detailed falling protection planning, and is closely related to the planning of installation order of the prefabricated or cast in place structures of the building. As a result of more carefully safety planning construction site safety will be improved.
The conclusions above demonstrate the intermediate findings according to the focus and direction of the BIM Safety research project. The empirical work onwards focuses on trials in pilot construction project where 4D BIM based site safety planning procedures are to be applied. Identified further testing and development needs are for example, to facilitate the safety related modelling, producing quantity information for safety equipment directly from BIM, and to test the potential of BIM-based falling protection plan to support construction work at site and to improve site safety.

References


BIM Safety research project web-site http://www.vtt.fi/sites/bimsafety/


Google Sketch Up Construction Case studies, (available http://sketchup.google.com/community/casestudies.html [accessed on October 2009])


Safety Performance of Native and Migrant Employees on Construction Sites

Choudhry, R.M.
School of Civil and Environmental Engineering, National University of Sciences and Technology, Islamabad, Pakistan
(emails: choudhry03@gmail.com or rafiq.choudhry-scee@nust.edu.pk)

Fang, D.
School of Civil Engineering, Tsinghua University, Beijing, China
(email: fangdp@tsinghua.edu.cn)

Abstract

Construction is one of the most hazardous industries and good management of health and safety on construction projects can have a beneficial affect on employees. Understanding the safety culture of construction sites and perceptions of the employees are important factors in assessing safety needs. The objective of this research was to compare perceived safety performance of native and foreign employees working on construction sites that would enhance safety culture and positively impact safety performance of the organization. A questionnaire survey was conducted on the construction sites of a leading construction company. Questionnaires were distributed on 22 construction projects and the response rate was excellent, resulting in 1,120 valid questionnaires was analyzed. The analysis indicated that better safety performance was perceived by native employees as compared to foreign employees. Further results indicated that exhibiting compliance to safety procedures was higher among foreign employees compared with native employees. The findings of this study might be useful for project managers and safety practitioners who have employed both native and foreign employees and desire to improve safety performance on construction sites.

Keywords: construction safety, safety perceptions, native employee, foreign employee, safety performance
1. Introduction

To employ migrant workers in construction is a world-wide phenomenon which can be seen on almost all construction sites in the developed world. HSE (2006) has investigated whether migrant workers puts their health and safety at increased risk in comparison with other workers in similar positions. The findings revealed that migrants are more likely to be working in occupations where there are existing health and safety concerns and that it is their status as new workers that place them at added risk due to their relatively short periods of work and limited knowledge of the UK’s health and safety systems. The study reveals that migrants are premised on earning as much as possible in the shortest possible time which, add to their risk factors and that limited means of communication between migrant workers and indigenous supervisors place these workers at greater risk.

In China, construction workers are farm workers who migrate to large cities to earn cash on construction sites (Choudhry et al. 2008a). Generally, workers enter construction sites because they have few other alternatives. In Hong Kong, many construction workers are immigrants from the Mainland China. Construction is a hard, difficult and unattractive job for many Hong Kong’s native workers (Choudhry et al. 2008a). The Hong Kong territory does not possess enough agriculture land and continuously lacks construction labour. It is common practice that Mainland workers carry out construction works in Hong Kong on a daily or weekly basis. Rowlinson (2003) revealed that many of these workers have a low level of education and the majority has little or no training in a trade. In Hong Kong, however, there are construction workers from other countries that include India, Nepal, Pakistan, Myanmar, Vietnam and Cambodia to mention a few.

Gammon Construction Limited (GCL) hereinafter called the company is a well-established construction firm and a market leader in the Hong Kong construction industry (HKCI). Most of the labour force of the company is Chinese but the company also employs foreign workers. The company has implemented good safety, health and environment management systems on all of its construction sites. The company’s accident rate is lower than that of the Hong Kong construction industry (Choudhry et al. 2008a). The company’s safety management system is based on OHSAS 18001 (Occupational Health and Safety Assessment Series) and FIUO (Factories and Industrial Undertakings Ordinance Chapter 59 and 509) (Choudhry et al. 2008b). The concept of ‘safety culture’ is highly valued within the company and management believes that a positive safety climate is helpful for improving safety performance. The company wanted to know about safety performance of native and foreign employees. Thus, the main objective of this research was to compare perceived safety performance of natives and foreign employees working on the construction sites.

Few studies have compared the safety perceptions of different ethnic groups of workers. Studies to date (e.g. Zohor 1980; Mohamed 2002; Fang et al. 2006) have focused on identifying a set of safety climate factors. This research makes a unique contribution to safety studies to date by focusing on the safety perceptions and comparing the perceived safety performance of native and foreign employees working on construction projects. Thus, the perceived safety performance of local and foreign employees is compared in this research.
2. Literature Review

Globalization is becoming an inescapable fact when it is no longer a good idea for governments to legislate in isolation. Changes that once only affected one country’s population now have far reaching consequences when workers are able to find out work through internet agencies and travel to different countries at a relatively low cost (Bust et al. 2008). Together with the growing international activity in construction, there has been an increasing awareness of the importance of better understanding of cross-cultural management (Torrance, 2004). Langford (2000) revealed that culture frames the way in which we express ourselves and we express ourselves in a number of ways: verbally – what we say; paraverbally – how we say it; nonverbal – body language; and through action – doing things consciously or unconsciously in a particular ways.

People from different nationalities and ethnic groups express themselves and understand the behaviours of others in different ways, which are informed by specific sets of cultural knowledge and conventions (Bust et al. 2008). A cross-cultural misunderstanding can lead to health and safety problems. Research on construction safety in Kuwait (Kartam et al. 2000) reported that there was an extensive use of foreign labour; that different labour cultures and traditions reflect on human relations, different work habits and communication problems; and the workers were emotionally vulnerable and preoccupied with their problems. All these factors affected the concentration of the workers and consequently contributed to mistakes. In the pre-context of cultural issues it is interesting to investigate safety performance of native and foreign employees working on the construction sites.

Safety performance measurement techniques can be categorized into statistical measures, behavioural measures, periodic safety audits, and a balanced scorecard approach. The behavioural approach, safety audits, and balanced scorecard require a relatively long period of time to set up and are not easy to measure by the use of a questionnaire survey (Chan et al. 2005). Measurement of workers’ perceptions of safety performance requires respondents to judge the safety of their own construction sites. Nevertheless, the reliability of workers’ perceptions of safety performance of a construction project can present a problem in small samples because different respondents from the same construction site may have different perceptions of safety performance. This problem can be solved by using a large sample size as a prerequisite for maintaining statistical validity.

3. Research Method

From the literature review, an understanding was developed concerning the concepts of safety climate and safety performance. Potential safety attributes affecting safety performance at the company’s construction sites were identified. Questionnaires were used to capture employee perceptions to identify areas of safety that require improvement. Eight items questionnaire was designed for this research to investigate safety perceptions of native and foreign employees working on construction sites. For the purpose of this research, respondent having origin from Mainland China and Hong Kong were both considered native. Respondents from all other countries were considered foreigners or migrants. Twenty-two construction projects in Hong Kong were selected for the target sample. All these construction sites are the projects of a company whose annual revenue was approximately
US$1 billion and the company employs more than 2,500 full-time staff. A pilot study was carried out on construction sites to check the reliability, validity and usefulness of the questionnaire. The questionnaire was examined for content validity, structural validity and offensiveness of the language. They were asked to comment on if there is any overlapping of the wording or statements. Their feedback was used to refine the questionnaire and delete the unacceptable wording. Thus the questionnaire measured what it was supposed to.

The questionnaire was purposely designed to seek views of respondents on key aspects of safety performance on construction sites. The questionnaires were prepared both in English and Chinese versions. The questionnaire in its final form consisted of 8 statements about safety issues and consisted of two parts. The first part of the questionnaire related to the respondents’ general information. The questions included respondent’s project name, name of the company, ethnicity, e.g. whether a respondent is a local or foreigner? Further questions included the respondent’s job information, i.e. is he/she a worker, a clerical staff, supervisor or a manager? The second part consisted of three questions. First question (see Table 1) measured respondents’ perception of evaluating safety management for the surveyed projects.

Table 1: Safety Performance

<table>
<thead>
<tr>
<th>Please tick the appropriate number to indicate your level of agreement for safety performance.</th>
<th>Poor (10%)</th>
<th>Marginal (30%)</th>
<th>Average (50%)</th>
<th>Good (70%)</th>
<th>Excellent (90%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1. How do you evaluate the safety and health management of your site?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

The other two questions (see Table 2) measured respondents’ perception of compliance with safety procedures. Respondents were asked to indicate, on average, the percentage of time they and their co-workers follow all of the safety procedures for the job they perform.

Table 2: Compliance with Safety Procedures

<table>
<thead>
<tr>
<th>Please tick the appropriate number to indicate your level of agreement for safety performance.</th>
<th>On a scale of 0-100%, please indicate, on average the percentage of time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q2. I follow all of the safety procedures for the jobs that I perform</td>
<td></td>
</tr>
<tr>
<td>Q3. My co-workers follow all of the safety procedures for the jobs that they perform</td>
<td></td>
</tr>
</tbody>
</table>

Data were collected on 22 construction projects of a large construction company based in Hong Kong. In total 1,500 hard copy questionnaires were distributed randomly to a population of approximately 2,250 individuals. The response rate was excellent (86.3%) and 1,294 questionnaires were collected from the 22 construction sites. The questionnaires, which were completed by unclassified categories, such as clerical staff, were discarded and considered invalid to prevent a distortion of the results from
the data set. The sample size for the data analysis was thus reduced from 1,294 to 1120 called the valid sample or sample. Nonetheless, the sample is very large as compared with the population. Additionally, it is a random sample where each individual have the same chance as every other individual of being selected. Further, to check and avoid the problem of bias, it was decided to interview at least one employee working on each project of the company and thus 22 interviews were conducted to investigate compliance with the methodology.

4. Results of Research

The safety performance perceptions of native employees were compared with their foreign counterparts. The outcome may be of interest to those multi-national companies who are employing workers from various countries. The respondents were asked to evaluate the safety and health management at their site against any one of the following measures i.e. 10%, 30%, 50%, 70%, or 90%. From 1,120 respondents, 1089 were native employees and only 31 were foreigners. The results are presented in Table 3. The result shows that native respondents perceive safety management at their site to be slightly better 63.77% as compared with foreign (62.26%) respondents.

Table 3: Comparison of Safety Performance between Native and Foreign Respondent

<table>
<thead>
<tr>
<th>Description</th>
<th>Local</th>
<th>Foreign</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respondents</td>
<td>1,089</td>
<td>31</td>
<td>1,120</td>
</tr>
<tr>
<td>Results</td>
<td>63.77%</td>
<td>62.26%</td>
<td>63.73%</td>
</tr>
</tbody>
</table>

Another comparison was made between native and foreign respondents’ answers to questions requiring them to indicate on a scale of 0 (zero) to 100%, the percentage of time: (1) I follow all of the safety procedures for the jobs that I perform; (2) My co-workers follow all of the safety procedures for the jobs that they perform. The results are presented in Table 4. The results show that foreigner employees perceived a higher level of compliance with safety procedures (78.39%) as compared with the local respondents (73.06%) on construction sites. Nonetheless, if the results are compared between Q2 and Q3 i.e. between the respondent and co-workers, similar trends can be seen among native and foreign employees.

Table 4: Comparison of Compliance with Safety Procedures between Native and Foreigner

<table>
<thead>
<tr>
<th>Description</th>
<th>Respondents Compliance with Safety Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Local</td>
</tr>
<tr>
<td>Respondents</td>
<td>1,089</td>
</tr>
<tr>
<td>I follow all of the safety procedures for the jobs that I perform (Q2)</td>
<td>73.06%</td>
</tr>
<tr>
<td>My co-workers follow all of the safety procedures for the jobs that they perform (Q3)</td>
<td>63.98%</td>
</tr>
</tbody>
</table>
5. Discussion

Results have shown that native employees perceived that safety has been managed in a better way as compared with foreign employees. The score was 63.77% for the natives and foreigners’ score was 62.26%. The authors postulate that the natives were implementing and monitoring the safety procedures on the construction projects. In this case, they are in majority and being having better ownership, they perceived better safety performance. Their score is little bit higher as compared to that of foreigners while foreigners were cautious.

Additionally, results show that exhibiting compliance to safety procedures were perceived higher among foreign employees as compared with native employees. Foreigners got the score of 78.39% and natives got 73.06% for question Q2. For question Q3, foreigner and natives scores were 65.32% and 63.98% respectively. Again, the results showed that foreigners perceived a higher level of compliance with safety procedures.

These results are in line with Rowlinson (2003 p.170) that the accident rate for the imported labour on airport platform was less than that for the local labour. For this study, however, only 31 responses were received from foreigners as compared with 1,089 native respondents. A sample having more foreign employees may be considered for such a comparative study in future. We also suggest that a larger sample from different companies may be investigated such that results between safety performance of natives and foreign employees could be compared and broader conclusion could be arrived at.

6. Conclusion

The objective of this paper was to compare perceived safety performance of natives versus foreign employees in construction site environments that would improve safety culture and positively impact safety performance of the firm. A survey was conducted by distributing the questionnaire on 22 construction projects and the responses were analyzed. Results discussed in this study included that better safety management was perceived by native employees compared to foreign employees. The results indicated that exhibiting compliance to safety procedures among foreign employees was higher compared with local employees in the company in Hong Kong. Nevertheless, the objectives were company specific. The results are based on the 22 projects of a company and are applicable to the firm only. The findings of this study might be useful for project managers and safety practitioners who desire to improve safety performance of employees employed from different countries.

References


Development of a Practical Guide for Silica Dust Exposure Limits for Concrete Saw Cutting Methods

Middaugh, B.
Purdue University
(email: bmiddaug@gmail.com)
Hubbard, B.
Purdue University
(email: bhubbard@purdue.edu)
Zimmerman, N.
Purdue University
(email: neil@purdue.edu)
McGlothlin, J.
Purdue University
(email: jdm3@purdue.edu)

Abstract

Construction workers frequently utilize hand-held cut-off saws for cutting concrete and other hard materials. Without methods of dust control, concrete sawing produces elevated concentrations of ambient respirable particulate, a portion of which is composed of crystalline silica. Breathing elevated concentrations of respirable silica is associated with multiple diseases and disorders including silicosis, a progressive lung fibrosis. A recent study of hand-held saw cutting methods compared wet and vacuum dust control methods to an uncontrolled dry method. Results provided information on the levels of workers’ exposure to silica. In order to effectively translate this research into practical information for the construction worker, an exposure guide based on data from this case study has been developed to illustrate exposure potential per unit of work (e.g. cuts). The guide provides information on the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PEL) for the specific concrete cutting tasks, and how many cuts a construction worker can perform without exceeding the PEL. The guide provides a straightforward method for construction workers to quickly pre-determine their exposure levels so they can take appropriate actions to limit their exposure. However, there are noteworthy limitations when applying this guideline to other construction environments. These limitations are presented along with a general discussion on the difficulties of extrapolating experimental silica dust exposure data in the development of guidelines for contractors.

Keywords: construction saw, concrete, silica, quartz
1. Introduction

Crystalline silica, specifically alpha-quartz, is a principal health hazard within the roadway construction industry (Flanagan M., Seixas, Majar, Camp, & Morgan, 2003). Traditionally, inhalation of respirable silica was singularly thought of as a disease-causing agent for silicosis, a type of pneumoconiosis of the lungs; however, in recent decades, it has been identified with multiple health conditions and diseases. In addition to silicosis, crystalline silica has been implicated as a potential causal agent or risk factor for lung cancer, tuberculosis, renal disease, and various autoimmune disorders (NIOSH, 2002; Valiante, Schill, Rosenman, & Socie, 2004).

Silica exposure can occur during almost every step of roadway construction: from the excavation and placement of underground drains until the final sweep of the roadway after completion (Lumens & Spee, 2001). New methods of road repair and maintenance also present significant risk for exposure. Occupational classifications, like the construction laborer, perform a diverse assortment of these tasks during a work day. The duration of these work tasks may vary considerably based on the construction phase and specific jobsite characteristics. Historically, the wide variability in these factors has made roadway construction exposures very difficult to quantify (Flanagan M., Seixas, Majar, Camp, & Morgan, 2003; Woskie, Kalil, Bello, & Virji, 2002).

Because of the unpredictable nature of silica-producing tasks performed during a normal workday, this research has attempted to simplify and quantify inhalation exposure in terms of productivity and specific task duration. Utilizing a case study of concrete cut-off saws, the research provides 1) a protocol for the development of a practical guide for assessing and comparing inhalation exposure in terms of productivity for three dust control methods, and 2) a discussion of limitations for such an assessment.

1.1 Respirable silica generation and worker protection

Concrete sawing produces high levels of respirable (RSP) dust, a percentage of which is composed of crystalline silica (i.e. quartz) (Thorpe, Ritchie, Gibson, & Brown, 1999). Hand-held cut-off saws are used in almost every facet of construction, and are often used with diamond embedded blades to cut concrete materials including road surfaces, sidewalk surfaces, bridge decks, and curbs. Depending on the application, sawing is not normally performed for an entire workday, but illustrates a singular component of the many tasks performed by workers during a day.

Silica-related diseases are preventable by controlling exposure among workers performing tasks such as concrete sawing (OSHA, 2008). Industrial hygiene practices specify the order in which dust control systems should be prioritized: 1) engineering control (e.g. wet methods and Local Exhaust Ventilation (LEV) methods), 2) administrative control (e.g. training and worker rotation), and 3) personal protective equipment (e.g. respirators) (AIHA, 2003). The lowest control priority, respiratory protection, is the most widely used preventive dust measure (Nij, et al., 2003). In a study by Lumens and Spee (2001), respiratory protection was still seen on only 30 percent of jobsites, the most prevalent forms being paper dust masks (i.e. comfort masks) (Lumens & Spee, 2001; Rappaport, Goldberg, Susi, & Herrick, 2003)
Furthermore, the effectiveness of respirator use is often dependent upon adequate management training and control (AIHA, 2003). The following respiratory protection components are required by OSHA: respirator training, respirator fit testing, medical evaluations, and respirator maintenance (OSHA, 1997). Proper implementation of a respiratory protection program (RPP) can effectively prevent silica overexposure, but improper compliance with any one component of an RPP can present significant risk of misuse and health complications (Nash & Williams, 2000; AIHA, 2003; Flanagan M., Seixas, Major, Camp, & Morgan, 2003; Lahiri, Levenstein, Nelson, & Rosenberg, 2005). Respirators have low control priority because of these risks, and adherence to the many components of the RPP make implementation very costly. Therefore, engineering controls such as wet methods and LEV methods are preferred by OSHA, and can be as cost effective as a RPP. However, appropriate health assessments for these dust controls are not always practical or feasible for each individual application.

2. Materials and methods

In this case study, concrete cutting was performed during the sawing of expansion joints in concrete curbs. Standard personal air monitoring was used during cutting to determine the respirable dust exposure of professional laborers who voluntarily participated in this study. The study included three different sawing methods 1) a traditional dry sawing method, 2) a wet sawing method, and 3) a local exhaust ventilation sawing method (See Figure 1). In addition to measuring silica dust exposure, characteristics of concrete sawing were measured, including sawing rate and the average volume of concrete displaced. These characteristics provide a measure of both exposure and productivity.

Because slipping forms were used to pour the curb at a continuous standard size, the dimensions of the curb were approximately constant for all trials. The depth of cuts made by the worker was slightly variable and measured with a ruler in centimeters. The displaced area is represented by the area above the dotted line in Figure 2 for both chair back and extruded curb applications. The average displaced volume in cubic centimeters for a single saw cut was determined by measuring the displaced area of five random saw cuts per sample, taking the average of these cuts, and then multiplying this area by the saw blade width (BW) (See Equation 1). The total displacement in cubic centimeters was established by multiplying the average displaced area times the total number of saw cuts performed during the sampling period (See Equation 2). The number of saw cuts was recorded by researchers during the sampling period and verified by video analysis. Finally, a concrete displacement rate was calculated by dividing the total displacement by the sampling period duration in minutes (See Equation 3). The concrete displacement rate gives the volume of concrete in cubic centimeters removed per minute over the sampling period.

\[
\text{Displacement} = BW \times \left( \frac{\sum_{i=1}^{5} \text{Displace Area}}{5} \right)
\]  
(1)

\[
\text{Total Displacement} = \text{Displacement} \times \text{Cut}
\]  
(2)

\[
\text{Displacement Rate} = \frac{\text{Total Displacement}}{\text{Time}}
\]  
(3)
After the inhalation exposure and concrete displacement rate were determined experimentally for each dust control method, an exposure factor was developed, based on the assumption that exposure is dependent on the volume of material cut and the length of time required to cut the material. The resulting exposure factor equation is shown in Equation 4 as a ratio of the time-weighted average exposure (i.e. respirable dust exposure) to displacement rate. An equation to describe exposure was then developed based on the experimental exposure factor (Equation 4), and three additional variables: material removed per cut, removal time, and the number of cuts made, as shown in Equation 5. Upon verification with additional data and statistical analysis, the resulting equation (estimated as Equation 5) would allow construction professionals to estimate a worker’s respirable dust exposure for various curb cutting applications without performing direct air monitoring. To estimate a worker’s exposure to silica, the exposure calculated by using Equation 5 may be multiplied by the percent silica, which is determined experimentally based on the characteristics of the concrete being sawed.

\[
\text{Exposure Factor} = \frac{\text{Respirable Dust Exposure}}{\text{Displacement Rate}} \tag{4}
\]

\[
\text{Estimated Dust Exposure} = \text{Exposure Factor} \times \frac{\text{Material Removed per Cut} \times \text{Cuts}}{\text{Removal Time}} \tag{5}
\]

\[
\text{Estimated Silica Exposure} = \text{Estimated Dust Exposure} \times \%\text{Silica/100} \tag{6}
\]

3. Results

In the concrete saw case study, dramatic dust reductions were seen for both the wet sawing method and the LEV sawing method as compared to the dry sawing method; however, the wet and LEV sawing methods also showed reduced rates of concrete displacement which results in reduced productivity. The reduced productivity is mainly due to the operational needs and requirements of the dust suppression equipment (See Table 1). The wide range of the exposure and displacement rate for each saw method in very similar applications is a significant limitation when trying to estimate one standard exposure factor for each saw method.

3.1 Practical exposure guidelines

To illustrate the expected exposure to respirable silica dust, an exposure matrix for each saw method was developed from the case study data. This exposure matrix represents how a practical exposure guide could be developed (See Table 2). The exposure matrix was made specifically for a “chair back” curb, with an estimated standard individual cut volume of 130 cm³. For the proposed equation, the average experimental percent quartz (6.4%) from all saw methods was used. Estimations of respirable silica exposure were calculated for various cutting quantities in the matrix. The exposure matrix was also illustrated graphically in Figure 3.

The exposure concentrations can then be compared to regulatory limits and recommended standards for respirable silica dust. The Occupational Safety and Health Administration (OSHA) regulate air
contaminants using permissible exposure limits (PELs), which designate allowable levels of silica exposure (OSHA, 1997). The estimated exposure values from the proposed equation can be compared to the OSHA PEL of 0.1 mg/m$^3$ for respirable silica dust as an 8-hour time-weighted average (TWA). American Conference of Governmental Industrial Hygienist (ACGIH), suggests a threshold limit value (TLV) of 0.025 mg/m$^3$ for RSP crystalline silica for an 8-hour TWA (ACGIH, 2009). Both the OSHA PEL and the ACGIH TLV are noted as a horizontal line in Figure 3. A graph, such as Figure 3, could be used by the contractor to determine the number of cuts a worker may perform before exceeding the defined exposure limits for a single day’s work.

There is substantial value in developing a simple graph such as the one shown in Figure 3. This graph can easily be read and understood by the worker or supervisor and may contribute to worker health by reducing dust exposure beyond widely accepted standards. There are limitations to the proposed assessments; however, these limitations are primarily due to the variability of data and limitations associated with extrapolating these findings to other environments.

### 3.2 Limitations of silica exposure guide

There are a number of limitations for applying this silica exposure information to other construction environments. Limitations include:

1. Variability due to individual worker
2. Variability due to sawing task
3. Variability due to material being sawed
4. Variability due to environment

These are described in greater detail below.

#### 3.2.1 Individual worker

Because roadway construction is a mobile industry, worksites change frequently and worker turnover rates are high (Flanagan M., Seixas, Majar, Camp, & Morgan, 2003). Individuals composing a working crew can change on a daily basis as the distance between consecutive worksites is not always convenient or economical for workers. These workers may have different operating styles, affecting exposure through their endurance, operating speed, technique, and posture. Therefore, assuming one exposure factor for all individuals across an industry may be inadequate.

#### 3.2.2 Task

Specific sawing tasks also produce significant variability in dust generation. Influential factors include:
• The object being cut. For example, there is a difference in silica generation for a curb crosscut versus a sidewalk crosscut, or a cross cut of asphalt versus concrete.

• The outcome wanted. For example, a cut made for removing concrete curb is different than for a cut made for an expansion joint in new concrete.

3.2.3 Material

In terms of silica in concrete, the composition of concrete can vary among both application and region. Strength, speed of cure, density, and workability requirements of jobsite plans often define the exact “add mixture” of substances used within the concrete, and thus the percentage of crystalline silica within the concrete. It is also important to note that even though concrete mixtures are approximately homogeneous in new material, variations caused by maintenance practices of concrete often leads to varying quantities of crystalline silica throughout the roadway infrastructure. Maintenance, demolition, and removal of existing roadway structures and materials can often lead to highly unpredictable levels of silica content.

3.2.4 Environment

For outdoor settings, environmental conditions such as ventilation, weather, and surrounding objects can have a profound effect on exposure (Thorpe, Ritchie, Gibson, & Brown, 1999). For example, there is a difference in dust levels if the saw cut is made on an open roadway or in an alley due to natural ventilation and surrounding objects. Thorpe et al. (1999) also reported that certain wind directions and wind speeds can cause workers to be enveloped in a cloud of dust. Using the current case study, a comparison of experimental data with wind direction also showed a high variability in the worker’s exposure to respirable dust. All of these factors can contribute to a wide variation in exposure. The proposed equation should be validated with additional data to provide more information about the impact of various factors on silica exposure for various cutting methods.

4. Conclusions

Inhalation of respirable silica dust causes negative long term heath effects for construction workers, and appropriate engineering controls and personal protection equipment need to be employed to reduce worker exposure. This paper outlines a method for developing a practical guide for assessing a worker’s expected exposure for a specific sawing task, based on the dust control method, the number of cuts made by the worker, and the concrete composition. The practical guide is this study is based on research performed to identify worker dust exposure when sawing a concrete chair back curb with a hand-held concrete cut-off saw. The development of exposure charts for various operations would be useful for contractors in determining and preventing worker overexposure to respirable silica, especially when multiple tasks are performed during a day. However, there are limitations to extrapolating these guides into other construction environments and further research is needed to develop and validate more comprehensive guides for various construction operations. Real-time particulate monitoring technology may also improve the ability to quantify exposure per unit of work, and also reduce variability in inhalation levels.
5. Acknowledgement

This research study was supported by the participating contractor, E & B Paving, Inc. and by the NIOSH and the Health Pilot Research Project Training Program of the University of Cincinnati Education and Research Center Grant #T42/OH008432-04. A special thanks to Matt Gillen, Construction Sector Program Coordinator (NIOSH), for encouraging the translation of the research results into practical applications for the industry.

Table 1. Measured Respirable Dust Exposure and Displacement Statistics for Sawing Periods.

<table>
<thead>
<tr>
<th>Saw Method</th>
<th>N</th>
<th>Respirable Dust (mg/m³)</th>
<th>Displacement Rate (cm³/min)</th>
<th>Exposure Factor (mg·min/m²·cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>16</td>
<td>19.9 (48.6, 5.22)</td>
<td>232 (299, 156)</td>
<td>0.086 (0.216, 0.019)</td>
</tr>
<tr>
<td>Wet</td>
<td>13</td>
<td>3.93 (16.9, 1.39)</td>
<td>108 (249, 64.5)</td>
<td>0.043 (0.186, 0.008)</td>
</tr>
<tr>
<td>LEV</td>
<td>11</td>
<td>4.02 (13.77, 1.71)</td>
<td>140 (202, 106)</td>
<td>0.028 (0.098, 0.012)</td>
</tr>
</tbody>
</table>

Notes: N= number of sawing periods sampled.

A Arithmetic mean (maximum, minimum).

B Exposure Factor (mg·min/m²·cm³) = [Exposure/Displacement Rate]

Table 2. Case Study: 8-Hour Respirable Silica Exposure Matrix for Various Cut Quantities during the Cutting of “Chair Back” Curb.

<table>
<thead>
<tr>
<th>Number of Cuts</th>
<th>Saw Method</th>
<th>Wet</th>
<th>LEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.007</td>
<td>0.004</td>
<td>0.002</td>
</tr>
<tr>
<td>20</td>
<td>0.022</td>
<td>0.011</td>
<td>0.007</td>
</tr>
<tr>
<td>30</td>
<td>0.037</td>
<td>0.018</td>
<td>0.012</td>
</tr>
<tr>
<td>40</td>
<td>0.052</td>
<td>0.026</td>
<td>0.017</td>
</tr>
<tr>
<td>50</td>
<td>0.067</td>
<td>0.033</td>
<td>0.022</td>
</tr>
<tr>
<td>60</td>
<td>0.082</td>
<td>0.041</td>
<td>0.027</td>
</tr>
<tr>
<td>70</td>
<td>0.097</td>
<td>0.048</td>
<td>0.031</td>
</tr>
<tr>
<td>80</td>
<td>0.112</td>
<td>0.055</td>
<td>0.036</td>
</tr>
<tr>
<td>90</td>
<td>0.127</td>
<td>0.063</td>
<td>0.041</td>
</tr>
<tr>
<td>100</td>
<td>0.142</td>
<td>0.070</td>
<td>0.046</td>
</tr>
<tr>
<td>110</td>
<td>0.156</td>
<td>0.078</td>
<td>0.051</td>
</tr>
<tr>
<td>120</td>
<td>0.171</td>
<td>0.085</td>
<td>0.055</td>
</tr>
<tr>
<td>130</td>
<td>0.186</td>
<td>0.092</td>
<td>0.060</td>
</tr>
<tr>
<td>140</td>
<td>0.201</td>
<td>0.100</td>
<td>0.065</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-----</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>150</td>
<td>0.216</td>
<td>0.107</td>
<td>0.070</td>
</tr>
<tr>
<td>160</td>
<td>0.231</td>
<td>0.115</td>
<td>0.075</td>
</tr>
<tr>
<td>170</td>
<td>0.246</td>
<td>0.122</td>
<td>0.080</td>
</tr>
<tr>
<td>180</td>
<td>0.261</td>
<td>0.129</td>
<td>0.084</td>
</tr>
<tr>
<td>190</td>
<td>0.276</td>
<td>0.137</td>
<td>0.089</td>
</tr>
<tr>
<td>200</td>
<td>0.291</td>
<td>0.144</td>
<td>0.094</td>
</tr>
</tbody>
</table>

Notes: An individual cut volume of 130 cm$^3$ was assumed, with a concrete silica content of 6.4%. Dashed borders represent OSHA PEL and ACGIH TLV exposure cut-off points.
Notes: An individual cut volume of 130 cm$^3$ was assumed, with a concrete silica content of 6.4%.

Figure 3: Estimated 8-Hour Respirable Silica Dust Exposure for Various Cut Quantities during the Cutting of “Chair Back” Curb.
References


The Effect of Illuminance on Task Performance

Hinze, J.
University of Florida, USA
(email: hinze@ufl.edu)
Taminosian, Z.
University of Florida, USA
(email: zacht@ufl.edu)
Olbina, S.
University of Florida, USA
(email: solbina@ufl.edu)

Abstract

Adequate lighting in the workplace would appear to be a fundamental requirement for optimal performance on any construction project. Various safety regulations stipulate the minimum levels of lighting that must be provided for workers. While these regulations may be sound, in reality few individuals have even a vague sense of the amount of lighting that is described when the number of lumens per square foot is stipulated. While most individuals will have some concept of the meaning of a given number of degrees Celsius, there is little understanding of the difference between 5 lumens, 25 lumens or 250 lumens. The subject of lighting was examined in a study of over 100 study participants who were asked to perform three basic tasks that required some visual acuity. These tasks were performed at three different levels of lighting under carefully controlled conditions. The objective of the study was to evaluate task performance in terms of speed and accuracy under different lighting conditions. The study determined that task performance took decidedly longer under lighting conditions of 0.3 lumens per square foot. While performance was noticeably faster at 3 lumens per square foot, the best performance was achieved at 18 lumens per square foot. It was also found that the number of errors made was markedly increased at the lower lighting levels. Errors made in construction settings can often be equated to mistakes that could have safety implications. This was an exploratory study that yielded several interesting findings. With the increase in night time construction for certain types of work, it will behove construction managers and safety professionals to become more mindful of the importance to monitor lighting conditions to ensure a productive and safe work environment.

Keywords: illuminance, lighting, performance, accuracy
1. Introduction

Productivity is vital to success in the construction industry. Productivity can be affected by many factors, including the environment in which work is performed. One aspect that has not been examined to a great extent is the level of illuminance in the construction work environment and the resultant impact on performance.

In the United States, the need for proper illuminance is clearly stated in guidelines promulgated by the Occupational Safety and Health Administration (OSHA) 29 CFR 1926 Construction Industry Regulations. These regulations address many aspects of the work environment. One of the requirements stipulates the minimum standards and practices for jobsite lighting or illuminance. While the OSHA regulations are focused on safety, it is generally understood that lighting characteristics of a jobsite might have a direct effect on productivity or performance.

The OSHA regulations stipulate that construction work performed in general construction areas can be performed under lighting conditions of a minimum of 3 footcandles while office work is to be performed with 30 footcandles of illuminance. While the concept of a foot-candle (the amount of light from a candle emitted on a square foot of surface area at a distance of one foot) is easy to understand, it is not a measure with which most people have any familiarity. For example, most individuals would have no way of assessing the illuminance level in a given room because they are not familiar with the measure of illuminance.

This lack of familiarity with foot-candle measurements was a key factor in the genesis of this research. The research was to provide greater insights about the meaning associated with different levels of light intensity. More importantly, this evolved into the central theme of the study which was to investigate how performance varies with different illuminance levels.

The level, type, and distribution of lighting on a jobsite may constitute a contributing or causal factor in the occurrence of accidents. While light levels are often noted as possible factors in accident reports, it is interesting to note that very little hard data exists in this area. Some specific cases can be found where light levels were ultimately deemed responsible for accident occurrences but these are lacking in abundance and detail. The objective of this research was to examine the relationship of illuminance levels with the speed and accuracy when performing simple tasks.

2. Review of literature

Adequate lighting is important to the optimal performance of most tasks. Most construction work is performed in the elements so there is often adequate natural light during normal daylight hours. There are instances on construction projects when artificial lighting is required to carry out the work, especially when work is performed indoors and during nighttime hours. According to the Illuminating Engineering Society of North America (IESNA), the advantages of good quality lighting include greater accuracy and better workmanship, improved quality of product, increased production, decreased cost, and the ability of the eye to see quicker and in greater detail (IESNA 2000).
Illuminance is defined as the density of luminous flux falling onto a surface and is measured in footcandles (lumens per square foot). Another term frequently used is luminance which relates directly to perceived brightness and depends on the illuminance on an object and its reflective properties. Luminance is measured in candela per square foot (IESNA 2000).

One highway study found that artificial lighting required for construction operations at night varied with the type of job and had the potential to affect the output of construction crews. This study found that inadequate lighting is a factor which affects productivity on a project-by-project basis (Ellis and Kumar 1993).

Evidence of a correlation between light levels and safety can be found in a number of studies. One such study found that reduced visibility on nighttime projects increased the inherent hazards of construction. This study also concluded that artificial lighting must be sufficient to permit clear visibility without creating glare. In addition, poor visibility must be addressed to maintain an acceptable level of work quality (Hinze and Carlisle 1990). Although three footcandles is the minimum OSHA standard for construction sites, IESNA claims that less than 30 footcandles is undesirable for common visual tasks (IESNA 2000).

A review of fatality cases that were investigated by OSHA from 1990 to 2007 revealed that there are a number of cases in which lighting was an apparent factor in accident causation. The following case has been paraphrased and describes the circumstances in which lighting was insufficient to ensure the worker safety.

Example Case: A worker on a nighttime crew on a dry-dock project was responsible for cleaning up sandblasting materials left by workers in the cargo tanks of a ship. While looking for materials, the employee descended into a “totally dark” fuel bunker tank. After reaching a lower level within the tank, the worker began walking around in the dark and stepped into an opening in the deck. He subsequently fell approximately 30 feet to his death.

An Internet search for incidences citing inadequate illuminance as at least a contributing factor provided an additional example. The accident involved a laborer who fell through a hole in the second story of a federal building which was under construction. Light meter readings taken at the accident location showed that illuminance levels were between 0.2 and 0.8 foot candles. Although OSHA requires only five foot candles in such an area, both the District of Columbia labor laws and the IESNA Lighting Handbook require 10 foot candles for working spaces where simple visual tasks are performed (IESNA 2000).

According to Peter Boyce, a former head of the Lighting Research Center’s Human factors program in Troy, New York, “The purpose of lighting is to enable people to see and do things” (Morgan 2001). Mark S. Rea, Director of the Lighting Research Center, stated that “A successful lighting application must deliver light where it is needed” (Morgan 2001). For this reason it is important to consider which type of lighting might be used to produce optimum quality and productivity.
Xenon-filled lamps are often used in the construction industry and supply bright white light with excellent color rendering properties. Fluorescent tubes are a common choice for ambient lighting but have poor color rendering and a weak beam (Fischer n.d.). This makes fluorescent tubes a poor choice if the tasks require seeing at a distance or distinguishing color. Incandescent lamps produce a continuous spectrum of light (IESNA 2000).

Insufficient lighting is considered by many contractors to be the root source of problems with nighttime construction. This can be seen in the study by Hinze and Carlisle (1990) where a number of respondents indicated a drop in the quality of surface finishes when road construction was carried out at night. Unevenness of the paving surface was the main problem indicated and inspection of the work was also a problem due to shadows. The study found that many state highway agencies agree that the difficulty of providing adequate lighting has an adverse impact on quality.

3. Research methodology

3.1 Overview

The objective of this research was to examine the relationship between illuminance levels and task performance. It was decided that three different exercises would be performed by study participants. The exercises involved sight-related tasks that were evaluated in terms of task completion times and accuracy. The selected tasks required the ability to make minute visual observations.

Three different tasks were devised that were performed by each research participant. The first exercise consisted of the research participant determining the mint date of five U.S. pennies that were affixed to a white card. The pennies were oriented so all mint dates could be easily read from left to right (see Figure 1A). Research participants were asked to simply read off the dates by examining the pennies on the card without actually touching the pennies. The second exercise consisted of each research participant determining the size of three different drill bits by reading the size that was etched into the drill bits (see Figure 1B). For this test, the participants were permitted to pick up the drill bits to determine their sizes. The third exercise consisted of the research participant extracting specific information from a data sheet (see Figure 1C). These exercises were developed to explore the level of performance when lighting conditions were modified.
3.2 Testing environment

The testing environment was a critical factor in conducting the illuminance tasks. It was imperative that the illuminance level be well-controlled for all tests. Rooms with windows were considered but these were eventually deemed unacceptable as the illuminance levels would vary excessively with the time of the day and with the amount of cloud cover. A storage room was finally selected as it had no windows, and it had ample empty space for conducting the experiments. The storage room was also an ideal location as there were a minimum of external distractions.

The testing area was constructed in one corner of the storage room. The area consisted of a card table with white poster board attached to top surface, a chair, and four lights. The lights included a combination of fluorescent, compact fluorescent, incandescent, and halogen lights. A white sheet was placed above the table area to help diffuse the light. The lights were arranged so that only reflected light came to the table surface. This arrangement is shown in Figure 2.
The light fixtures were placed at an elevated position relative to the testing table surface and directed upward so the light would be reflected through the “diffusion ceiling”. By altering the number of lights that were on at one time, a combination was achieved whereby the illuminance levels could be easily adjusted for 0.3 foot candles, 3 foot candles or 18 foot candles. The illuminance levels were monitored across the white table surface and repeatedly yielded consistent results. Periodically during testing, these illuminance levels were verified with a light meter. Illuminance levels were checked prior to beginning the testing each day and at random but frequent intervals during the study.

### 3.3 Illuminance test procedure

This study employed a within-subjects design. Each participant completed the three tasks at three different levels of illuminance, namely 0.3 foot candles, 3 foot candles, and 18 foot candles. To conduct the coin test, there were three cards prepared with five pennies affixed to each, one set for each illuminance level. For the drill bit test, there were three sets of three drill bits, one set for each illuminance level. For the data retrieval test, the research participants were asked to extract specific information that was asked of them. Prior to performing the assigned tasks, the participants were asked to provide information on their age, vision impairment, whether or not corrective lenses were being worn, and if any reading or learning impairments existed. The participants’ eye color was also noted.

Since the illuminance study was conducted on a university campus, it was decided that university students would be suitable subject candidates. Students are generally young individuals whose vision tends to be better than that of the older population. Students were approached and were asked to volunteer approximately ten minutes of their time to participate in the illuminance study.

A standardized procedure for the illuminance study was devised. The research participants entered the testing room one at a time. The test procedure was explained to each participant. The illuminance level was adjusted to 3 footcandles. The participant then conducted the coin task, drill bit task, and data retrieval task at that lighting level. The illuminance level was then adjusted to either 0.3 foot candles or 18 foot candles. An eye adjustment period was allowed and the next set of tasks was
performed. If the illuminance level for the second series of tasks was 0.3 foot candles, the third series of tasks was performed at 18 foot candles, and vice versa.

4. Results

The objective of this research was to examine the relationship between illuminance levels (at 0.3 foot candles, 3 foot candles and 18 foot candles) and task performance. The selected tasks required the ability to make visual observations.

4.1 Study participant characteristics

In total, there were 115 study participants in this research. They were all university students in the age range of 17 years to over 60 years, with a median age of 22 years. Of the 115 participants, 89 (77.4%) were male and 26 (22.6%) were female. Although eye color was not found to be a significant variable in terms of task performance at different illuminance levels, the majority of the subjects described themselves as having either blue (34.8%) or brown (45.2%) eyes. Other eye colors included hazel, green and combinations of these colors. Vision impairment was reported by 59 (51.3%) of the subjects. The most common type of impairment was near-sightedness as reported by 48 (81.4%) of those 59 subjects. Of these 59 subjects, 51 (86%) relied on visual correction in the form of glasses and contacts, with 27 and 24 subjects, respectively. Others reported that their visual impairment had been surgically corrected. While 51 subjects reported using corrective lenses, only 37 wore corrective lenses during the test.

4.2 Performance at differing illuminance levels

The primary objective of this study was to evaluate how task performance is altered at different illuminance levels. In order to examine the relationship between illuminance levels and performance the data were analyzed using a variety of conditional criteria. All statistical analyses of data were performed using the Statistical Package for the Social Sciences (SPSS) software, version 16.

The primary measure of task performance was the completion times for the different tasks. Since errors in task performance were anticipated, it was decided that when subjects made errors the completion time would be increased by 20%, resulting in 20% time penalty for each error. With the assessment of the penalty, it was assumed that comparisons could still be made between completion times of all study participants. The results of the task performance times with the penalty assessments for errors are summarized in Figure 3. Note that the task performance times for the coin test and the drill bit test decrease as the illuminance level is increased. The task performance times for the coin tests decreased from 13.63 seconds at 0.3 foot candles, to 8.54 seconds at 3 foot candles, to 6.29 seconds at 18 foot candles. Similarly, the task performance times for the drill bit test decreased from 39.23 at 0.3 foot candles, to 27.38 at 3 foot candles, to 22.37 at 18 foot candles. It is also evident that
the drill bit test was most challenging as the task performance times for this test are considerable longer than for the other tests.

The data retrieval exercise generated results that were not expected. The task performance times were 5.27 seconds at 0.3 foot candles, 9.68 seconds at 3 foot candles, and 4.09 at 18 foot candles. The task performance time for the 3 foot candles illuminance level is an anomaly. Closer consideration of the nature of the testing resulted in an understanding of the higher task performance times for the data retrieval at 3 foot candles. First of all, the same chart was utilized for all three illuminance levels. In addition, the first tasks performed by the participants were at 3 foot candles. The data retrieval task consisted of extracting specific data from a line chart. Study participants commented that once they understood the format of the line chart that the subsequent tasks (at higher and low illuminance levels) were much easier to perform. As a result, the task performance at 0.3 foot candles was generally faster than at 3 foot candles, simply because the participants did not have to study the format of the line graph to answer the subsequent questions. The participants also commented that since the data sheet consisted of black lettering on white paper that low lighting did not seriously compromise data retrieval. Thus, a strong learning curve effect was evident with the use of the data sheet.

![Figure 3: Task performance times with error penalties at different illuminance levels](image)

It was not apparent how much the overall task performance times were impacted by the assessment of additional task time for each error or if the penalty assessment was appropriate. Since the penalty might be construed as being arbitrary, the results were examined by isolating the test results of tasks where no errors were made (see Figure 4). From this figure, the same general pattern of task performance is observed. The task times for the coin test are 9.47 seconds for 0.3 foot candles, 6.88 seconds at 3 foot candles, and 5.25 seconds at 18 foot candles. Similarly, the task times for the drill bit task are 30.32 seconds at 0.3 foot candles, 26.63 seconds at 3 foot candles, and 20.88 seconds at 18 foot candles. The general pattern of improvement in task performance at higher illuminance levels is evident in the figure. The pattern of task performance in the data retrieval task continues to reveal the
influence of the learning curve effect, with the longest performance time being associated with the illuminance level of 3 foot candles, the first test of the series.

A comparison of median values and mean values of task performance times showed no appreciable difference between these values. Thus, the use of mean values of task performance was deemed acceptable due to the sufficiently large sample size. While outliers were present, they were not found to appreciably affect the mean and median values.

The coin test results were examined for the two conditions where an error penalty was assessed on the task performance time and the task performance where no errors were made. These results are shown in Figure 5. From these results, it is apparent that the error assessments yielded longer task performance times. From this figure it might also be deduced that more errors are associated with the tasks performed at lower illuminance levels.

Figure 4: Task performance times with no error at different illuminance levels

Figure 5: Coin test results with error penalties and with no errors
The drill bit test results were also examined for when a time penalty was assessed for errors and when no errors were made. The results (shown in Figure 6) are generally similar to the coin test results, namely that the task performance times associated with errors are longer than the task times when no errors were made. The task performance time for the illuminance level of 0.3 foot candles is particularly high in relation to the time without errors. The number of errors at 3 and 18 foot candles seems to be small since the task performance times appear to be close to the times without errors.

![Figure 6: Drill bit test results with error penalties and with no errors](image)

4.3 Accuracy of task performance

In addition to task completion times, the number of errors that were made during each task performance was recorded. Records were kept of the number of errors that were made with each task and at each illuminance level. In the results, an anomaly was noted in the data retrieval test. Note that the test sequence began with the illuminance level set at 3 foot candles. The second and third tests were alternatively performed at 0.3 foot candles and 18 foot candles.

For the data retrieval test, the same data sheet was utilized for all three illuminance levels. For this data retrieval test, the number of errors made at 3 foot candles was 21, but the number of errors made at 0.3 foot candles was six and the number of errors made at 18 foot candles was also six. After completing the test, several study participants mentioned that the first test (performed at 3 foot candles) took the most time because they were looking at the data sheet for the first time. Once the format of the data sheet was understood, data retrieval was relatively easy. It became evident that the errors made at 3 foot candles were attributed to the newness of the test rather than the illuminance level. Thus, there was an obvious strong learning curve effect with the data retrieval test. Note that the tests on the coins and the drill bits involved a different set of coins and a different set of drill bits for the three tests that a participant performed. Because of the strong learning curve effect, further analysis of errors was discontinued on the data retrieval test.
The coin test was associated with the most errors among the different tests. For example, at 0.3 foot candles there were 51 errors, at 3 foot candles there were 21 errors, and at 18 foot candles there were 8 errors. Several study participants commented that it was difficult to see some of the dates on the coins, whether due to the wear on some coins or perhaps the buildup of grim on some coins. Nonetheless, there were a total of 80 errors made on the coin tests. With 115 study participants and 5 coins to assess for each of three illuminance levels, this translates to 4.6 percent of the date identifications being in error, or conversely, 95.4% of the dates were correctly identified.

The study participants made relatively few errors in the drill bit size determination test. Differences in the number of errors were associated with the illuminance levels. For 0.3 foot candles there were 11 errors, at 3 foot candles there were 7 errors, and at 18 foot candles there were 2 errors. This resulted in a total of 20 errors for the drill bit test. Since there were three drill bits that were examined at each illuminance level, this equates to 1.9% of the size assessments being made in error, or conversely, 98.1% of the size determinations being correct. The drill bit test performance was probably more accurate than the coin test because the drill bits could be held by the hand and positioned for ease of size determination. In the coin test, the study participants were not permitted to touch the coins when determining the dates.

To summarize the error information, the error data for the coin test and the drill bit test were combined. The summary of the number of errors recorded at each illuminance level is shown in Figure 7. The highest number of errors (62) occurred at the lowest illuminance level of 0.3 foot candles. This was followed by 28 errors at 3 foot candles and 10 errors at 18 foot candles. The decrease in errors with increased illuminance is quite apparent. Thus, the accuracy of task performance improved with higher illuminance levels.

![Figure 7: Total number of task errors at different illuminance levels](image)

5. Conclusions

The objective of this research was to examine the relationship between illuminance levels (ranging from 0.3 foot candles to 18 foot candles) and task performance. The selected tasks required the ability to make minute visual observations. At the selected illuminance levels the results showed that the time
of task performance was increased significantly as the lighting level decreased. Also, as the illuminance levels were decreased the accuracy of task performance declined.

The study demonstrated that learning curve effects were quite apparent. Despite this, the influence of illuminance levels on task performance times and accuracy were still evident.

Although not an initial topic of specific interest, task performance was shown to be influenced by vision impairment of study participants. Participants with eye impairment (whether corrective eyewear was worn or not) took longer to complete the tasks than those subjects without vision impairment. Thus, subjects with vision impairment and corrective eyewear completed their tasks with longer completion times than those subjects with no vision impairment.

Results suggest that construction tasks can be performed quite well at the higher levels of illuminance that were examined. Although the safety regulations in the United States stipulate acceptable minimum illuminance levels ranging from 3 to 30 foot candles, it is evident that some tasks could not be performed as effectively at the lower illuminance levels. It can readily be concluded that safety performance could readily be compromised at lower light levels, especially if good visibility was required to address specific hazards. Just as errors were noted to increase with lower illuminance levels, safety can be compromised when lighting is inadequate.

6. Recommendations

This research involved a reasonably large sample of more than 100 subjects and statistically significant difference were noted in the completion times of specific tasks and the number of errors made at different illuminance levels. If future research were to be conducted, a larger sample size could examine the influence of additional variables, such as illuminance level and vision impairment. Also, while this study examined task performance at three different illuminance levels, further studies could examine additional illuminance levels. For example, the full range of acceptable minimum illuminance levels of 3 to 30 foot candles should be examined.

The learning curve effect was evident in this study. While the results of this research were still quite compelling, any future study should be conducted such that there is less of an influence from the learning curve effect. One procedural change in the testing procedure would be for the subjects to be provided with sample versions of the task materials prior to conducting the experiment, along with the instructions on how to perform each task.

There is currently very limited lighting information available on the illuminance levels actually encountered on construction sites. Further could be conducted with the objective of quantifying the illuminance levels commonly encountered at specific project locations or when performing certain tasks. It was also noted that there is considerable variability in light meter readings. Protocol should be established so that these reading are taken with some level of consistency to allow comparisons to be made between different field readings.
To ensure the safety of construction workers, adequate lighting should be provided at all work locations on construction sites. All individuals in positions of leadership on construction projects should be aware of the minimum illuminance levels to be provided for construction workers. Where lighting is questionable, illuminance levels should be measured to determine the need to provide artificial lighting. It must always be remembered that the illuminance levels established in the regulations are minimum levels and that construction leaders should always strive to maintain safe lighting levels, regardless of the regulations.

References


Many construction firms have adopted standard safety practices to help control the incidence of injuries. These types of practices include worker orientation sessions, safety meetings, safety inspections, drug testing, accident investigations and so on. While these programs have proven to be effective in reducing injuries, some circumstances arise in which unique hazards are present in which a focused initiative is developed and implemented to specifically address such hazards. An example of such an initiative would be one to address excess dust or one to address a specific rigging hazard. A study of such initiatives was conducted through a survey questionnaire. This initial research effort was followed by several case studies. It was found that even when hazards were very different that these programs tended to have many similar characteristics. Many of these were implemented successfully. Furthermore, these initiatives were developed and implemented in a manner that can be modelled. The development and implementation of a focused safety initiative includes such components as the motivation to address a specific hazard, an established benchmark for the program, a champion to shepherd the initiative, worker involvement in the development, implementation of the program, monitoring the program, taking corrective actions when needed, measuring success and finally recognizing success.

Keywords: injury reduction, jobsite hazards, safety initiatives
1. Introduction

In terms of dangerous occupations, construction work is among the hazardous and the most physically demanding in the United States (National Safety Council). The dangerous aspects of construction work can be largely attributed to the ever-changing nature of the work, i.e., the work environment is in a construction state of change. Unlike work in other industries, construction projects are unique and can present conditions that have not been encountered on other projects. Even when projects are similar, work conditions can be quite different, including the landscape, weather, and physical location. Because of these different factors, the hazards encountered by construction workers can be quite different from project to project.

Statistics show that 4.7 out of every 100 full-time construction workers experience a work-related injury each year that will require medical treatment, i.e. referred to as the Occupational Safety and Health Administration (OSHA) recordable injuries. The U.S. Bureau of Labor Statistics (BLS) indicates that there were over 300,000 non-fatal recordable construction worker injuries in 2008 in all industries (BLS 2009). The number of first aid injuries in construction is expected to number in the millions.

With the high injury rate, it would seem logical that construction firms would expend considerable effort to reduce workplace injuries. Historically, many firms have been reluctant to invest funds in safety because the workforce is quite mobile. A firm would be reluctant to invest in any training if the worker was likely to soon become employed by another firm. As a result, many construction workers remained untrained and did not fully appreciate the importance of recognizing and avoiding workplace hazards. In recent years, more construction firms have become more aggressive about safety. Many proactive construction companies have taken major steps in identifying and eliminating the causes of accidents on job sites. Many of these firms have come to the realization that the initial investment and the continuous efforts to maintain a good safety record do pay off.

Construction firms with good safety records generally have well developed safety programs. These companies devote employee manpower and strong financial resources to maintain the health of their workforce and to prevent high medical and insurance costs. With a strong commitment to worker safety, many companies have realized that in order to prevent job related incidents, they must not only establish safety programs but they must also establish a strong safety culture, a work environment in which every worker knows that safety is a core company value.

Past safety research studies in the construction industry have examined overall safety management efforts to pursue the zero injury objective. These studies have examined the impact on safety performance of such safety initiatives as worker orientation, pre-task planning, jobsite safety audits, recognition programs, and so on. These initiatives tend to be generic in nature in that overall project safety tends to be addressed by these efforts.

While the overall efforts in safety have been proven, little is known about any efforts that might be expended to address specific hazards. This was examined in a research study. The purpose of this research was to answer a fundamental question, “How do construction firms and projects develop,
structure, and successfully implement effective programs to prevent or to address specific types of jobsite hazards?” These specific hazards may be unique and they may never have been encountered on previous projects. These focused safety programs are tailored to address specific hazards. These programs were expected to vary in a number of ways, including the motivation to address the jobsite hazards and the manner in which they were addressed. The objective was to be able to model the process of implementing a focused safety program.

2. Research methodology

The objective of this research study was to gather information on how safety programs with a focus on specific hazards are initiated, how they are developed, how they were structured, how obstacles are overcome, the extent that the workers are involved in the process, and how the programs are implemented on construction projects. When possible, information was sought regarding documented evidence of the extent of success of specific programs.

A survey questionnaire was developed that contained a variety of questions related to programs designed to address specific types of hazards on construction sites. Many of the questions sought answers that could be answered by simply checking the applicable answers. A few questions requested open-ended responses. The survey was designed to be completed in five to ten minutes. The final survey consisted of five sections which included such topics as general project information (size, type contract, labor arrangement, duration, cost, etc.), type of project workforce/subcontractors, project safety performance, descriptions of any focused safety programs implemented at the project level, and focused safety programs implemented on past projects.

It was decided that a large sample size was most desirable for this research effort. This was based on the realization that construction firms may implement a variety of safety interventions to address specific hazards (falls, cave-ins, heat, noise, or conditions that injure hands, eyes, backs, feet, etc.). To obtain a large sample size (over 100 responses) the research team sent the surveys to all industrial contractors for whom addresses were known. In addition, a large insurance carrier representative agreed to send the surveys to all of its construction clients in the U.S.

The statistical program, Statistical Package for the Social Services (SPSS), was selected to analyze the data. All of the raw data, aside from the narrative comments provided in the survey, were included in the data analysis. The data of particular interest related to those safety programs that had innovative approaches, especially those resulting in improved safety performances. Safety performance,
measured in terms of the OSHA recordable injury rates (RIR) achieved on the projects, was examined as to the extent that they were influenced by various practices.

The objective of this research was to determine how construction firms and projects develop, structure, and successfully implement effective programs to address specific types of jobsite hazards. A total of 220 completed surveys were returned for analysis. The analysis of the questionnaire survey responses provided valuable insights, but the survey responses lacked the detailed information that was desired. In addition, nearly half of the responses did not describe focused safety programs. Instead, half of the respondents described the implementation of generic safety initiatives such as incentive programs, worker orientation programs, and similar programs that do not have specific focus. These overall safety initiatives did not meet the criteria of the focused safety programs, as specific hazards were not the focus of these efforts. Of those responses that related to programs that did satisfy the focused safety criteria, most provided only abbreviated information, with little or no details. As a result, the research team decided that it was necessary to conduct a second study that would obtain more detailed information through in-depth case studies.

The second or follow-up study consisted of case studies to supplement the results of the survey study. To conduct the case studies, visits were arranged to large construction projects. At the time that the visits were arranged, the project leaders were simply asked permission to visit the site and to discuss project safety. A total of twelve site visits were scheduled. After a researcher came onto a project site, a discussion was held with various site leaders, including the owner’s site personnel, safety managers, job superintendents, and project managers. After the researcher had an understanding of the project under construction, questions were asked to identify a focused safety program. On each project that was visited, information was obtained on a focused safety program, whether initiated by the general contractor, owner or a subcontractor. On some projects, several focused safety programs were identified. When more than one focused program was identified, a decision was made by selecting the one program that appeared to be most interesting to the researcher.

Although the project safety personnel (the contact individuals) had prior awareness of the objective of the research, many did not fully grasp the actual intent of the research until it was fully described to them during the site visit. As a result, some of the focused safety programs were not identified until the site visit was well underway or until a jobsite walkthrough was conducted.

After a focused safety program was identified and described by a project contact person, other personnel were generally introduced to the researcher. Although there were no structured questions developed for documenting these cases studies, a general topic outline was followed to ensure that specific topics were examined. For example, the following types of was sought for each case study:

- Describe this project (duration of the project, number of workers, number of subcontractors, etc.).
- Description of the focused safety program in general terms?
- How the focused safety program began?
• What were the steps that were followed to develop the focused safety program?

• Describe any impediments to program implementation.

• How was the program received by the workers?

• Was the program successful? If so how was success measured?

• What type of support did corporate management provide?

After an extensive interview was conducted with the jobsite representative, usually the safety manager, a jobsite tour was provided. Next, shorter interviews were conducted with other project team members, including personnel representing the owner, prime contractor, and often a subcontractor. By discussing the focused program with various personnel a thorough understanding of the program was developed. Whenever possible, information documenting the focused safety program was also obtained. There was no reluctance to share any information about these programs. Eight case studies were chosen from the twelve projects that were visited. Two of the projects had developed safety programs, but did not have strong focused safety programs that warranted inclusion in this study. Copious notes were taken to document all aspects of the focused safety programs that were implemented. To the extent that it was possible, the information on program implementation was recorded in chronological order. These case study descriptions were then written up. It was during this period that similarities between the focused safety programs were sought. The ultimate objective was devise a model or template that could apply in the development and implementation of any focused safety program. As these case studies were written up, it became apparent that the focused safety programs tended to follow similar patterns of initiation, development and implementation. Because of the similarities, a standardized format evolved for the case study descriptions.

3. Results

3.1 Introduction

Prior safety studies have not examined the details of how specific programs were developed or successfully implemented to address specific hazards. While the safety culture of a project might be well established, the details of the implementation of specific programs have not been extensively examined. This study captured data of specific program implementation through five different portions of the survey which were as follows: general project information, project workforce and subcontractors, project safety performance, specific safety programs - project level, and programs implemented on past projects.

The attributes being examined in the focused safety programs included any program or approach that was implemented at one or more construction sites to reduce or eliminate specific hazards. For the mailed survey there were 225 respondents, but upon closer examination it was determined that some
respondents provided information on programs that did not satisfy the description being used to define focused safety programs. When these extraneous comments were removed from the responses, 120 valid and usable responses remained.

### 3.2 Survey results

The 120 respondents represented a diverse sample. Generally, the project described by the respondents would be characterized as being either medium or large. The average project was over $128 million with nearly one million worker hours expended. The median number of subcontractors on a project was 12 with these subcontractors completing 57.7 percent of the work.

Nearly three-fourths of the respondents represented contractors and most of the remaining respondents represented owners. A few respondents considered their employer’s role to be that of a contractor/owner client.

Focused safety programs are often untried and unproven efforts that are designed to improve safety performance. As a result, smooth implementation is not assured. In fact, there may even be barriers to successful implementation. The survey asked about such problems with implementation. Major obstacles to implementation of specific focused safety programs were encountered on 59 percent of the projects. The obstacles were noted as follows:

- Resistance to the initiative or resistance to change (33.3%)
- Old school mentality (14.3%)
- Enforcement difficulties (11.9%)
- Difficulties in training (9.5%)
- Language barriers (4.8%)

Half of the focused safety programs included in this study were initiated at the project level while the others were initiated at the corporate level. Worker involvement in the safety process is one of the most important aspects of implementing a focused safety program as indicated by 72% of the respondents. From the 120 survey responses it was noted that the programs are fairly evenly divided between those championed by project personnel and corporate personnel. Similarly, they tend to be fairly evenly divided between those implemented on only one project versus being implemented on all company projects. While half of the programs were started from scratch, the remainder tended to modify existing programs to suit their unique needs.
3.3 Case studies of focused safety programs

As already noted, the case studies of the focused safety programs were selected without regard to their specific focus or emphasis. The case studies were written up by using a common organizational approach, namely a brief overview description of the focused safety program, along with a chronology of the development and implementation of the program. The programs were selected without regard to their specific focus or emphasis. Any program that satisfied the criteria of a focused safety program was included in the case studies. This resulted in a selection of diverse emphasis areas being addressed by the focused safety programs identified on the eight jobsites that were visited. The focus areas were identified as follows:

1. Safe loading and unloading of trucks: A program designed to ensure the safe loading and unloading of delivery trucks. Specific guidelines were established that there be only one layer of materials on flatbed trailers, that workers not be present on the trailer where materials might shift, that stanchions must be in place on trailers to help contain materials, tag lines must be placed in the eyes of each choker or spreader, access ladders must be secured to flatbed trailers for access, mandatory training was stipulated for riggers and handlers, and so on.

2. Eye safety program: An effort to address an unusually harsh environment where iron filings were frequently blown into workers’ eyes. The focused program was designed to educate workers about the importance of eye safety, to regularly remind workers (posters, memos, personal verbal reminders and toolbox meetings) to wear the appropriate eye protection, and to constantly monitor the level of compliance among workers.

3. Back strain reduction program: To address the disproportionate number of back strains and pulls, this employer implemented a flex and stretch program focused on protecting the back. The program was mandatory for all employees on the project site.

4. Housekeeping program: Recognizing the importance of proper housekeeping on the construction site, the employer devised a scoring system by which the quality of housekeeping was monitored through jobsite audits. All site personnel, including all subcontractors, participated in the program. When unacceptable scores were recorded, work was stopped in the area until an acceptable level of housekeeping was established.

5. Barricade tape program: Ensuring the consistent and proper use of barricade tape was the focus of this program. The program addressed both red and yellow barricade tape that was to be tagged to identify the party responsible for setting up the barricade tape, describe the danger, and identify the access/egress areas. This program helped to ensure that a contractor would not abandon a barricaded area without removing the tape, while others would not enter the area because of the tape. With the tag, it would always be possible to contact the party that had originally installed the tape.
6. Steel beam tie-off program: This program was designed to integrate a fall arrest system that is rigged to each steel beam before the beam is hoisted into place. This is essentially an arrangement where a horizontal life line is attached to every exterior beam and every carrier beam prior to being installed. The employer instigated a penalty fee against supervisors who did not maintain 100% compliance with the program.

7. Underground metal detection program: Because of the possibility of cutting into or damaging underground cables, pipes, or other structural features, an employer implemented guidelines on conditions when metal detectors were to be used to locate underground features. The program also specified the appropriate metal detectors to be used. These detectors were to be employed whenever excavation work was deeper than 6 inches (150 millimeters).

8. Hand protection program: This program was developed and implemented to address the disproportionate number of hand injuries that were being encountered on projects. Hand safety was stressed through various posters, slogans, training sessions, and even the publication of a safety “hand book”. The company realized that most hand injuries could have been prevented with the use of the proper gloves, and this was the focus of the program. Although the company implemented the program where gloves were to be worn at all times (100%), exceptions were clearly noted. The program was monitored through a measure referred to as the hand injury incidence rate.

The focused safety programs were designed to address hazards that were identified on specific projects. In some cases, the hazards were known to exist on all company projects, so a company-wide implementation effort was employed. In others, the hazards were specific to single projects and the programs were implemented specifically on those projects.

4. Conclusions: the template of a focused safety program

As the written descriptions of the case studies were being prepared, it became evident that there were similarities in the steps commonly taken in the development and implementation of the focused safety programs. This was despite the fact that the subject areas of the various programs were very different. At any rate, there was an apparent alignment between the different case studies in terms of the stages of development and in program implementation. Nine distinct steps or stages were identified in the process of developing and implementing focused safety programs.

A template was created to serve as a model for new focused safety program development and implementation. The template or model incorporates the nine stages involved in the life of a new focused safety program. The focused safety template is intended to aid in the initiation and development of new policies or programs that are to address specific hazards. The stages of program development followed a similar pattern despite variations in the severity of the incidents they were designed to address. The template suggests a general course of action that has been used to create successful focused safety programs regardless of the severity of the hazard (see Figure 1). This template can be utilized as a guide to create, develop, and implement focused safety programs.
regardless of type of work being performed or company size. The template presents a step-by-step approach to properly implement focused safety programs. The template describes the stages necessary to monitor, evaluate and modify a focused safety program to maximize program effectiveness.

![Focused Safety Program Template](image)

### 4.1 Initiation or genesis of the program (step 1)

Every program has a point of genesis. The need for a program can result from an increased number of specific jobsite incidents. It might be a serious accident that dramatizes a severe jobsite risk. The ideal motivation for program initiation is a proactive awareness of a jobsite risk, as these can be put in place before any injuries actually occur. Unfortunately, many programs have their beginnings following a series of injuries or a single severe injury. Safety managers, jobsite managers, and workers should identify any specific risks and jobsite hazards in order to be proactive in creating focused safety programs.
4.2 Benchmark (step 2)

Once the need for a program is apparent, it is important to establish a benchmark by which to assess program success and to set goals for program implementation. Benchmarks are important as they create a starting point from which to grow and they provide corporate managers with solid numbers that help represent program success. Benchmarks are also important in order to properly compare program costs with program savings in terms of financial accounting. Numbers provide clear cut ways to represent program success. Benchmarks are also important for establishing goals such as a reduction in the RIR, reduction of specific types of first aid cases, or a reduction in the observation of non-compliance activities. Establishing viable benchmarks helps safety professionals promote their programs on their jobsites.

4.3 Champion of the program (step 3)

Every successful program must have a champion. The champion is an individual who takes ownership of the program and provides the motivation to move the program forward through implementation. Typically the champion is a jobsite safety professional. The champion might be a corporate safety manager or anyone who has the authority to initiate a focused safety program and who can take the lead in its development and implementation. Often there is more than one champion when corporate managers decide to back and promote the ideas of a jobsite safety professional.

4.4 Development of the program (step 4)

It is important to properly assess a situation and discuss the best course of action before attempting program implementation. A focused safety program should never be developed in a vacuum. The ideas of many participants will yield the best results. Communication is key between workers, jobsite management, and corporate management. Worker involvement is imperative. Bringing all the active parties results in more ideas being generated for successful implementation. While a severe or dramatic incident will usually expedite program initiation and development, it is important to systematically develop the program before attempting implementation. Programs whose project introductions are rushed do not achieve the same level of worker response as programs that are carefully planned. As seen in the template, this stage of the program is constantly evolving. Never consider a program to be “cast in stone”. Proper monitoring facilitates direct feedback for the evolution of successful program development. Program champions, while typically innovative thinkers to begin with, must understand that programs must be able to adapt in order to achieve maximum worker acceptance and ultimately, optimal results. This will ensure that necessary modifications and changes are made as more information becomes available.
4.5 Implementation of the program (step 5)

Similar to program development, proper communication is essential to achieve success when implementing a new program. New focused safety programs mean that the “norm” that has been established to perform a specific task is being altered or adjusted in order to reduce or eliminate a particular risk. While such ideas should be readily accepted, adjustments to the “norms” that workers have created are typically viewed with skepticism. It is human nature to somehow have doubts about change. This is where programs must be properly “sold” on the project sites. Workers must be properly informed of the identified or perceived risks. It is also important that these new changes be presented in a positive way. Focused safety programs are designed to maintain the health and safety of the workers. This positive acceptance is started during program development and through positive communications. Encouragement and acceptance of worker feedback on the program must be promoted for the workers to “own” the new program. Thoughtful adaptation is also crucial in the implementation stage.

4.6 Monitoring and inspecting for compliance (step 6)

The monitoring and inspecting stage is critical to the success of focused safety programs. It is during this stage that program achievements are noted and recorded. This provides information to safety professionals and managers from which decisions can be made to revise and modify the program. Careful monitoring of the program ensures a continued focus on the program’s intent of addressing specific jobsite risks. The monitoring and inspection data can be used to provide feedback for further program development. This also provides an initial check on the level of success that is achieved with the program.

4.7 Corrective action (step 7)

The monitoring and inspection stage may identify areas of non-compliance. This is when it is important to understand the underlying reason(s) for the level of non-compliance. If the lack of compliance is the result of poor communications, greater publicity about the program would appear needed. If some individuals are simply not taking the program seriously, appropriate measures must be taken or the program will fail. Corrective actions must be established and implemented when a program is not being followed. Typically, when the previous stages of program development are properly executed, non-compliance is reduced because worker acceptance is high. Depending on the severity of the risk involved and the amount of non-compliance present, proper communication is often all that is needed to prevent the need for serious disciplinary actions. Obviously, non-compliance that results in at risk behaviors that endanger worker lives must be dealt with in a strong and forceful manner, possibly termination.
4.8 Measure of success (step 8)

It is important to recognize success if the program is going to become an established component of a broader safety program. Measuring success addresses doubts and answers any questions that workers have regarding the importance of the program. This aids in worker acceptance of the program. Measuring success also provides answers to corporate entities about the importance of the program. This stage, along with the ability to accurately present the measures of success compared with the established benchmarks, often determines whether or not the program will expand from a job specific to a company-wide program. If the measures are not as expected, adjustments may need to be made to achieve the program goals.

4.9 Recognition of success (step 9)

This last stage, recognition of success, is often overlooked or is not carried out in the traditional manner. Like any endeavor, it is important to recognize when a goal has been set, pursued, and achieved. This positive recognition promotes program acceptance, and workers do not get complacent after an extended duration following program implementation. This recognition acknowledges the measure of success achieved and helps carry specific jobsite programs onto other projects. While the success of the program may not be celebrated in a formal way, the success can readily be recognized by publicizing the successes of the program and by making the program a part of the corporate safety program.

5. Recommendations

It is recommended that the focused safety template be considered for use by various firms in the construction industry to help facilitate the creation of new safety initiatives. Successful programs entail a clear objective of gaining acceptance of the program by the workers. The template displays the step-by-step process by which focused safety programs are created, developed, implemented, monitored, modified and continually improved. The template may be used as a guide for new programs and to make adjustments to existing programs that are not yielding the desired level of success.

Focused safety programs can be equally successful on large project or in small firms. Regardless of the setting, it is important to execute each of the stages of the template. The safety professionals, jobsite managers, and corporate managers must demonstrate initiative in program development and they must have the ability to adapt and adjust the program in order to achieve maximum results. The single, most valuable component throughout this process is the art of communication among the many players involved in project execution. Through successful communication, ideas, results, and positive responses permeate throughout the program. When everyone takes program ownership, programs succeed, workers stay healthy and everyone wins.
Efforts to improve safety performance should not be dormant. The wide dissemination of information on focused safety programs is encouraged. Ideally a clearinghouse of information would be created that would provide information of documented successes with focused safety programs that addressed different types of hazards. This would provide others with solutions devised by other firms. It is also suggested that “measures of success” and “success recognition” should be studied further. While all construction projects see different climates, basically all have similar dangers and risks. Project experiences should not be ignored when common risks are experienced company wide.

References


Site Manager Training and Safety Performance

Hare, B.

School of the Built and Natural Environment, Glasgow Caledonian University, UK

(email: b.hare@gcu.ac.uk)

Cameron, I.

School of the Built and Natural Environment, Glasgow Caledonian University, UK

(email: i.cameron@gcu.ac.uk)

Abstract

This paper presents findings on research undertaken by the authors and funded by the Institution of Occupational Safety and Health on factors relating to superior safety performance amongst construction firms in the UK. Specifically, the level of training delivered to site managers was analysed in relation to annual accident rates. A random sample, consisting of 100 construction firms, was asked to provide details of the type and duration of H&S training delivered to their construction site managers. This was analysed and categorised against a three point scale: up to two days training; Construction Skills ‘Site Managers Safety Training Scheme’ (SMSTS) – 5 days training; National/Scottish Vocational Qualification for H&S – Level 3 or above. This was cross tabulated with the annual number of ‘reportable’ accidents per 100,000 workers employed (including sub-contractors). The results were as follows: up to two days training (m: 1825); SMSTS (m: 1566); N/SVQ 3 or above (m: 211). This shows that increased durations of training are associated with lower accident rates. If duration is accepted as a measure of ‘level’ of training then the findings support the general hypothesis that increased levels of training lead to increased safety performance. This adds a new dimension to previous studies that have generally compared the mere presence, or otherwise, of training with safety performance. Integrating H&S management with the site management function can only be done when site managers are competent. This research has established a baseline in relation to the minimum level of H&S training for site managers as well as providing evidence for increased investment to achieve superior performance.

Keywords: education, safety, supervisor, training
1. Introduction

Britain’s construction industry is the country’s largest employment sector. It is also one of the most hazardous. In the last 25 years, over 2,800 people have died from injuries they received as a result of construction work (HSE 2009). Many more have been injured or made ill. In terms of ill health, HSE have published figures that show the industry exceeds the all-industry average rates with respect to musculoskeletal disorders; occupational dermatitis; mesothelioma, asbestosis and diffuse pleural thickening; and work related hearing loss, with vibration related disorders only being surpassed by the extractive industries (ibid).

Despite this the industry is working hard to reverse the trend. Overall there has been a continuing reduction in the rate of fatal and major injuries since the introduction of the Health and Safety at Work Act 1974 (ibid). Fatal construction accidents for the year 2008/09 were 53, a decrease from the previous year of 72, which is also the lowest on record (ibid). The rates of all reportable accident types per 100,000 workers for the year are also the lowest on record at 1400 per 100,000. However, there is a large disparity between contractors’ performance, especially in relation to the size of the organisation, where larger contractors have generally found to be safer (BOMEL 2001, HSE 2006). There are exceptions to this rule, however, where small to medium sized enterprises (SME) have also shown to perform well (Kheni et al 2006).

2. Superior safety performance

Jaselskis et al (1996) present a useful summary of research conducted from 1976 to 1993 investigating characteristics of construction organisations with superior safety performance. Recurring themes associated with high performance were:

1. Senior management’s commitment to safety
2. Safety inductions and training
3. Stable employment conditions
4. Incentive schemes and goal setting for safety performance
5. Client support for safety

Pan-industry studies, which included construction, also found similar factors (Cohen 1977; Cohen and Cleveland 1983). Most of the work summarised by Jaselskis was conducted in the USA where safety performance is typically measured in both accident rates and Experience Modification Rating (EMR). This EMR is based on the previous year’s accident claims and directly affects the organisation’s insurance premium. The research methodologies invariably use these measures as dependent variables, where correlations are made with independent variables (success factors). This approach has its limitations when considering the multi-causal nature of accidents (Duff et al 1993, HSE 2006,
Jaselskis et al decided to measure organisational factors at company level as well as project level. They found evidence that larger contractors were safer than smaller ones. This is in line with findings in the UK (BOMEL 2001, HSE 2006). Although, there was stronger statistical evidence showing the organisation’s length of experience as more important. When faced with the decision of where to set the threshold for high performers Jaselskis et al simply took the average rate of accidents for the industry and split the sample into those above average and those below.

Jaselskis et al found six statistically significant factors in relation to superior safety performance at the company level:

- Higher number of pages in the safety manual
- Higher budget spent on safety programmes
- Higher number of training hours for foremen and safety personnel
- Higher number of formal and informal safety meetings or safety inspections
- Higher percentage of safety co-ordinator’s time spent on safety
- Presence of an alcohol and drug testing programme

Jaselskis et al decided that the number of pages in the safety manual was a valid measure of the level of detail in a safety programme. However, such an assumption in the UK may be open to criticism due to the perceived bureaucracy linked to construction safety (Baxendale and Jones 2000, CIRIA 1997, HSE 1997; 2003). There are obvious issues of the quality of any safety document that appears lengthier than it needs to be.

Investment in safety resources, including training, meetings and time (in general) can be seen as indicative measures of senior management commitment to safety. It is interesting also to see time and resources specifically for the management of safety featuring here. However, the qualifications of line managers or safety personnel were not considered.

At the project level similar factors were found to be present on the higher performing projects:

- Greater project manager experience (including time on similar size projects)
- Lower project staff turnover
- Higher number of formal and informal safety meetings
- Field safety representatives spent a greater percentage of time on safety
The combined organisational and project findings from Jaselskis et al match other industry research findings. Abudayyeh, et al (2006) measured organisational profile (size, type, structure etc.) as well as resources such as safety programmes, safety staff and safety budgets. They highlighted a relationship between safety performance and the time the safety manager spends on site. Three ordinal categories were used “always on site”, “occasionally on site” and “not on site” (ibid). A linear relationship was found where those always on site had the lowest accident rates, those occasionally on site were higher and those not on site were the highest. Although, assuming larger sites tend to be safer it may be expected that larger (safer) sites would be those where the budget allows for a full time safety member of staff. Likewise, the further down the project scale, the less one would expect to find safety personnel. Another significant finding by Abudayyeh, et al was a link between the amount of budget for safety (equipment, training, programmes) and accident rates. A negative linear relationship was found to exist; although not significant.

These findings highlight, in general, the main factors to consider and help understand what differentials exist between superior performers and the rest. But it must be acknowledged that there are a great number of other factors underpinning these main ones that have not came to the fore, such as safe systems of work, adequate planning and supervision, site rules etc... These underpinning factors are assumed to be pre-requisites for any organisation.

3. Safety training

The United Kingdom’s National Qualifications Framework (see Table 1) provides a hierarchical list of generic qualifications, including National Vocational Qualifications (NVQ), which can be used as a ranking system for safety qualifications. If the safety qualification is gained through higher education it can also be mapped to an NVQ level. Other qualifications, e.g. Scottish qualifications (SQV) are also compatible with NVQ levels. This is a generic method to rank qualifications. Each level exists whether a safety qualification exists or not.

Table 1: National Qualifications Framework

<table>
<thead>
<tr>
<th>NVQ Level</th>
<th>National Qualifications Framework</th>
<th>Higher Education Qualifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Entry Level Certificate(NQF)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>NVQ Level 1, Level 1 Certificate, GCSEs at grade D-G</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>NVQ Level 2, Level 2 Certificate, Level 2 Diploma, GCSEs at grade A*-C</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>NVQ Level 3, A’ Levels, Level 3 Certificate, Level 3 Diploma</td>
<td>Certificates of Higher Education</td>
</tr>
<tr>
<td>4</td>
<td>NVQs, Level 4 Certificate, Level 4 Diploma</td>
<td>Ordinary bachelor’s degree, Foundation Degrees, Diplomas of higher education and other higher diplomas</td>
</tr>
<tr>
<td>5</td>
<td>NVQs, Level 5 Certificate, Level 5 Diploma, Higher National Diploma</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>NVQs, Level 6 Certificate, Level 6 Diploma</td>
<td>Bachelor’s degrees with honours, Graduate certificates and diplomas</td>
</tr>
<tr>
<td>7</td>
<td>NVQs, Level 7 Diploma, Level 7 Fellowship, Level 7 Advanced Professional Certificate</td>
<td>Master’s degree, postgraduate diplomas, postgraduate certificates</td>
</tr>
</tbody>
</table>
Highly specialist Diploma from a professional body

Sources: IOSH (2009; QCA 2009)

Safety qualifications are offered in many vocational forms, from short duration courses provided by independent training organisations, to full-time higher education qualifications. The Institution for Occupational Safety and Health (IOSH) has an extensive list of safety qualifications on its website which illustrates the vast array of qualifications a safety practitioner could possibly have. This framework can also be mapped to training qualifications for line managers, including construction site managers.

Safety training for line managers is seen as an effective method of improving competence and influencing behaviour (Abudayyeh 2006). The number of hours training per month for project managers has been linked to lower accident rates (Hinze 2002: p69, Jaselskis 1996). However, this does not consider the level or quality of that training, for example NVQ levels. In the UK the Construction Skills Site Managers Safety Training Scheme (SMSTS) is considered the industry standard, being recognised as an indicator of competence for site managers (HSE 2007: p111). This is a 5 day, course including a final exam. A comparable course is offered by IOSH. Both are considered to be equivalent to NVQ level 0. Site managers can undertake a higher level of safety training, including the National Examination Board in Occupational safety and Health (NEBOSH) Certificate in Construction Safety and Health (Level 3). Other training programmes are also offered at NVQ Level 3. Training and education above this level is generally undertaken by safety specialists.

4. Measures used for data collection

Measures of safety training for line managers was based on NVQ levels. However, there were a number of safety qualifications and training programmes for line managers outside of the NVQ structure, including merely awareness training. Therefore, the ranking of these were:

1. H&S NVQ 3
2. SMSTS/MS (equivalent to NVQ 0)
3. 2 day course or less

The SMSTS and IOSH Managing Safely (MS) courses are the most common forms of safety training undertaken by site managers, as discussed previously. Other higher level qualifications usually undertaken by site managers were categorised at NVQ Level 3. All short duration courses, one-off CPD events and in-house seminars were ranked below SMSTS/MS and fell below the NVQ framework.

Organisational safety performance can be measured in a number of different ways. The first, and most frequently used, is by accident frequency or incidence rates. Accident Injury Rate (AIR) is the most common measure used in the UK including by HSE to calculate industry statistics. Other
measures are available. However, AIR is the easiest to calculate and also provides the best opportunity for obtaining the requisite data from organisations. The required data to calculate AIR is the number of accidents and average number of employees per annum. AIR is calculated thus:

\[
\text{Number of reportable accidents / Average number employed} \times 100,000
\]

Reportable accidents are those covered by the Reporting of Injuries Disease and Dangerous Occurrences Regulations 1995 (RIDDOR). In order to make valid comparisons between organisations, it is necessary to break down accident types, identify types of injured parties as well as definitions of those employed. This is because different organisations record accident data to different levels of detail. Therefore, it is wrong to assume all figures are comparable. For example, some organisations only collect data for ‘reportable’ accidents, whereas others may include minor accidents (not required to be reported by law). Further, construction organisations tend to subcontract work but not all will record accidents suffered by subcontractors. There is also the issue of who is counted in the ‘average number employed’ figure. Again, sub-contractors may not be counted. Further, the ratio of administration and office staff to manual on-site workers can distort the figures. This is because manual site workers are at a considerably higher risk of experiencing an accident than office staff (HSE 2006). Therefore, if two similar sized organisations had the same number of site accidents but one had more office staff, then this organisation would return a lower AIR.

Therefore, the following distinctions were made to isolate the required data:

1. Accidents:
   a. Detail number of accidents in each level of severity: fatal/major; over 3 day; minor.
   b. Cross tabulate these accidents to employees; sub-contractors; members of the public.

2. Average number employed:
   a. Distinction between site employees, site sub-contractors and office staff.

By isolating these figures it was possible to calculate a more reliable AIR thus:

\[
\frac{\text{Number of reportable site accidents (including sub-contractors)}}{\text{Average number of site workers (including sub-contractors)}} \times 100,000
\]

Ideally, several years’ data would help smooth out any volatile peaks and troughs in AIR. However, this needs to be weighed against the likelihood of obtaining several years’ data. Therefore, it was decided to use data for one financial year only.
5. Data sources

Safety respondents were sourced via the construction specialist group membership of IOSH email database, industry contacts and the HSE construction web forum. The only parameter used was that the respondents worked for a contractor in the UK construction industry.

A total of 31 completed questionnaires were received. However, an alternative source of data was found during the research. This was the Contractors Health and Safety Assessment Scheme (CHAS), a health and safety competence assessment scheme. The assessment includes a questionnaire with similar questions to those included in the research questionnaire. The scheme has a website interface (CHAS 2007), which allows access to contractor information including a contact name. This allowed an opportunity to extend the dataset for analysis.

The CHAS website states that it has 14,000 contractors in its database (ibid). However, the research parameters and the existing completed questionnaires dictated which organisations could be selected. Further, there were issues specific to the CHAS database that restricted which files could be used. The parameters for selection were as follows:

- The database has basic functionality for searching. The most convenient way to find construction contractors was to select organisations labelled ‘Construction & Refurbishment’. This reduced the database to a possible 750 organisations.

- The database includes very small organisations, including those with less than 5 employees. The smallest number of employees found within the returned ‘research’ questionnaires was 40. Therefore, this was used as a minimum threshold.

- The required information was contained in the contractor’s completed CHAS questionnaire, which can be viewed online. However, not every file included the contractor’s questionnaire. Further, some questionnaires were either difficult to read (scanned copies of handwritten documents) or were incomplete. These files were ignored.

- Finally, the contact name was emailed or phoned to confirm some details and if their organisation’s information could be used.

The CHAS data allowed almost all the required information to be completed. All that needed to be confirmed by the contractor was the numbers of sub-contractors employed and the split between site and office staff (and confirm if they were included in accident statistics). A total of 70 contractors’ data were obtained using this method. Therefore, the sample consisted of 31 questionnaires and 70 datasets obtained from CHAS/Construction Line. This made a total of 101 datasets. The Department for Trade and Industry (DTI) classifies construction work into two broad sub-sectors ‘civil engineering’ and ‘building’. There was a high number of building contractors in the sample; however, civil engineering contractors were adequately represented. Table 2 shows the industry sub-sectors for the sample. However, contractors tend to work in more than one industry sector. Hence, the frequencies total more than 101.
Table 2: Industry sub-sectors

<table>
<thead>
<tr>
<th>Sector</th>
<th>Sub-sector</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil engineering</td>
<td>Services/utilities</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Transport</td>
<td>27</td>
</tr>
<tr>
<td>Building</td>
<td>Housing</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>Commercial/industrial</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Demolition</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>222</td>
</tr>
</tbody>
</table>

Descriptive statistics for the organisations’ age, turnover and numbers employed (including sub-contractors) are shown in Table 3. An inspection of Table 3 reveals the wide range of contractor size within the sample. For example, turnover varies from a minimum of £4m to a maximum of £700m. The 101 organisations in the sample employed a total of 201,193 workers (including sub-contractors).

Table 3: Age, turnover and numbers employed

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Median</th>
<th>Std. Deviation</th>
<th>Min/Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>37.9</td>
<td>30.5</td>
<td>29.5</td>
<td>2/147</td>
</tr>
<tr>
<td>Turnover (£m)</td>
<td>90</td>
<td>30</td>
<td>200</td>
<td>4/700</td>
</tr>
<tr>
<td>Employed*</td>
<td>1,972</td>
<td>293</td>
<td>7,995</td>
<td>48/60,500</td>
</tr>
</tbody>
</table>

*including sub-contractors

Table 3 also shows a noticeable difference between the mean and median of ‘turnover’ and ‘employed’. This is indicative of a skewed sample. A ‘positively skewed’ histogram is expected with this type of data i.e. gravitating towards zero.

6. Findings

The dependent variable for this study is AIR (per 100,000 site workers). Figure 1 illustrates how this variable is distributed for the sample. The values are positively skewed as expected. A reference line, showing the industry average AIR, for the year data was collected, of 1,790, is also included. Approximately 70% of the sample were below the industry average. The mean AIR for the sample was 1,586 (median 952), with standard deviation of 1,580. The sample also includes 2 contractors with an AIR of zero (turnover of £8m and £43m).
Table 4: AIR: Line management safety training

<table>
<thead>
<tr>
<th>Line Mgr. safety Training</th>
<th>Mean</th>
<th>Median</th>
<th>N</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above H&amp;S NVQ3</td>
<td>210.60</td>
<td>222.00</td>
<td>5</td>
<td>215.41</td>
</tr>
<tr>
<td>SMSTS/MS</td>
<td>1566.56</td>
<td>968.00</td>
<td>62</td>
<td>1652.54</td>
</tr>
<tr>
<td>2 Day or Less</td>
<td>1825.15</td>
<td>1047.50</td>
<td>34</td>
<td>1472.27</td>
</tr>
<tr>
<td>Total</td>
<td>1586.49</td>
<td>952.00</td>
<td>101</td>
<td>1580.27</td>
</tr>
</tbody>
</table>

Table 5 shows analysis of safety training for line management. Higher levels of training were associated with a lower AIR. The mean rank of ‘Above H&S NVQ3’ was 11.00; ‘SMSTS/MS’ was 50.49; and ‘2 day or less was 57.81. The Kruskal-Wallis chi-square test was significant beyond the 0.01 level: $\chi^2 (2) =11.175; \ p = 0.004$. Post hoc Mann-Whitney tests (with Bonferroni adjustment) found a significant difference between ‘Above H&S NVQ3’ and ‘SMSTS/MS’: $U = 31; \ p = 0.001$ (two tailed). There was also a significant difference between ‘Above H&S NVQ3’ and ‘2 Day or Less’: $U = 9; \ p < 0.001$. Therefore, the average AIR of organisations that train line managers to the highest safety level was significantly different from those with lower levels of safety training. But the difference between the middle rank (SMSTS/MS) and lowest rank (2 Day or Less) was not significant.
7. Discussion and conclusions

An ordinal association between the level of safety training and AIR was found in the sample. Although, there was a relatively small number of cases (5) in the ‘H&S NVQ3’ category. The average AIR of organisations that train line managers to the highest safety level was significantly different from those with lower levels of safety training. But the difference between the middle rank (SMSTS/MS) and lowest rank (2 Day or Less) was not significant.

This finding is not surprising, considering the abundance of research confirming the importance of safety training to safety performance. However, the linear association with the ‘level’ of training and education is of extra importance. The extent of safety training or qualification is expected to be a significant factor in relation to competence but no research was found to confirm this assumption. Therefore, this finding reinforces the argument for pursuing higher levels of safety qualification for line managers.

Integration of safety management with the line management function can only be done when line managers are competent enough to accept this responsibility (Cameron et al 2004). Therefore, it is worthwhile establishing, amongst other things, the minimum level of safety training or qualification in this respect.

Having said this, there is the question of whether the training has influenced performance or if training is merely one of many commitments displayed by a safety conscious organisation. For example Hinze (2002: p53) found a correlation between safety training and safety culture. Therefore, the interaction between training levels and other factors should be investigated with regard to superior safety performance.

Analysis of other organisational factors found statistically significant differences in relation to: Senior management’s (OSH) commitment; Client (OSH) commitment; the level of Safety Management System (SMS) in place; and the extent of a behavioural safety programme in place. However, these factors and their interaction with line management training will be discussed in a later paper.

References


QCA (2009) Qualifications can cross boundaries: [viewed 1/9/09]: http://www.qca.org.uk

Improving safety performance and reducing accidents are important aspects to the success of construction projects. However, many construction companies do not address safety because they do not fully understand the true costs of construction incidents and accidents. This paper provides a procedure and example for systematically integrating and calculating construction accident costs using the methodology proposed by Australia Safety and Compensation Council (ASCC). The costs of construction accidents are borne by the workers, employers, and the community and vary significantly for different severity categories. This paper demonstrates that the costs of construction accidents range from AUD$3,344 for short absence injury to more than AUD$1.6 million for permanent incapacity. The research findings show that construction accidents, especially the serious ones, can significantly impact the economic performance of a construction project. However, the expensive accident costs can be also considered as savings if the number of accidents can be effectively reduced through the investment into safety risk prevention programs.

Keywords: accident, cost, construction industry, safety risk prevention, construction project
1. Introduction and research aim

The construction industry is dynamic and diverse, and also has a reputation as one of the most unsafe industries. For example, in Australia in 2007-08, 14,409 claims for compensation were made by employees in the construction industry, accounting for 11% of all serious workers’ compensation claims. Although the incidence rate of claims in construction industry has fallen from 31 claims per 1,000 employees in 2000-01 to 22 claims per 1,000 employees in 2006-07, it remains much higher than the average rate of Australia (14 claims per 1,000 employees) and is the fourth highest amongst all industries for 2006-07 (ASCC, 2010), only after manufacturing, transport/storage, and agriculture/forestry/fishing. Meanwhile, the fatality incidence rate for 2007-08 was 5.6 fatalities per 100,000 employees in construction industry, which was more than twice the rate for Australia of 2.4 fatalities per 100,000 employees (ASCC, 2010).

Furthermore, the costs of construction accident/incident are very expensive (Feng 2009). In Australia, the cost of work-related injury and illness of construction industry bears 11% of the total costs from 17% of the total number of incidents, accounting for approx 6.3 billion and ranked as the 3rd highest among all industries, only after manufacturing (9.3 billion) and health and community services (6.7 billion) (ASCC, 2010). Previous studies have found that the expensive costs of construction accidents are the main driving force behind the industry’s movement of safety (Feng 2009) and the indirect costs of accidents are significantly higher than the direct costs. However, most construction companies are not able to systematically calculate accident costs due to lack of knowledge and understanding of the compensation mechanisms involved in accidents (Gavious et al 2009).

A reliable evaluation of the cost of construction accident can help managers and workers to internalise the importance of safety measures from an economic-managerial perspective (Gavious et al 2009). As an important part of a major research undertaking, this paper aims to develop a procedure and examples for systematically integrating and calculating the construction accident costs using the methodology proposed by Australia Safety and Compensation Council (ASCC). The next section is a theoretical background for evaluating the accident costs, while in the third section, the ASCC methodology is presented with data required for calculation listed. Section 4 presents the calculation processes and results while the last section discusses the research finding and concludes the paper.

2. Theoretical background

As discussed above, top managers’ motives for the introduction of accident prevention measures may stem from various concerns such as humanitarian, legal, company image and cost. Studies in construction and other industries in general indicate that the most important motive, however, is the economical one (Laufer 1987). This may explain the importance of quantifying construction accident costs in monetary value. The systematic study of accident costs was first documented by Heinrich in 1959. He classified the costs as direct and indirect, and concluded that indirect costs were about four times greater than direct
costs. Direct costs are those costs of occupational accidents within the industry which are directly measurable in financial terms, while indirect costs are those measured first in labour time and subsequently translated into financial equivalents (Leopold and Leonard 1987). According to ASCC (2009), direct costs include items such as worker’s compensation premiums paid by employers or payments to injured or incapacitated workers from workers’ compensation jurisdictions. Indirect costs include items such as lost productivity, loss of current and future earnings, lost potential output and the cost of providing social welfare programs for injured or incapacitated workers, etc. Direct and indirect cost can be further divided into many sub-categories; a hierarchy structure of different cost components is given as shown in Figure 1. The classification method of direct and indirect costs has been used by many researchers from different countries to analyse costs of accidents (Waehrer et al 2007, Gavious et al 2009). Other studies also classified costs as insured and uninsured (Grimaldi and Simonds 1984). Insured costs might include those items covered by the corresponding insurance for damages, while uninsured costs refers those must be paid by the company (Occupational Health and Safety Research Institute). Uninsured costs can be further divided according to various categories of accidents such as lost day cases and no-injury cases. Tang et al (2004) also summarised the financial costs of a construction accident in the context of Hong Kong’s construction industry, which included: (1) loss due to the injured person’s absence from work; (2) loss due to the injured person’s inefficiency after resuming work; (3) medical expenses; (4) fines and legal expenses; (5) loss of time of other employees; (6) equipment or plant loss; (7) loss due to damaged materials or finished work; (8) loss due to idle machinery or equipment; and (9) other losses.

Most of the previous cost studies for construction are limited to worker’s compensation costs (Waehrer et al 2007). Gavious et al (2009) conclude the reason for the marginalization of accident costs by managers, including: (1) managers tend to believe that most expenses are insured and therefore do not see a real reason to calculate these costs which requires data collection; (2) the common economic approaches assume the direct and indirect accident costs to be a kind of sunk costs (Oi 1974, Thaler and Rosen 1975); (3) measurement difficulties, overloaded managers, biased accounting methods and the low status of safety department. All these factors place challenge for evaluating the accident costs that indirect costs, which are usually also the uninsured costs, need to be evaluated carefully (Gavious et al 2009) and the calculation method should include organizational, social and macro-economic parameters to overcome the narrow economic approaches adopted by many managers (Adnett and Dawson 1998).

For most accident cost analysis, collecting data is a very difficult and complex process. Accident costs are incurred in different time period (e.g. immediately following the accident, later, when a replacement worker takes over, and on return of the injured worker after recovery); at different locations (e.g. at the site, in the field and in the office, at company head-office, in hospitals, in garages); and are handled by different organisations (e.g. the construction company, social security, and private insurance companies). The components of injuries and fatality compensation are also very complex, including lump sum and weekly payments for medical, hospital and ambulance expense, for transport and maintenance expense, for damages and legal costs, for investigation expense, etc (Ore 1992). Therefore, collecting data by
observation on sites is not feasible because accidents are unplanned and uncontrolled events (Laufer 1987).

Figure 1: A typical hierarchical approach to analyse construction accident costs

3. Data and methods

3.1 The methodology and its consideration

In order to calculate the costs of construction accidents, injuries and fatalities, this research employs the methodology developed and applied in 2004 by the National Occupational Health and Safety Commission (NOHSC 2004). The methodology is an adaptation of a 1995 Industry Commission report with further modifications based on the recommendations of independent reviews of the method by The Allen Consulting Group and Access Economics (ASCC 2009). In 2009, the methodology is employed by Australia Safety and Compensation Council (ASCC, 2009) to update the estimated cost of work-related injury and illness of all the industry sectors, including construction industry.

According to NOHSC (2004) and ASCC (2009), the basic methodology for deriving an estimate economic cost is to identify and define the categories of economic costs affecting the major economic agents, such as employers, workers and the community. Using the severity of an accident as a major driver of average cost, a scale for measuring incidents by the level of severity is created. This scale is
used to calculate an aggregate total costs to determine the overall level of direct and indirect costs. The economic costs associated with construction-related accidents and illness are estimated for a range of direct and indirect cost items over five severity categories, ranging from short periods off work with full return to normal duties to permanent incapacity and fatality, as shown in Table 1.

Table 1: Definition of different types of accidents and severity category (Source: NDS2)

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Severity Level</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short absence</td>
<td>Less than 5 days off work</td>
<td>A minor work-related injury or illness, involving less than 5 working days absence from normal duties, where the worker was able to resume full duties.</td>
</tr>
<tr>
<td>Long absence</td>
<td>Five days or more off work and return to work on full duties</td>
<td>A minor work-related injury or illness, involving 5 or more working days and less than 6 months off work, where the worker was able to resume full duties.</td>
</tr>
<tr>
<td>Partial incapacity</td>
<td>Five days or more off work and return to work on reduced duties or lower income</td>
<td>A work-related injury or illness which results in the worker returning to work more than 6 months after first leaving work.</td>
</tr>
<tr>
<td>Full incapacity</td>
<td>Permanently incapacitated with no return to work</td>
<td>A work-related injury or disease, which results in the individual being permanently unable to return to work.</td>
</tr>
<tr>
<td>Fatality</td>
<td>Fatality</td>
<td>A work-related injury or disease, which results in death.</td>
</tr>
</tbody>
</table>

The methodology for deriving the estimate for total costs is composed with the following six steps (Source: ASCC 2009):

1. Identify the major categories of economic costs borne by economic agents (employers, workers and the community)

2. Determine the best source of measurement for each cost item

3. Define the levels of severity of injury or disease to differentiate between accidents with different cost structures

4. Identify which cost items apply to each severity category

5. Determine the number of accidents which fall into each severity category, and the average duration of times lost for a typical incident in each category

6. Calculate the average cost of a typical accident in each severity category by aggregating the typical costs associated with each cost item, and
In general, the methodology used in this research is based on the *incidence approach* identified by Access Economics (2004). The incidence approach assesses the number of people entering the compensation systems during a particular year as a result of construction accident and the costs (both current and expected future costs) associated with those cases. Since only new cases are measured under the incidence approach, in order to estimate the total costs the expected future cost of new cases over the lifetime of a case is used to proxy the cost in the reference year of cases that were already in the system at the start of the current reference year.

The alternative approach is called *prevalence approach* which assesses the number of people within the compensation or medical systems at a given point in time, regardless of when the injury or illness occurred (ASCC 2009). The prevalence approach has its disadvantage that the source of prevalence data relating to accident is relatively inaccurate or incomplete. While the incidence approach allows a better estimation of the economic cost of disease cases, since it allows the future costs for new cases to be followed over the expected lifetime of the case, which means the level and structure of current costs will accurately reflect ongoing costs into the future. Therefore, incidence approach is selected to estimate the cost of construction accidents. This approach has also been used by other researchers to tabulate the construction accident costs in the US (Gavious et al 2009).

Associated with the incidence approach, ‘ex-post’ approach is selected to distribute costs. In this approach costs are attributed to accidents after they occur and as a direct result of the accident. The alternative view is an ‘ex-ante’ approach, where the expected costs of incidents are estimated in advance of the event or incident. This approach is traditionally associated with a prevalence approach to measure total costs, where total expenditures for a given year are appointed across the categories of injury or illness. An important distinction between these two views is the treatment of workers’ compensation premiums paid by employers. Under the ‘ex-post’ treatment, such payments are not considered as a cost to the employer but treated as a burden to the community as compensation payments are re-distributed to injured and ill workers. Under the ‘ex-ante’ treatment, workers’ compensation premiums are considered as a cost to employers for all accidents that will occur in the reference year. However, it should be noted that the choice of the method for assigning costs will affect the distribution of costs between economic agents but not the level of total costs (ASCC 2009).

**3.2 Components of accident costs**

Identifying the proportion of costs borne by workers, employers and the community is a very important part of this research. Estimating the burden of economic costs will allow an understanding of the incentives on employers and regulators to provide a safe workplace. The distribution of the burden of costs is achieved by defining the major aspects of total costs and assigning the proportion of these cost groups to each of the economic agents (workers, employers and the community). The six cost classifications are identified as follows:
• Production disturbance costs (PDC) – costs incurred in the short term until production is returned to pre-incident levels

• Human Capital Costs (HCC) – long run costs, as loss of potential output, occurring after a restoration of pre-incident production levels

• Medical Costs (MEDC) – costs incurred by workers and the community though medical treatment of workers injured in work-related incidents

• Administrative Costs (ADMINC) – costs incurred in administering compensation schemes, investigating incidents and legal costs

• Transfer costs (TRANC) – deadweight losses associated with the administration of taxation and welfare payments, and

• Other Costs (OTC) – includes costs not classified in other areas, such as the cost of carers and aids and modifications

The six conceptual groups can be further divided into many cost components that borne by workers, employers and the community. Some of the cost components are considered as indirect costs, which need to be estimated individually under each severity category. Appendices 1 to 3 provide the detailed estimation method for each cost item. Some of the indirect cost items are estimated across all applicable severity categories due to the lack of available data relating to distribution by severity. For example, the overtime and over-employment, medical and rehabilitation costs and investigation costs are considered to be included in all severity categories, while legal costs are assumed to be incurred for full incapacity and fatality accidents only. The detail cost components under each conceptual group and their distributions are summarized in Table 2.

Table 2: Summary of the cost items and their distributions by severity

<table>
<thead>
<tr>
<th>Conceptual group</th>
<th>Cost item</th>
<th>Borne by agent(^1)</th>
<th>Direct or indirect cost(^2)</th>
<th>Distribution by severity(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production disturbance costs</td>
<td>Cost of overtime and over-employment</td>
<td>E</td>
<td>I</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Employer excess payments</td>
<td>E</td>
<td>I</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Staff turnover costs</td>
<td>E</td>
<td>D</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Staff training and retraining costs</td>
<td>E</td>
<td>I</td>
<td>PI, FI, FT</td>
</tr>
<tr>
<td></td>
<td>Loss of current income</td>
<td>W</td>
<td>I</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Compensation payments</td>
<td>C</td>
<td>I</td>
<td>LA, PI, FI, FT</td>
</tr>
<tr>
<td>Human capital costs</td>
<td>Loss of future earnings</td>
<td>W</td>
<td>I</td>
<td>PI, FI, FT</td>
</tr>
</tbody>
</table>

190
<table>
<thead>
<tr>
<th>Medical costs</th>
<th>Loss of government revenue</th>
<th>C</th>
<th>I</th>
<th>LA, PI, FI, FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social welfare payments for lost income earning capacity</td>
<td>C</td>
<td>D</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Threshold medical payments</td>
<td>E</td>
<td>D</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Medical and rehabilitation costs</td>
<td>W</td>
<td>I</td>
<td>All</td>
<td></td>
</tr>
<tr>
<td>Rehabilitation</td>
<td>C</td>
<td>D</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Health and medical costs</td>
<td>C</td>
<td>D</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Administrative costs</th>
<th>Legal fines and penalties</th>
<th>E</th>
<th>D</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigation costs</td>
<td>E</td>
<td>I</td>
<td>All</td>
<td></td>
</tr>
<tr>
<td>Travel expenses</td>
<td>W</td>
<td>I</td>
<td>All</td>
<td></td>
</tr>
<tr>
<td>Legal costs</td>
<td>W</td>
<td>I</td>
<td>FI, FT</td>
<td></td>
</tr>
<tr>
<td>Funeral costs</td>
<td>W</td>
<td>D</td>
<td>FI, FT</td>
<td></td>
</tr>
<tr>
<td>Inspection and investigation costs</td>
<td>C</td>
<td>D</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Travel concessions for permanently incapacitated workers</td>
<td>C</td>
<td>D</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Transfer costs</td>
<td>Deadweight costs of welfare payments and tax losses</td>
<td>C</td>
<td>D</td>
<td>-</td>
</tr>
<tr>
<td>Other costs</td>
<td>Carers costs</td>
<td>W</td>
<td>I</td>
<td>FI</td>
</tr>
<tr>
<td>Aids and modifications</td>
<td>W</td>
<td>I</td>
<td>FI</td>
<td></td>
</tr>
</tbody>
</table>

1. E=Costs borne by employer, W=Costs borne by worker, and C=Costs borne by community
2. D=Direct cost, I=Indirect cost
3. SA=Short absence, LA=Long absence, PI=Partially incapacity, FI=Full incapacity, FT=Fatality, All=All severity categories

### 3.3 Discounting future monetary value

In this study, costs that occur in the future such as loss of future earnings for the reference year are modelled using present value calculation. The value of future payments or income streams are modified to an equivalent reference year monetary value by considering factors which affect the value of currency over time, such as saving and price/wage inflation. This information can be combined into a single value – called the discount rate, which summarizes the likely changes in the value of money over time. According to ASCC 2009, the discount rate used in this study is composed of three parts: (1) the opportunity cost of saving, modelled by average investment rates for common savings instruments; (2) the price based inflation that based on average consumer price index (CPI) movements over a selected period of time; and (3) a productivity factor which is measured as wage increases above the prevailing
wage inflation rate. The productivity factor is only used in present value calculations involving real wages and attempts to model the implicit increase in wages for an individual and their experience and resulting productivity increases over time.

In this study, the rates used to form the discount rate were 6.5 per cent p.a. for savings and 2.6 per cent p.a. for inflation. This represents a discount rate of 3.9 per cent. When considering wage present value calculations, the productivity rate of 1.75 percent p.a. was applied, leading to a modified discount rate of 2.15 percent.

4. Calculation and results

Using the ASCC methodology, the typical average cost of a construction incident can be estimated by calculating the average cost associated with each relevant direct and indirect cost item. Those costs are then aggregated over each cost item to derive an overall estimate. Table 3 demonstrates the calculated items that comprise the total costs estimate. The table shows the major cost groups and categories, with costs further divided into different severity categories. The key parameters for the calculation are listed in Appendix 4. Under the lifetime approach (‘incidence’ and ‘ex-post’ approach), the cost of construction accidents borne by employers, workers and the community ranges from AUD$3,344 for short absence injury to AUD$1,686,819 for full incapacity accident. It is noteworthy that the cost for full incapacity injury is higher than fatality accident since more on-going costs will be exposed to the employers, workers and the community after the occurrence of a full incapacity accident.

Table 3 Calculation of the costs per accident, AUD$, 2005-06

<table>
<thead>
<tr>
<th>Conceptual group</th>
<th>Cost item</th>
<th>Short absence</th>
<th>Long absence</th>
<th>Partial incapacity</th>
<th>Full incapacity</th>
<th>Fatality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production disturbance costs (PDC)</td>
<td>Cost of overtime and over-employment</td>
<td>132</td>
<td>2,120</td>
<td>18,133</td>
<td>35,447</td>
<td>3,610</td>
</tr>
<tr>
<td></td>
<td>Employer excess payments</td>
<td>1,495</td>
<td>1,495</td>
<td>1,495</td>
<td>1,495</td>
<td>1,495</td>
</tr>
<tr>
<td></td>
<td>Staff turnover costs</td>
<td>-</td>
<td>-</td>
<td>29,498</td>
<td>29,498</td>
<td>29,498</td>
</tr>
<tr>
<td></td>
<td>Staff training and retraining costs</td>
<td>-</td>
<td>-</td>
<td>2,588</td>
<td>2,588</td>
<td>2,588</td>
</tr>
<tr>
<td></td>
<td>Loss of current income</td>
<td>331</td>
<td>5,299</td>
<td>45,333</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Social welfare payments</td>
<td>-</td>
<td>10,659</td>
<td>29,636</td>
<td>29,636</td>
<td>29,636</td>
</tr>
<tr>
<td></td>
<td><strong>Total PDC costs</strong></td>
<td><strong>1,958</strong></td>
<td><strong>19,572</strong></td>
<td><strong>12,682</strong></td>
<td><strong>98,662</strong></td>
<td><strong>66,826</strong></td>
</tr>
<tr>
<td>Human capital costs (HCC)</td>
<td>Loss of future earnings</td>
<td>-</td>
<td>-</td>
<td>15,500</td>
<td>1,032,482</td>
<td>1032,482</td>
</tr>
<tr>
<td></td>
<td>Loss of government revenue</td>
<td>-</td>
<td>1,320</td>
<td>11,385</td>
<td>258,120</td>
<td>258,120</td>
</tr>
<tr>
<td></td>
<td>Compensation and welfare payments for lost income earning capacity</td>
<td>-</td>
<td>10,529</td>
<td>86,886</td>
<td>168,290</td>
<td>168,290</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>11,579</td>
<td>113,771</td>
<td>1,458,892</td>
<td>1458,892</td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-----</td>
<td>--------</td>
<td>---------</td>
<td>-----------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td><strong>Total HCC costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Medical costs (MEDIC)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threshold medical payments</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Medical and rehabilitation</td>
<td>462</td>
<td>2,187</td>
<td>12,091</td>
<td>12,097</td>
<td>6,111</td>
<td></td>
</tr>
<tr>
<td>costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rehabilitation</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>9,667</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Health and medical costs</td>
<td>305</td>
<td>656</td>
<td>2,055</td>
<td>1,452</td>
<td>367</td>
<td></td>
</tr>
<tr>
<td><strong>Total MEDIC costs</strong></td>
<td>1,267</td>
<td>3,343</td>
<td>14,646</td>
<td>23,716</td>
<td>6,978</td>
<td></td>
</tr>
<tr>
<td><strong>Administrative costs (ADMC)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legal fines and penalties</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>828</td>
<td>13,798</td>
<td></td>
</tr>
<tr>
<td>Investigation costs</td>
<td>28</td>
<td>527</td>
<td>832</td>
<td>2,374</td>
<td>2,840</td>
<td></td>
</tr>
<tr>
<td>Travel expenses</td>
<td>6</td>
<td>27</td>
<td>257</td>
<td>11,232</td>
<td>404</td>
<td></td>
</tr>
<tr>
<td>Legal costs</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>11,970</td>
<td>11,970</td>
<td></td>
</tr>
<tr>
<td>Funeral costs</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3,617</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel concessions for</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5,616</td>
<td></td>
<td></td>
</tr>
<tr>
<td>permanently incapacitated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>workers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total ADMINC costs</strong></td>
<td>34</td>
<td>554</td>
<td>1,089</td>
<td>32,020</td>
<td>32,629</td>
<td></td>
</tr>
<tr>
<td><strong>Transfer costs (TRANSC)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deadweight costs of welfare</td>
<td>85</td>
<td>590</td>
<td>4,484</td>
<td>31,015</td>
<td>6,205</td>
<td></td>
</tr>
<tr>
<td>payments and tax losses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total TRANSC costs</strong></td>
<td>85</td>
<td>590</td>
<td>4,484</td>
<td>31,015</td>
<td>6,205</td>
<td></td>
</tr>
<tr>
<td><strong>Other costs (OTC)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carers costs</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>32,345</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Aids and modifications</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>10,169</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Total OTHERC costs</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>42,514</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td>3,344</td>
<td>35,638</td>
<td>260,672</td>
<td>1,686,819</td>
<td>1,571,529</td>
<td></td>
</tr>
</tbody>
</table>

5. Discussion and concluding remarks

This paper gives an example of how to calculate the true costs of construction accidents using the methodology developed by Australia Safety and Compensation Council (ASCC). The main advantage of this method is that indirect costs of construction accidents were taken into consideration and converted into monetary value. As discussed at the beginning of this paper, the expensive costs of construction accidents are the main driving force behind the industry’s movement of safety. This view has been proved by this study that construction accidents, especially serious ones such as full incapacity and fatality, will adversely impact the economic performance and the success of construction projects, since the costs of serious accidents are very high.

In general, the methods adopted in this paper can be used as reference for analysing construction accident costs in other countries. However, it should be noted that the construction accident costs components and
evaluation methods will be different in different countries and backgrounds. Therefore, researchers need to be careful when doing similar studies in other countries.

On the other hand, the high costs of construction accidents can be converted to savings if the safety performance was improved by investing in safety risk prevention measures. Construction companies should input both physical and cultural inputs into safety management, in which as a result, the number of incidents and injuries can be reduced and therefore the accident costs can be saved. As concluding remarks, future studies can be focused on the cost-benefit analysis to investigate the connections between safety performance, costs of accidents and the benefits of investing in safety risk prevention programs.

**References**


Feng, Y. B., (2009), ‘Physical input and cultural input in work accident prevention of building projects: an economic perspective’, *Proceedings of 10th APRU Doctoral Students Conference: Promoting Originality and Diversity in Research, 6-10 July 2009, Kyoto University, Japan*.


Occupational Health and Safety Research Institute, (2007), *Analysis of the profitability of investment in accident prevention on construction sites*


Appendix

Appendix 1: Cost items and assumptions of the cost items for employers (Source: ASCC 2009)

<table>
<thead>
<tr>
<th>Cost Category (Group)</th>
<th>Estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of overtime and over-payment</td>
<td>Average weekly earnings × duration of absence in weeks × 0.4.</td>
</tr>
<tr>
<td>(PDC)</td>
<td></td>
</tr>
<tr>
<td>Employer excess payments (PDC)</td>
<td>Average cost per day claim (estimating from NDS data) multiplied by 3.3 days.</td>
</tr>
<tr>
<td>Staff turnover costs (PDC)</td>
<td>Turnover and recruitment costs are estimated to be equal in value to 26 weeks at average earnings less the amount simply ‘brought forward’ by work-related incidents</td>
</tr>
<tr>
<td>Staff training and retraining costs</td>
<td>Average weekly earnings × 2.5.</td>
</tr>
<tr>
<td>(PDC)</td>
<td></td>
</tr>
<tr>
<td>Medical threshold payments (MEDC)</td>
<td>Average threshold medical payments, $500 in payments.</td>
</tr>
<tr>
<td>Legal fines and penalties (ADMINC)</td>
<td>Average fine per conviction × number of convictions / total number of incidents</td>
</tr>
<tr>
<td>Investigation costs (ADMINC)</td>
<td>Worker’s compensation expenditure relating to conducting investigations.</td>
</tr>
</tbody>
</table>

a For claims of longer duration or severity (such as permanent incapacity and fatality), the injured worker is assumed to be replaced after 8 weeks. The distribution of labor on-costs is based on data from ABS Major Labor Costs survey, and includes costs such as payroll tax and superannuation.

b Employer excess provisions differ between jurisdictions, both in terms of nature and period. The most common form of employer excess is 4 days, where the employer is liable for the costs associated with the first four days of a claim. However, some jurisdictions require no employer excess provisions. The weighted average of the excess period over each jurisdiction is 3.3 days. For severity category 1 the actual days lost are used in this calculation. For other categories, 3.3 days is used to proxy employer excess payments.

c Training and re-training are assumed to occupy approximately 2.5 weeks, covering both the time of the worker and also any training responsibilities of existing staff.

d based on CPM estimates, the average fine per conviction is $27,595 and the prosecution rate is assumed to be 3% of incidents for permanent incapacity and 50% of incidents for fatalities.

Appendix 2: Definitions, methods and assumptions of cost items for workers (Source: ASCC 2009)

<table>
<thead>
<tr>
<th>Cost (Group)</th>
<th>Category</th>
<th>Estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of current income (PDC)</td>
<td>Residual item, total PDC less employer and society share of PDC.</td>
<td></td>
</tr>
<tr>
<td>Loss of future earnings (HCC)</td>
<td>Difference between expected future earnings in the absence of a work-related injury or disease and expected future income following the incident.</td>
<td></td>
</tr>
<tr>
<td>Medical and rehabilitation costs</td>
<td>The difference between medical costs incurred less medical payments covered by workers’ compensation less government rebates.</td>
<td></td>
</tr>
<tr>
<td>Cost Category (Group)</td>
<td>Estimation</td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>Travel expenses (ADMINC)</td>
<td>Estimated from workers’ compensation payments made for travel expenses (6% of NDS non-compensation payments).</td>
<td></td>
</tr>
<tr>
<td>Legal costs (ADMINC)</td>
<td>Difference between the average legal costs and overheads for a dispute and the amount received in compensation for legal cost.</td>
<td></td>
</tr>
<tr>
<td>Funeral costs (ADMINC)</td>
<td>Average funeral costs are estimated at $3,617. Brought forward funeral costs are the discounted present value of a funeral at the time of life expectancy compared with the age at the time of the incident.</td>
<td></td>
</tr>
<tr>
<td>Carers (OTC)</td>
<td>Estimated applicable Disability Support Pension payments of $1,687 per annum, discounted to present value over the period between the incident and reduced life expectancy.</td>
<td></td>
</tr>
<tr>
<td>Aids and modifications (OTC)</td>
<td>Estimated applicable Disability Support Pension payments of $530.4 per annum, discounted to present value over the period between the incident and reduced life expectancy.</td>
<td></td>
</tr>
</tbody>
</table>

*Workers are assumed to increase productivity (through experience and job knowledge) at the rate of 1.75% per annum. This figure is used in conjunction with discount and inflation rates to determine the present value of future income streams.*

*b* Medicare covered services that are bulk-billed are assumed to incur no cost to the individual. Workers are assumed to bear 15% of the total cost of the services when that service is not bulk-billed and covered by Medicare. On average, 47% of total costs result from Medicare covered services, with the remaining 53% of costs available to be covered by private health insurance. Private health insurance covers 44% of cases, with the worker paying the gap payments of 5% on these costs. the costs of the remaining services are fully borne by the individual.

*c* Average legal costs and overheads per dispute are estimated to be $11,970 per dispute. According to CPM data, disputes occur at a rate of 1 dispute per 8 claims. Average compensation for legal costs varies according to the severity of the incident, but comprises 62% of non-compensation payments.

**Appendix 3: Definitions, methods and assumptions of cost items for community (Source: ASCC 2009)**

<table>
<thead>
<tr>
<th>Cost Category (Group)</th>
<th>Estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lost revenue (PDC/HCC)</td>
<td>The taxation value of the present value of all future earnings over the period in which the individual is unable to work or that is lost through premature fatality.*</td>
</tr>
<tr>
<td>Social welfare payments (PDC/HCC)</td>
<td>Average cost per recipient of social welfare programs. *</td>
</tr>
<tr>
<td>Health and medical costs (MEDC)</td>
<td>Total Medicare costs that are not borne by the worker.</td>
</tr>
<tr>
<td>Rehabilitation (MEDC)</td>
<td>Average cost of rehabilitation service (per recipient) reported by the Commonwealth Rehabilitation Service. *</td>
</tr>
<tr>
<td>Inspection and investigation costs (ADMINC)</td>
<td>Average cost per inspection reported by workers’ compensation jurisdictions.</td>
</tr>
<tr>
<td>Travel concessions for permanently incapacitated (ADMINC)</td>
<td>Expenditure on travel costs by workers’ compensation jurisdictions as a proxy for travel concessions.</td>
</tr>
</tbody>
</table>
Transfer costs (TRANC)

\(^a\) Based on average weekly earnings over the period of lost earnings, with an average taxation rate of 40%. Savings, inflation and productivity rates are also applied in determining the present value of future income streams. This total is split into short and long term costs. Short term costs are incurred in the period between the incident and return to work, while long term costs are incurred in the period following nominal return to work or replacement and retirement or to reduced life expectancy.

\(^b\) Workers who suffer severe incidents are assumed to rely on the Disability Support pension (average cost per case is $10,659 p.a.) following a period of compensation (for compensated incidents).

\(^c\) Workers who suffer a permanent incapacity are assumed to rely on the CRS (average cost per case is $3,362 p.a.) following the period of compensation (zero for non-compensated incidents).

\(^d\) The community is assumed to match compensation payments for travel costs 1-1 with the individual, in effect assuming a 50 per cent travel concession for severely incapacitated workers.

---

Appendix 4: Parameters specific to severity and nature categories (Source: ASCC 2009)

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Short absence</th>
<th>Long absence</th>
<th>Partially incapacity</th>
<th>Full incapacity</th>
<th>Fatality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average duration of absence</td>
<td>Days</td>
<td>1.6</td>
<td>25.6</td>
<td>219.0</td>
<td>428.1</td>
<td>43.6</td>
</tr>
<tr>
<td>Average age of incident</td>
<td>Years</td>
<td>33</td>
<td>35</td>
<td>41</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>Average medical cost</td>
<td>AUD$ per claim</td>
<td>462</td>
<td>2,187</td>
<td>12,091</td>
<td>12,097</td>
<td>6,111</td>
</tr>
<tr>
<td>Average investigation costs</td>
<td>AUD$ per incident</td>
<td>28</td>
<td>527</td>
<td>832</td>
<td>2,374</td>
<td>2,840</td>
</tr>
<tr>
<td>Average travel cost</td>
<td>AUD$ per claim</td>
<td>6</td>
<td>27</td>
<td>257</td>
<td>11,232</td>
<td>404</td>
</tr>
<tr>
<td>Average medicare coverage of costs</td>
<td>%</td>
<td>66%</td>
<td>30%</td>
<td>17%</td>
<td>12%</td>
<td>6%</td>
</tr>
</tbody>
</table>
Abstract

The construction industry has a reputation as one of the most unsafe industries in terms of high incident, injury and fatality rates. A successful Safety Risk Management System (SRMS) can reduce accident rates and protect construction company’s physical, organizational and human capitals, hence bring benefit to the project and the company. However, unlike investment in IT or real estate projects which will benefit the firm by selling products such as software and properties, the benefits of inputting money and human resources into safety management cannot be measured easily in tangible and physical terms. In addition, the prior expenses on accident risk prevention measures and approaches always seem very expensive, hence safety risk management system has been considered as a non-returnable investment that is not of benefit to anyone. This misunderstanding widely exists among construction contractors and clients. This paper aims to develop a quantitative measurement model to analyse the return on investment (ROI) of safety risk management systems in construction projects. The model introduced in this research was validated by a case study using data acquired from a real project. Through this study, the economic benefit of a SRMS has been expressed in monetary values hence the stakeholders of construction projects will have a better understanding of the significance and value of (aka return on) investment in safety risk management in construction.

Keywords: return on investment, construction safety management, risk management, cost of construction accident, investment in safety
1. Introduction and research gap

The construction industry is dynamic and diverse, and is of critical importance to a nation’s economy. For example in Australia, in 2006-07, the industry employed 936,000 people, represents 9% of the Australian workforce and creates 6.4% of the Gross Domestic Product (GDP) (ASCC, 2008). However, due to the complexity of construction sites, market fragmentation, and high level of small sub-contractors, the construction industry also has a reputation as one of the most unsafe industries (Ore, 1992; Gambatese et al., 1999; Haslam, 2005; Zou et al., 2007; ASCC, 2008; and Gambatese et al., 2008). For example, in Australia in 2006-07, 14,120 claims for compensation were made by employees in construction industry, accounting for 11% of all serious workers’ compensation claims, which means there were 39 employees per day requiring one or more weeks off work because of work-related injury or disease. The incidence and fatality rates of construction remained much higher than the average level of Australia for the past several years (ASCC, 2008). On the other hand, the costs of construction accident/incident are also very expensive (Feng, 2009). The cost of work-related injury and illness of construction industry bears 11% of the total costs from 17% of the total number of incidents, accounting for approx 6.3 billion and ranked as the 3rd highest among all industries, only after manufacturing (9.3 billion) and health and community services (6.7 billion) (ASCC, 2009). These data indicate that the construction industry is one of the most dangerous industries so safety management is of critical importance to human life and substantial savings can be made by preventing incidents, which has been considered as the main driving force behind the industrial safety movement (Teo et al., 2009).

Construction safety risk management is not where a company generates revenue but it is a place that does generate profit by reducing safety risk and thus the potential for loss. Effective safety risk management system (SRMS) can be used as a company strategy by construction firms to earn a competitive position of optimum advantage (Rechenthin, 2004). There are three sources of competitive advantage: physical resources, organisational resources, and human resources. Physical resources refer to the organisation’s plant, equipment and finances; organisational resources are the organisation’s structure, planning, and coordinating abilities; while human resources refer to employees’ skills, judgments and intelligence (Barney and Wright, 1998). An effective SRMS protects physical resources and implies an effective organisational resource, but the greatest impact of safety on competitive advantage is the human capital resources. Effective safety management can develop the human capital elements of skills, behaviours, and management system.

Successful SRMS has the potential for assisting the company in cost leadership and providing differentiation. The reduction in construction accident rates can lower operating costs and perhaps most importantly reduce the risk of large losses due to catastrophic injury events (Rechenthin, 2004). Decision makers’ motives for the most introduction of a SMS may stem from various concerns such as humanitarian, legal, company image and cost. Studies in construction and in industry in general indicate that the most important motive, however, is the economical one (Laufer 1987). In reality, however, safety is still not one of the main concerns by stakeholders of the project. Although nowadays there is a growing urge for a shift from ‘lowest-price wins’ to ‘multiple-criteria selection’ practices in tendering stage, the price that the contractor firm offers is still the most important factor the client concerns when selecting a contractor (Holt et al., 1994; Egemen and Mohamed, 2006).
Since intense competition makes construction market dominated by clients groups (Egemen and Mohamed, 2006), their ignorance of safety may force contractors to cut off their inputs into safety management. In addition, compared with the large amount of inputs at the beginning, it always takes years to identify the benefits of safety management, especially when many benefits are intangible and hard to calculate in monetary value, such as company image and worker’s satisfaction (Muñiz et al., 2009). Those barriers lead to a misunderstanding that accident prevention and safety management is a non-returnable investment that is not of benefit to anyone (Occupational Health and Safety Research Institute, 2007). Therefore, the research gap can be identified as follow: in order to promote effective SMS in the construction industry, convincing evidence must be provided to prove the economic benefits of investing in safety risk prevention and management, which has not been done by previous studies. To fill this gap, a return on investment (ROI) model has been developed. Then the model was verified by a case study using the data from a real construction project.

2. Return on investment and cost-benefit analysis theory

Analysing the cost versus benefits (CBA) and return on investment (ROI) to guide company’s investment decisions is clearly important for business and organizations (Stone et al 2005). ROI can be defined as a type of cost-benefit analysis conducted from investor’s perspective (Stone et al 2005). It represents a project’s net output (cost savings and/or new revenue that results from a project less the total project costs), divided by the project’s total inputs (total costs), and expressed as a percentage (see equation 1). The inputs are all of the project costs such as hardware, software, programmer’s time, external consultants, and training (Jeffery 2004).

\[
\text{ROI} = \frac{TPO - TPI}{TPI} \times 100\% \quad (1)
\]


The complexity of the ROI calculation model differs from project to project. Basically, the more complicated the investment, the more complicated the formula becomes. But the main steps for calculating return on investments are very similar and can be briefly described as six steps: data collection; isolate effect of training; converting data to monetary value; identify intangible benefits; tabulate program costs; and calculating the return on investments (ROI) (Rohs 2006, Phillips 1997). The ROI evaluation process can be very complicate. Many factors should be considered when conducting an ROI calculation (Jeffery 2004). For example, the assumptions underlying the cost and benefits of projects; the ability to measure and quantify the costs and benefits; the risks that the project will not be completed on time and on budget and will not deliver the expected outcomes; whether there is a sensitivity analysis and how it is interpreted; whether the project have senior management and end user support; how important the intangible benefit is; etc.
2.1 Costs of construction accidents

The above section tells us that the investment and outcome are the two main elements to analyse the ROI. From the perspective of safety management, the investment refers to construction company’s resource inputs in accident prevention and management strategies, such as on-site accident prevention facilities, personal protection equipments (PPE), staff training, design for safety, etc. On the other hand, the outcomes or benefits of investing in safety management refer to the reduction of accident rates, which can be measured by benchmarking the improvement of safety performance and calculating the savings on account of no accident. To measure the savings, we must have a clear understanding of the cost of construction work-related accident.

The systematic study of accident costs was first documented by Heinrich in 1959. He classified the costs as direct and indirect, and concluded that indirect costs were about four times greater than direct costs. Direct costs are those costs of occupational incidents within the industry which are directly measurable in financial terms, while indirect costs are those measured first in labor time and subsequently translated into financial equivalents (Leopold and Lenard 1987). The classification method of direct and indirect cost is also supported by other recent studies, such as the study by Leopold and Lenard (1987). Australia Safety and Compensation Council (ASCC 2009) conduct a study on cost of work-related injury and illness for Australian employers, workers and the community. The methodology adopted by the ASCC report provides a good example of evaluating the direct and indirect costs of construction incidents that borne by workers, employers and the community. According to the ASCC (2009) report, the components of incidents costs can be summarized as in Figure 1:

![Figure 1: Cost borne by workers, employers and the community (source: ASCC 2009)
Since this study focuses on GCC’s building developments in Australia, five mutually exclusive severity categories of incidents are adopted to classify the types of incidents (Table 1) and the definitions are available from the National Dataset for Compensation-based Statistics, 2nd edition (NDS2), and are based on incident severity and duration of absence. The cost items presented in Figure 1 can be distributed to the five types of incidents according to the severity type.

**Table 1: Definitions of different types of incidents and severity category**

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Severity Level</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short absence</td>
<td>Less than 5 days off work</td>
<td>A minor work-related injury or illness, involving less than 5 working days absence from normal duties, where the worker was able to resume full duties.</td>
</tr>
<tr>
<td>Long absence</td>
<td>Five days or more off work and return to work on full duties</td>
<td>A minor work-related injury or illness, involving 5 or more working days and less than 6 months off work, where the worker was able to resume full duties.</td>
</tr>
<tr>
<td>Partial incapacity</td>
<td>Five days or more off work and return to work on reduced duties or lower income</td>
<td>A work-related injury or illness which results in the worker returning to work more than 6 months after first leaving work.</td>
</tr>
<tr>
<td>Full incapacity</td>
<td>Permanently incapacitated with no return to work</td>
<td>A work-related injury or disease, which results in the individual being permanently unable to return to work</td>
</tr>
<tr>
<td>Fatality</td>
<td>Fatality</td>
<td>A work-related injury or disease, which results in death.</td>
</tr>
</tbody>
</table>

Using this methodology, the average cost associated with each severity category can be determined as shown in Table 2. Interested readers may refer to the “The cost of work-related injury and illness for Australian employers, workers and the community: 2005-06” for details. Under the ASCC approach, the cost of construction incidents and injuries in 2005-06 borne by employers, workers and the community ranges from AUD$3,372 for short absence injury to AUD$1,689,193 for full or permanent incapacity. It is noteworthy that the cost for full incapacity injury is higher than fatality incident since more on-going costs will be exposed to the employers, workers and the community after the occurrence of a permanent incapacity incidence. In addition, the results summarized in Table 2 is based on the statistics of the year 2005-06, while the costs of construction incidents in the year 2006-09 should also be available since the project under study was all developed after the year 2006. To solve this problem, a discount rate of 3.9 per cent was employed to calculate the future costs for the following years. This discount rate was also used in the ASCC methodology for discounting future monetary values of new cases for the reference year.
Table 2: Summary of average cost associated with each severity category from 2005 to 2009

<table>
<thead>
<tr>
<th>Cost of reference year</th>
<th>Short absence</th>
<th>Long absence</th>
<th>Partial incapacity</th>
<th>Full incapacity</th>
<th>Fatality</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005-2006</td>
<td>3,344</td>
<td>35,638</td>
<td>260,672</td>
<td>1,686,819</td>
<td>1,571,529</td>
</tr>
<tr>
<td>Employer</td>
<td>2,460</td>
<td>5,297</td>
<td>55,100</td>
<td>74,180</td>
<td>54,694</td>
</tr>
<tr>
<td>Worker</td>
<td>337</td>
<td>5,326</td>
<td>61,090</td>
<td>1,065,853</td>
<td>1,048,473</td>
</tr>
<tr>
<td>Community</td>
<td>547</td>
<td>25,015</td>
<td>144,482</td>
<td>546,786</td>
<td>468,362</td>
</tr>
<tr>
<td>2006-2007</td>
<td>3,474</td>
<td>37,028</td>
<td>270,838</td>
<td>1,752,605</td>
<td>1,632,819</td>
</tr>
<tr>
<td>2007-2008</td>
<td>3,610</td>
<td>38,472</td>
<td>281,401</td>
<td>1,820,957</td>
<td>1,696,499</td>
</tr>
<tr>
<td>2008-2009</td>
<td>3,751</td>
<td>39,972</td>
<td>292,376</td>
<td>1,891,974</td>
<td>1,762,662</td>
</tr>
</tbody>
</table>

1 The discount rate used to estimate the costs from the year 2006 to 2009 is 3.9 per cent per year.

2.2 Investment in Safety Risk Management

Safety investment often refers to those costs of accident prevention activities, which aim to protecting the health and physical integrity of workers and the material assets of a contractor (Tang et al. 1997). The components of safety investments have been discussed in many previous studies, such as training, drug testing, safety incentives, staffing for safety, personal protective equipments, safety facilities, safety programs, etc (Laufer 1987, Brody et al. 1990, Tang et al. 1997, and Hinze 2000). Feng (2009) summaries the components of safety investments and classifies them into six main categories, which together with their sub-categories are demonstrated in Figure 1. In our study, the Safety Investment Ratio (SIR) was used to enable the comparison of the level of safety investment among projects of different sizes and scopes (Feng 2009). The SIR is therefore defined as follows:

\[
SIR = \frac{\text{Total Safety Investment}}{\text{Contract Sum of Project}} \times 100\% \quad (2)
\]

Where the total safety investment is the sum of safety investment components listed in Figure 2, and the contract sum refers to the total budget of the project.
3. The proposed ROI model

Based on the literature review, the specific model for calculating the return on investment of construction safety management system is illustrated as Figure 3. The step-by-step process of the ROI model is described in the following sections:

**Step 1 – Calculating the cost of construction incidents**

This step is critical to the research because accident cost is the key data to calculate the benefit – savings amount from improvement of safety performance. Therefore, a comprehensive and accurate methodology is essential for analyzing the ROI. The ‘incidence approach’ and ‘ex-post approach’ which have been used in an Australia Government report (ASCC 2009 and NOHSC 2004) are applied in this study to calculate the accident cost. A serious of data is needed at this step, such as the number of incidents under different severity categories, staff training and/or retraining costs and durations, medical and rehabilitation costs, investigation costs, etc. The calculation processes will not be given in this paper, interested readers may refer to the full report for details.
Figure 3: ROI Model proposed by this study

**Aspect 1: Measuring the cost of construction incidents and calculating the value of benefits**

**Methodology:**
- ASCC (2009) and NOHSC (2004) methodology
- Calculating the savings due to improvement on safety performance and reduction of accident rates

**Required Data:**
- Participant company’s estimation of the construction accident costs;
- Detail of project information, such as number of workers on site, total working hours, average wages, etc.; Industry average level of incident & injury rate, etc.

**Aspect 2: Measuring the cost (investment) of SMS**

**Methodology:**
- Compare the investment in SMS of project with the investment level of the industry average

**Required Data:**
- The monetary value of different safety investment components;
- Expenses on SMS of the industry average level, etc.

\[
ROI = \frac{\text{Gross Savings} \times \text{Efficiency Indicator} - \text{Extra Investment}}{\text{Extra Investment}} \times 100\%
\]

**Step 2 – Calculating the benefit (ie savings) of SRMS**

This step is the core element of the study, because convincing benefits can prove the significance and necessity of safety management that accident prevention is not a non-returnable investment, but has huge impact on people and company finance. For construction companies with a systematic and better safety management system, the prior inputs into safety management seems much more expensive than their competitors, but once the benefits are calculated in monetary value, one can see how much economic benefits can be generated through an effective safety system. Direct benefit of SMS can be defined as the savings on costs of no incidents; those can be calculated through comparing the accident rates of target project with national or industry indicators, then multiplying the difference with the cost per accident or with workers’ hourly wage. On the other hand, the direct benefit can also be reflected by the savings on working hours of the project compared to the industry average. The
monetary value of savings on hours of no accident can be measured by multiplying the saving on hours with worker’s hourly wage.

**Step 3 – Measuring the extra cost (ie investment) of SRMS**

In this study, the investment in certain SMS will be compared with the safety investment of the Industry Average level to examine whether higher safety investment can bring economic benefit to the project. According to the literature review, the components of safety investment can be grouped into six categories, including safety staff costs, safety training costs, safety equipments and facilities costs, safety committee costs, safety promotion and incentive costs, and costs of new technologies, methods or tools designed for safety.

Based on the three aspects discussed above, the ROI of SMS can be calculated through a simple mathematical process using the results from previous steps that related to the monetary value of costs and benefits. The final form of the ROI calculation formula is demonstrated in Table 3.

**Table 3: The ROI calculation formula: definitions and description**

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ROI_c</strong></td>
<td>This ROI calculation reflects whether a higher investment in health and safety can achieve the target of safety improvement, and bring economic benefits to the project performance.</td>
</tr>
<tr>
<td>IASP_i</td>
<td>Industry Average Accident Level under Severity i for Standard Project: According to NDS2, the severity of construction accident is classified into five categories. So IASP_i is the number of incidents under certain severity of a standard project, it reflects the accident level of the industry average.</td>
</tr>
<tr>
<td>NAPP_i</td>
<td>Number of Incidents under Severity i for Particular Project: NAPP_i is the number of incidents under certain severity that actually occurred on construction site.</td>
</tr>
<tr>
<td>IC_i</td>
<td>Incident Cost: ACi refers to the cost of construction accident under certain severity category. It includes those burdened by workers, employees and the community</td>
</tr>
<tr>
<td>IHSSP</td>
<td>Investment in Health &amp; Safety for Standard Project: IHSSP is the amount of expenses on SMS for a standard project. It reflects the inputs in health and safety measures of the industry average level.</td>
</tr>
<tr>
<td>IHSPP</td>
<td>Investment in Health &amp; Safety for Particular Project: IHSPP is the amount of expenses on SMS for a particular project. It reflects company’s inputs in health and safety for certain project.</td>
</tr>
</tbody>
</table>
4. Case Study

To verify the ROI model proposed in above sector, a case study of a Medical Research Centre (MRC) project will be utilized. The MRC project is developed by General Construction Company (GCC) (For confidential consideration, the names are fictional, but the company and the project are real). GCC is one of the world’s leading project management and construction companies with the headquarter located in Australia. In 2002 GCC introduced a safety management system which focuses on the current safety program, improves performance and addresses what is missing on the human and cultural side of the equation for the company to a safe workplace. This SMS has been implemented to all GCC projects across the country, including the MRC project. The project under study is owned by a large university in Australia.

Site-work of the MRC project commenced in November 2007 and the construction period lasted for about 30 months. The total project investment was approx 100 million of which 3.02% was input into safety management, which is much higher than the industry average of 2.0%. At first, its focus was to increase the initial costs of projects because of higher safety management investment, assumed and accepted by the client (university). However, under an effective safety management system, it was possible to see how, on this huge site, accident would not occur that might unfortunately occur in similar projects. The basic information of the MRI project is illustrated in Table 4; the statistics of Australia construction industry of the reference year is listed in Table 5; the comparison of statistics of safety performance between the MRC and the Industry Average is demonstrated in Table 6.

Table 4: Basic information of the MRC project

<table>
<thead>
<tr>
<th>Project name</th>
<th>Medical Research Centre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project location</td>
<td>New South Wales</td>
</tr>
<tr>
<td>Construction period (months)</td>
<td>30</td>
</tr>
<tr>
<td>Total project investment (AUD$ million)</td>
<td>100</td>
</tr>
<tr>
<td>Safety Investment Ratio (SIR, as a% of total project budget)</td>
<td>3.02</td>
</tr>
<tr>
<td>Total hours worked on this project (hrs)</td>
<td>711,192</td>
</tr>
</tbody>
</table>

Table 5: Statistics of incidents, injuries and fatalities of construction industry in Australia (2007-2009)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Short absence</strong>¹</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of claims</td>
<td>5454</td>
<td>5520</td>
<td>5487</td>
</tr>
<tr>
<td>Frequency rate</td>
<td>16.4</td>
<td>13.1</td>
<td>14.75</td>
</tr>
<tr>
<td><strong>Long absence</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of claims</td>
<td>11560</td>
<td>11709</td>
<td>11634.5</td>
</tr>
<tr>
<td>Frequency rate</td>
<td>8.6</td>
<td>7.9</td>
<td>8.25</td>
</tr>
<tr>
<td><strong>Partial incapacity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of claims</td>
<td>1730</td>
<td>1838</td>
<td>1784</td>
</tr>
<tr>
<td>Frequency rate</td>
<td>1.3</td>
<td>1.2</td>
<td>1.25</td>
</tr>
<tr>
<td><strong>Full</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of claims</td>
<td>1115</td>
<td>1133</td>
<td>1124</td>
</tr>
</tbody>
</table>

¹ Short absence: Number of claims, Frequency rate
The data for short absence injuries is based on the statistics of NSW rather than the national scope, because in Australia, Jurisdictions have different excess period where the costs of injury/disease are paid during the excess period before compensation from insurers is kicks off. Since the project under study is located in NSW, the statistics of NSW were selected for data analyzing.

Frequency rates of occupational injuries and diseases is the number of cases expressed as a rate per 1 million hours worked by employees. Such rates are calculated using the following formula:

\[
\text{Frequency rate} = \frac{\text{number of occupational injury and disease cases} \times 1,000,000}{\text{number of hours worked}}
\]

Frequency rate for fatal incident is based on per 100 million hours worked by employees.

(Source: The Safe Work Australia Online Statistics Interactive National Workers' Compensation Statistics Databases)

### Table 6: Comparison of statistics of safety performance between MRC project and Industry Average

<table>
<thead>
<tr>
<th>Number of incidents &amp; injuries</th>
<th>MRC</th>
<th>Industry Average</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>First aid injury</td>
<td>50</td>
<td>Unavailable info</td>
<td>-</td>
</tr>
<tr>
<td>Short absence</td>
<td>2</td>
<td>9.28</td>
<td>7.28</td>
</tr>
<tr>
<td>Long absence</td>
<td>1</td>
<td>5.87</td>
<td>4.87</td>
</tr>
<tr>
<td>Partial incapacity</td>
<td>0</td>
<td>0.89</td>
<td>0.89</td>
</tr>
<tr>
<td>Full incapacity</td>
<td>0</td>
<td>0.53</td>
<td>0.53</td>
</tr>
<tr>
<td>Fatality</td>
<td>0</td>
<td>0.02</td>
<td>0.02</td>
</tr>
</tbody>
</table>

In Table 6, the number of claims for the Industry Average (IA) is estimated based on the statistics in Table 5 using the following steps: (1) take the number of ‘long absence’ as an example, the project duration for the SPI1 was from FY 2007-08 to FY 2008-09, hence the frequency rate (FR) of this incidents should be the average frequency rate of these two financial years:

\[
\text{FR of long absence for IA} = \frac{8.6 + 7.9}{2} = 8.26
\]

(2) Once the frequency rate is fixed, the number of claims can be measured using the following equation:

\[
\text{No. of long absence} = \frac{\text{FR of long absence} \times \text{hrs worked}}{1,000,000 \text{ hrs}} = \frac{8.26 \times 711,192 \text{ hrs}}{1,000,000 \text{ hrs}} = 5.87
\]

Once the difference in number of incidents and the cost of relevant incidents are determined, the savings on reduced number of incidents can be therefore calculated. The calculation processes of the
savings for the MRC project are demonstrated in Table 7. For this project, approx AUD$1.5 million can be saved from a better safety performance compare to the Industry Average.

Table 7: Calculation of savings on account of no incidents of the MRC project

<table>
<thead>
<tr>
<th>MRC</th>
<th>Short absence</th>
<th>Long absence</th>
<th>Partially incapacity</th>
<th>Full incapacity</th>
<th>Fatality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Difference in safety performance</td>
<td>7.28</td>
<td>4.87</td>
<td>0.89</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>Costs of incidents (AUD$)</td>
<td>3,681</td>
<td>39,222</td>
<td>286,889</td>
<td>1,856,466</td>
</tr>
<tr>
<td></td>
<td>Savings on each severity (AUD$)</td>
<td>26,794</td>
<td>191,011</td>
<td>255,331</td>
<td>983,927</td>
</tr>
<tr>
<td></td>
<td>Saving of no incidents (AUD$)</td>
<td>1,491,654</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In terms of safety investment, data of the relevant components summarized in Figure 1 were collected from GCC. For the MRC project, the total inputs for safety management was AUD$3,021,126. With a total project budget of AUD$100 million, the SIR for this project is estimated to be 3.02% (total safety investment divided by project budget). In terms of safety investment of the Industry Average, a SIR of 2% of the total project budget will be assigned to the Industry Average. Therefore the extra safety investment of the MRC project can be calculated as follows:

\[
\text{Extra Safety Investment} = \text{AUD$3,021,126} - \text{AUD$100 million} 	imes 2\% = \text{AUD$1,921,126}
\]

Through the above data collection and calculation processes, the return on safety investment can be calculated using simple mathematical equation as follows:

\[
\frac{\text{Savings of no incidents} - \text{Extra Safety Investment}}{\text{Extra Safety Investment}} \times 100\% = \frac{1,491,654 - 1,921,126}{1,921,126} \times 100\% = 24.08\%
\]

5. Discussions

5.1 The case studied

From this ROI calculation, we can see that although the safety investment ratio (3.02%) for the MRC project was much higher than the Industry Average (2.0%), the MRC project has also achieved a better safety performance than the Industry Average. With a higher safety investment, approx AUD$1.5 million can be saved from the reduced number of construction incidents, which could generate a return on safety investment of 46.08%. It should be noted that the figures of ‘difference in safety performance’ in Tables 6 and 7 were not rounded to integers, such as the number of fatal incident for Project 1 was estimated to be 0.02, which could not happen in real life. However, it is still considered reasonable to keep those numbers which are less than one (incident) because: (1) although the data collection and analyzing were based on single project, the comparison study was however designed to analyze the entire industry and the results reflect the safety performance under different safety investment levels of the industry rather than single project; (2), besides comparing the number of claims of incidents, an alternative way of comparing the safety performance is to measure the lost days (or hours) between the GCC projects and Industry Average, hence the figures listed in Table 6 and 7 can be also converted into lost days (or hours) and keeping the fraction will make the results more accurate.
more convincing and accurate, and (3) the difference in safety performance can be also considered as a reflection of the probabilities of occurrence of incidents.

5.2 Limitation and recommendations for future study

The main limitation of this research is the exclusion of intangible benefits. For many reasons, the intangible benefits are often very difficult to be measured in monetary value in many industries. In terms of construction sector, intangible benefits of safety investment may include, but not limited to, worker’s motivation, client’s satisfaction, company’s market share, image and reputation, etc. So far there are still few systematic methodologies that are able to measure the intangible benefits subjectively, which is also an important limitation faced by this research. In general, the value of intangible benefit is often considered to be much larger than the tangible benefits, hence the overall benefits will be much more significant if the value of intangibles can be calculated.

Further work can be done to replicate this research on a larger scale. For example, future studies can involve more projects from the same company. The ROI model proposed in this paper can be also used as a self-assessment tool within a company to determine the success of a SMS by comparing the safety performance before and after the implementation of a SMS. In general, the more construction projects get involved, the more accurate the research result will be. In addition, the model developed in this study can be also utilized to compare the ROI of safety investment of different construction companies. Replication of this research on a larger scale will allow researchers to assess the generalisability of the findings across the construction industry to have a better understand of safety investment.

6. Conclusion

With the development of the construction industry, the significance of safety risk management has been realized my project stakeholders. Governments, scholars, and industry players have put lots of commitment into safety risk management, developing guidelines, tools and systems to prevent incidents and injuries. However, the high prior expenses on safety management often place conflicts with traditional project objective by increasing tendering prices. Meanwhile, many previous studies were focused on the input stage (investment and management) of SRMS rather than the output stage (safety performance), some of which analyzed the costs of incidents and injuries but didn’t link the incident costs with benefits. Hence inputing resources into safety are often considered as a non-returnable investment.

The focus of this research is on the return on investment (ROI) of the safety risk management system of construction projects. The main research findings of this study can be concluded as follows: first, a quantitative method has been developed to measure the ROI of safety management system, which provides an innovative and objective way to prove the important of safety management in construction projects; second, the high costs of construction incidents – especially full incapacity and fatality – will largely impact the financial performance of construction projects that reducing the number of claims will bring huge savings to the project; third, under an effective SMS, the increasing expenses on safety management will be covered by the savings from no incidents.
The ROI model proposed in this paper was verified by a case study of a Medical Research Center projected developed by General Construction Company. Using the methodology of the ROI model, the safety investment of this MRC project has achieved an ROI of 46.08%, which proves that increasing investment in SRMS can bring economic benefits to the construction project. The significance of this study is that it provides a good example of measuring the benefits of safety investment using quantitative approaches. The data analysing of this study was based on the actual statistics collected from relevant database rather than traditional methods such as questionnaire survey and interview, which guarantees the objectiveness and accuracy of data analysing and research findings. On the other hand, the way of data collection and analysing has also provides a good example for the collaboration between university and industry company. One of the departure points for this study is that the industry company (such as GCC) was urgently searching for a way to evaluate the performance of their safety management system, hence the collaboration agreement has given the advantage that the researchers had more accessory to the data which may not be acquired from other sources.

References


Occupational Health and Safety Research Institute, (2007), Analysis of the profitability of investment in accident prevention on construction sites.


Sharing Construction Safety Knowledge through Social Networks

Fang, D.
Department of Construction Management, School of Civil Engineering, Tsinghua University
(email: fangdp@tsinghua.edu.cn)

Huang, J.
Department of Construction Management, School of Civil Engineering, Tsinghua University
(email: huangjixin@tsinghua.org.cn)

Fong, P. S.W.
Department of Building & Real Estate, the Hong Kong Polytechnic University
(email: bspafong@polyu.edu.hk)

Abstract

Construction employees’ lack of safety knowledge is one of the most important reasons for the high accident rate in the construction industry. Research into safety knowledge sharing through social networks is crucial because social networks are a significant vehicle for the transfer of knowledge. This study discusses what kinds of employees are usually consulted by others separately on safety knowledge, and how safety knowledge is transferred among employees in different positions on construction sites in order to use specific measures to improve construction safety knowledge sharing. This study adopted the name-nominated method to design the questionnaire, and investigated 267 employees on 24 construction sites in the Chinese mainland. The logistic regression and frequency analysis methods were used to analyze how construction employees selected ten types of social relations as the objects of their safety knowledge sharing; these included family, friends, colleagues, former classmates, and so on. The study also discusses the effects of different age, work type, education and tenure on employees’ choice of safety knowledge sharing objects. Safety knowledge sharing networks based on job position on the construction site are described, and finally, the study further discusses the above findings from both theory and comparison aspects. The results of this study led us to the conclusion that “masters” and gangmasters should play a more important role in safety knowledge sharing, that less educated and low-tenure employees prefer to put safety-related questions to their supervisors, and that the education factor is more critical than tenure. The study also puts forward some suggestions to improve the safety knowledge sharing of construction employees, including strengthening the safety responsibility and knowledge level of “masters” and gangmasters, and enhancing the provision of supervisors’ safety education to novice and less educated employees.

Keywords: construction safety, construction site, gangmaster, master, demographic character
1. Introduction

Construction safety is a major issue worldwide, and the large number of construction-related accidents and unsafe incidents causes considerable damage in many societies every year. Many investigations have shown that employees’ lack of safety knowledge is a critical reason for the high accident rate in the construction industry (Huang 2001; Jiang 2002; Chua and Goh 2004; Hadikusumo and Rowlinson 2004). Therefore, improving employees’ safety knowledge would be a significant way to enhance construction safety.

Currently, safety training is the main channel to improve construction safety knowledge. However, there are many kinds of tacit knowledge in the construction industry (Fong and Chu 2006). Knowledge can be divided into explicit and tacit knowledge, and tacit knowledge is nonstandard, difficult to express in language, and can only be easily understood through thinking and practice. Current safety training is untimely, passive, limited by the environment and works against the transfer of tacit knowledge (Jiang 2002). A study on safety knowledge sharing in social networks is therefore greatly needed because the social network (whereby employees and all their social relations form a solid network) is an effective means of transferring tacit knowledge (Nahapiet and Ghoshal 1998; Hansen 1999; Ipe 2003).

Until now, no articles studying the impact of social networks on safety knowledge sharing in the construction industry have been found, and many studies have only focused on general knowledge with regard to social networks, without thinking about them in connection to safety knowledge in the construction industry. For example, Chay et al. (2005) indicate that trust between two persons and differences in language and gender can affect knowledge sharing to a great extent. Dan (2003) shows that reward, team spirit, a culture of trust and leaders’ behavior affect knowledge sharing. Brass (1995) considered that the similarity-attraction paradigm is an important theory of knowledge sharing which can make employees’ sharing of knowledge much easier, and this has been shown in aspects of education, age, gender, reputation, job, and so on. In addition, Allen (1977) found that the distance between two employees’ desks influences the probability of their sharing knowledge, the distance of 6 feet making it 4 times more likely than when the distance is 60 feet. In other words, Allen indicates that the shorter the distance between two employees’ desks, the higher the probability of sharing knowledge. Elzarka et al. (1999) indicated that many of the safety standards and regulations for construction activities are vague, ambiguous, and inconsistently categorized. At the same time, safety knowledge and experience gained by a company’s personnel is not utilized in an organized and efficient manner. Sharing of knowledge and experience from past projects will improve the performance of current and future projects.

2. Research Methodology

Based on a literature review and expert interviews, this study investigates ten types of construction employees: project managers, engineers, safety officers, foremen, electricians, welders, mechanicians, scaffolders, woodworkers, and masons, who all have a close relationship with or considerable influence on construction safety.
The concepts of foreman, engineer and gangmaster are often confused in the Chinese contexts. Even employees with same title very often do different work on different construction sites. Aiming for accurate selection of the objects for investigation, and to make sure these concepts are easily understood in cultures different from the Chinese construction industry, this study defines these three positions as follows.

1. An engineer is an employee who mainly does interior technical work in construction projects, including compiling construction organizational design, resolving technical problems in the process of construction, filling out records of techniques, and so on.

2. A foreman is a special kind of engineer. They take charge of the organizing and constructing of part-to-item work. A foreman’s main responsibility includes leading in terms of technique, quality, schedule and safety in the construction process of professional work; following the project manager’s orders in professional work; taking account of the work completed; and so on.

3. In China, a gangmaster is an employer or agency providing laborers for construction projects, and his main work includes taking primary charge of the technique, quality, schedule and safety of his group’s work; managing his group workers; tracking his group workers’ work; explaining safety techniques to his group workers; and so on.

The name-nominated method was employed in this study to ask a core question: To whom would you turn if you encountered a construction safety problem in your work? Respondents were asked to choose two people and write down these two individuals’ job titles and their most important relationship (choosing from family, relative, good friend, friend, colleague, supervisor, subordinate, master, townee and classmate). The frequency analysis method was employed to study the selection information of all the relationships, and the logistic regression method was used to find the main factors. Lastly, this study adopted the Graphic-Method of social network to display safety knowledge sharing network based on job position on the construction site.

About thirty students from the author’s University helped to conduct this questionnaire investigation, and many of the questionnaires were filled in via face-to-face interviews because many of the workers had insufficient education to be able to fully understand the questionnaire. The study involved sending out 330 questionnaires to 27 construction sites in Beijing; copies were returned by 267 respondents, including 21 project managers, 23 engineers, 24 safety officers, 21 foremen, 25 gangmasters, 28 electricians, 26 welders, 22 mechanicians, 29 scaffolders, 28 wood workers and 20 masons. The collected information has been processed and findings are discussed in the sections below.
3. Distribution of safety knowledge sharing objects of construction employees

In the Chinese mainland, the people consulted for safety knowledge are mainly construction workers’ supervisors and colleagues; the former represent 38% of all the people being consulted, and the latter account for 29%. At the same time, the proportions of master, townee and classmate among all the people consulted are 2%, 2% and 0.4% respectively (Figure 1).

Figure 1: Distribution of people consulted by construction employees for safety knowledge

This study further analyzed the distributions of the different types of people consulted according to work type, age, education and tenure (from Figures 2 to 5).

Figure 2: Comparison between workers and managers on people consulted for safety knowledge
Figure 3: Comparison between young and old employees on people consulted for safety knowledge

Figure 4: Comparison between more and less educated employees on people consulted for safety knowledge
Figure 5: Comparison between new and senior employees on people consulted for safety knowledge

The findings show that:

1. Managers are more likely than workers to be selected by colleagues as consulting objects.

2. Younger employees are more likely than older ones to select their supervisors as consulting objects. At the same time, older employees are more likely than younger ones to select colleagues as consulting objects.

3. Supervisors are more frequently selected as consulting objects by less educated employees than by more educated ones. However, colleagues are less frequently selected by less educated employees than by more educated ones.

4. Supervisors are selected as consulting objects by new more often than by senior employees. At the same time, new employees select colleagues as consulting objects less than senior employees do.

From the above, we know that the construction employees’ demographic factors, e.g. age, education and tenure, separately affect the selection of their consulting objects for safety knowledge. However, because young, less educated and new employees all prefer to consult their supervisors with regard to safety knowledge, this study further adopts the logistic regression method to assess the degree of influence of these factors (Tables 1 and 2).
Table 1: Logistic regression of the supervisor as a dependent variable

<table>
<thead>
<tr>
<th>Step 1(a)</th>
<th>B</th>
<th>S.E.</th>
<th>Wald</th>
<th>df</th>
<th>Sig.</th>
<th>Exp(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>-.346</td>
<td>.133</td>
<td>6.795</td>
<td>1</td>
<td>.009</td>
<td>.707</td>
</tr>
<tr>
<td>Constant</td>
<td>.419</td>
<td>.370</td>
<td>1.283</td>
<td>1</td>
<td>.257</td>
<td>1.520</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step 2(b)</th>
<th>B</th>
<th>S.E.</th>
<th>Wald</th>
<th>df</th>
<th>Sig.</th>
<th>Exp(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>-.348</td>
<td>.132</td>
<td>6.948</td>
<td>1</td>
<td>.008</td>
<td>.706</td>
</tr>
<tr>
<td>Tenure</td>
<td>-.055</td>
<td>.022</td>
<td>5.963</td>
<td>1</td>
<td>.015</td>
<td>.947</td>
</tr>
<tr>
<td>Constant</td>
<td>.860</td>
<td>.413</td>
<td>4.343</td>
<td>1</td>
<td>.037</td>
<td>2.364</td>
</tr>
</tbody>
</table>

Table 2: Logistic regression of the colleague relationship as a dependent variable

<table>
<thead>
<tr>
<th>Step 1(a)</th>
<th>B</th>
<th>S.E.</th>
<th>Wald</th>
<th>df</th>
<th>Sig.</th>
<th>Exp(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work type</td>
<td>-.878</td>
<td>.290</td>
<td>9.161</td>
<td>1</td>
<td>.002</td>
<td>.415</td>
</tr>
<tr>
<td>Constant</td>
<td>-.483</td>
<td>.209</td>
<td>5.349</td>
<td>1</td>
<td>.021</td>
<td>.617</td>
</tr>
</tbody>
</table>

The following results are obtained from Tables 1 and 2.

1. The education and tenure of construction employees have a negative influence on their selection of supervisors as consulting objects with regard to safety knowledge. This is to say, less educated and low-tenure employees clearly prefer to ask their supervisors for safety knowledge, and other factors have no obvious influence.

2. The work type of construction employees has an obvious influence on the likelihood of their selection of colleagues as consulting objects regarding safety knowledge. This means that colleagues are selected as consulting objects considerably more by managers than workers.

4. Safety knowledge consulting networks in construction projects

It has been shown that work relations come before all others as consulting objects in the construction industry. Aiming to reveal a more accurate picture of safety knowledge sharing in the construction industry, this study further explores safety knowledge sharing networks based on job positions.

The job positions of interviewees and their consulting objects were ascertained through the name-nominated method in the questionnaire, and a safety knowledge sharing network was then drawn up. Because the job positions selected by interviewees were too many to show in the figure, this study uses the cluster analysis method to divide all job positions into major and minor kinds, and only the major kind of job position is shown in Figure 6. However, some minor job position selections are necessary and significant, so they were plotted as dashed lines. In addition, “project manager” in Figure 6 includes project managers, deputy project managers and project safety managers.
The arrows in Figure 6 denote the direction of consulting behavior with regard to safety knowledge, and the percentages close to the arrows mean the proportion of that kind of consulting object in relation to all the consulting objects of a specific job position of interviewees. The percentages under job positions refer to the proportion of that type of interviewee selecting the same type of employee as a consulting object.

Figure 6: Safety knowledge consulting network based on job position in a construction project

The following results are obtained from Figure 6:

1. The safety officer is the most important consulting object of all the job positions. The proportions of wood workers, scaffolders, mechanics, welders, electricians and masons who would consult a safety officer are 19.5%, 20.5%, 23.9%, 18.7%, 15.5%, and 13.6% respectively. Also, the proportions of project managers, engineers, foremen and safety officers who would consult a safety officer on safety knowledge are 21.3%, 21.9%, 30.9% and 24.4% respectively.

2. The foreman is also a very important job position in terms of safety knowledge, and foremen are consulted by most workers. The proportions of wood workers, scaffolders, mechanics, welders, electricians and masons who consulted their foremen are 14.7%, 19.2%, 20.7%, 26.4%, 17.9% and 18.4% respectively.

3. A project manager is critical in the whole safety knowledge consulting network, and safety officers, engineers, foremen and project managers often consult project managers, in the following proportions: 34.1%, 23.5%, 24.0%, and 30.0% respectively.
4. Gangmasters are seldom consulted by construction employees, with proportions between 1% and 7% for all job positions, which is far below the frequencies of consulting foremen and safety officers.

5. Discussion

Given the above characteristics and the phenomenon of safety knowledge sharing in the Chinese construction industry, the study now discusses the reasons and measures.

5.1 Demographic factors clearly affect the selection of consulting object

Whether demographic factors influence the selection of knowledge sharing objects has been discussed in previous studies. Tang (2000) indicated that the job, tenure and age of employees in the finance industry have positive relations with knowledge sharing attitude (Tang 2000). Xiahou (2000) found that junior and young employees in the finance industry usually have lower motivation with regard to knowledge sharing (Xiahou 2000). In contrast, Liu’s (2002) research showed that the gender, age, education and marital status of employees in the tourism industry have no relationship with knowledge sharing (Liu 2002). Cross et al.’s (2001) investigation in the US also revealed that age, education, and tenure of employees affected the selection of consulting objects (Cross et al. 2001).

This study found that while the education and tenure of employees in the construction industry have an obvious influence on their selection of their supervisors as consulting objects in terms of safety knowledge, work type and age do not. In contrast, the work types of employees have an obvious influence on selecting their colleagues as consulting objects, but education, age and tenure do not.

From the above research, there are two problems which have to be discussed. The first is why different research has yielded different results on the same scientific problem? There may be two reasons for this, one being that the research objects were in different industries, and different industries’ cultures will affect knowledge sharing behavior. In addition, construction is a project-based industry, in which people who work on one project may not see each other again in other projects. This influences who you can consult on a project. The other possible reason is that Cross et al. (2001), Xiahou (2000), etc. did not consider the characteristics of knowledge sharing objects, which actually prove to have great influence on the selection of knowledge sharing objects. The second problem is related to why work types, education and tenure have an influence on the sharing objects of safety knowledge in this study. The reason may be that new employees are not familiar with their colleagues, and supervisors are seen as having more authority and experience than others. Highly educated employees have higher status in a project and therefore feel more confident than less educated employees. Construction workers in China are mostly farm workers who regard their kin relationships and geographical affinities much more highly than managers, so it is understandable that they consult their colleagues much less than managers. Based on the above discussion, some suggestions can be made to improve safety knowledge sharing, such as by strengthening supervisors’
responsibilities for safety training for new and less educated employees, and reinforcing team training for workers.

**5.2 Gangmasters should play an important role in safety knowledge sharing**

The work and safety management system is shown in Figure 7, in which the solid line means work affiliation and the broken line means safety supervision relationship.

![Figure 7: Work and safety management system in construction projects in China](image)

From Figure 7, it can be seen that gangmasters are of great importance and directly command workers. Usually, a construction company needs a gangmaster’s support to manage workers (Hao 2006). Generally, employees ask their supervisors if they have work-related questions, but this study found that workers seldom consult their gangmasters about safety knowledge. There may be two reasons for this, one being that gangmasters have a low level of professional knowledge and lack safety knowledge (Huang 2001), the other being that a gangmaster is a labor contractor or agent of the labor contractor who is the workers’ employer, and thus has a tensional relationship with them.

As a result, this study tentatively puts forward some suggestions, including emphasizing the gangmasters’ safety responsibilities in labor subcontracting, increasing safety training for gangmasters, and inviting gangmasters’ involvement in safety meetings and the designing of safety plans.

**6. Conclusion**

The main conclusions to be drawn from this study are as follows:

1. Demographic factors obviously affect the selection of consulting objects. More specifically, the education and tenure of employees in the construction industry have an obvious influence on the
The selection of supervisors as consulting objects with regard to safety knowledge, but work type and age factors do not. The work type of an employee has an obvious influence on whether or not they select their colleagues as consulting objects, but education, age and tenure do not.

2. The project manager is crucial in the whole safety knowledge consulting network, and is mostly selected as a consulting object by middle managers in construction projects.

3. Gangmasters should play a more important role than before in safety knowledge sharing, since they are the direct employers of workers and thus have a great influence on their behavior. However, workers seldom consult their gangmasters on safety knowledge, so gangmasters’ effect on safety knowledge sharing should be reinforced.

7. Acknowledgement

Appreciations go to the Natural Science Foundation of Beijing (Grant No. 8072015), Natural Science Foundation of China (Grant No. 70172005 and 70572007) and National Science and Technology Planning Project (2006BAJ01B04-03) for their continuous supports.

References


Modelling the Dynamics of Safety on Construction Projects: an Undiscovered Rework Perspective

Irumba, R.
Makerere University, Uganda
(email: irumba@tech.mak.ac.ug)
Kerali, A.G.
Makerere University, Uganda
(email: agkerali@tech.mak.ac.ug)
Wilhelmsson, M.
Royal Institute of Technology, Sweden
(email: mats.wilhelmsson@abe.kth.se)

Abstract

Globally, the construction industry has a poor safety record. This paper is on understanding and modelling the dynamics of safety on construction projects. The methodology adapted was case-study research and system dynamics modelling of a hotel building complex in Wakiso District, Uganda. The case-study project recorded a major accident during the construction phase leading to death of eleven people and injuries of twenty six others. This accident was a result of design errors and poor construction practices. The scope of the developed safety model is restricted to the effects of undiscovered rework, schedule pressure and cost pressure on accident frequency. In this paper, the occurrence of accidents is hypothesised to depend on undiscovered rework (defined as the unnecessary effort of redoing a process or activity that is incorrectly implemented the first time). High levels of undiscovered rework lead to a high frequency of accidents on projects. The results of this study reveal that the time to detect rework is a possible safety policy parameter. By strengthening quality inspection of a project, faults are detected and corrected early enough before they lead to accidents. It was also observed that the tendency to accelerate projects can breed accidents on projects. Accelerated projects tend to experience high levels of unsatisfactory work compared to projects implemented following their planned schedule. From the management perspective, effective supervision of the design and construction process is recommended as the best strategy to avoid accidents. For further work, as a step towards developing a holistic view of safety, the model should be extended to capture the relationships between safety and equipment, safety and materials, and safety and labour.

Keywords: accident, construction industry, modelling, occupational safety and health, undiscovered rework.
1. Introduction

Construction is often identified as a high-risk industry and the reality is that the industry has injury and fatality statistics that make it one of the most dangerous industries in which to work (Rowlinson, 2004; Hinze, 2007). The construction process involves hazardous activities such as working at height, manual handling of equipment, exposure to harmful materials, structure demolitions, lifting operations, scaffolding, site clearance and earth works. Falls, contacts with electricity and accidents involving heavy equipment are the three foremost causes of occupation injuries in the construction sector (Mungen and Gurcanli, 2005). Other causes of accidents include collapse of earthwork, lifting of weights, toxic materials and suffocations, and fire and explosions, amongst others (Tam et al., 2003). Construction is also characterised by tight competition for contracts and site personnel are often under pressure to deliver work on schedule and within specific cost limits. Indeed, safety is often neglected.

In Uganda, there has been a proliferation of construction accidents in the recent past. Between 1996 and 1998 a total of 146 accidents were reported in the construction industry, 17 of which were fatal cases (Lubega et al., 2000). In relation to other industries, this translates into 31% of total industry accidents and 47% of the total industry fatality (see Table 1 and Table 2 for details).

**Table 1: Distribution of accidents per industry in Uganda (1996-1998)**

<table>
<thead>
<tr>
<th>Industry</th>
<th>1996</th>
<th>1997</th>
<th>1998</th>
<th>Total</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>39</td>
<td>68</td>
<td>43</td>
<td>150</td>
<td>50</td>
</tr>
<tr>
<td>Electricity, gas and water</td>
<td>20</td>
<td>19</td>
<td>10</td>
<td>49</td>
<td>17</td>
</tr>
<tr>
<td>Construction</td>
<td>46</td>
<td>49</td>
<td>51</td>
<td>146</td>
<td>49</td>
</tr>
<tr>
<td>Transport and Communication</td>
<td>0</td>
<td>6</td>
<td>2</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Government</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Mining and Quarry</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Commerce</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>18</td>
<td>6</td>
</tr>
<tr>
<td>Services</td>
<td>25</td>
<td>25</td>
<td>32</td>
<td>82</td>
<td>28</td>
</tr>
<tr>
<td>Total</td>
<td>151</td>
<td>174</td>
<td>151</td>
<td>476</td>
<td></td>
</tr>
</tbody>
</table>

Source: (Lubega et al., 2000:7)

**Table 2: Distribution of fatal accidents per industry in Uganda (1996-1998).**

<table>
<thead>
<tr>
<th>Industry</th>
<th>1996</th>
<th>1997</th>
<th>1998</th>
<th>Total</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Electricity, gas and water</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Construction</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>17</td>
<td>6</td>
</tr>
</tbody>
</table>
From 1999 to 2010, the trend of accidents occurrence has not changed with the construction industry continuing to witness fatal accidents over the period (see Table 3). The major causes of construction accidents in Uganda have been cited as inadequate site supervision, use of incompetent personnel, and use of inappropriate construction techniques (Lubega et al., 2000).

### Table 3: Examples of accidents on construction sites in Uganda (1999-2010).

<table>
<thead>
<tr>
<th>Date of Incident</th>
<th>Accident Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>26th January 2010</td>
<td>Collapse of an excavation for a commercial building on Plot 3, Luzwum Street, Kampala City killing two people and causing injuries to five others.</td>
</tr>
<tr>
<td>15th March 2009</td>
<td>Collapse of Mirembe shopping Arcade on Plot 5A, Nasser road, Kampala due to failure of an excavation at an adjacent foundation. Four people died and twenty were injured.</td>
</tr>
<tr>
<td>26th February 2009</td>
<td>Collapse of an excavation for a foundation on Plot 5, Snay Bin Amir Street, Kampala. One person died and five were injured.</td>
</tr>
<tr>
<td>14th October 2008</td>
<td>Collapse of an excavation for NSSF Pension Towers on Plots 15A, 15B and 17 on Lumumba Avenue, Kampala. Seven people died and two were injured.</td>
</tr>
<tr>
<td>30th January 2008</td>
<td>Collapse of a four-storey building at St. Peters S.S, Nalya, Wakiso District. Eleven people died and fifteen were injured.</td>
</tr>
<tr>
<td>16th Sept. 2007</td>
<td>Collapse of the USS one million perimeter wall fence under construction for Makerere University, Kampala. No injuries or fatalities were recorded.</td>
</tr>
<tr>
<td>20th Sept. 2006</td>
<td>Collapse of the building under construction for Tick Hotel, Kampala North killing two workers.</td>
</tr>
<tr>
<td>25th July 2006</td>
<td>The collapse of the walls of a trench to lay water pipes in Kansanga, Kampala, killing two workers of Sogea Satom construction firm.</td>
</tr>
<tr>
<td>8th March 2006</td>
<td>The collapse of a church building in Kalerwe, a suburb to the north of Kampala city, killing twenty people and injuring dozens of others.</td>
</tr>
<tr>
<td>21st October 2004</td>
<td>The collapse of a two-storey building at Seguku, Kajjansi, Entebbe road trapping more than five workers in its rubble. The crash left the building flat on the ground.</td>
</tr>
<tr>
<td>31st August 2004</td>
<td>The collapse of a building at the proposed site for the five star J &amp; M Airport Hotel Apartment and Leisure Centre at Bwebajja, Wakiso District killing 11 people and injuring 26 others.</td>
</tr>
<tr>
<td>24th August 2004</td>
<td>Collapse of a five storey building at Good Hope Nursery and Primary School in...</td>
</tr>
</tbody>
</table>
From the statistics and discussions above, it is evident that construction safety is a serious problem in Uganda as it is elsewhere. This paper is on understanding and modelling the dynamics of safety on construction projects based on a case-study of a failed hotel building complex in Uganda. In particular, the scope of the safety model discussed in this paper is restricted to the effects of undiscovered rework on safety. In the context of this paper, rework is defined as the unnecessary effort of redoing a process or activity that is incorrectly implemented the first time. Typically, rework is caused by errors made during the design and construction process.

Prior to studies by Love et al. (1999a, 1999b), it was generally accepted that rework is caused by uncertainty generated by poor information, which is often missing, unreliable, inaccurate, and conflicting. However, following studies by Love et al. (1999a, 1999b, 2000, 2002) and Love and Edwards (2004) rework is considered to be a consequence of numerous factors which can be categorised as technical, quality and human resource.

The technical factors include design errors, design changes, and construction errors originating from poor detailing and workmanship. Other technical factors that cause rework relate to poor quality of project documentation and the failure to follow building regulations. On the other hand, quality factors mainly relate to lack of quality assurance, lack of incentives and rewards and poor partnering relationships. Indeed, unpleasant relationships between designers and contractors inhibit the development of teamwork and joint problem solving and as a result design errors are more prevalent which may eventually result into structure failures and accidents during the construction stage.

Finally, the human resource factors relate to the support provided by the employee’s organisations so that they can perform their jobs effectively and productively. The important considerations are training, motivation and skill level. The main causes of rework resulting from poor skills are defective workmanship, disturbances in personnel planning, delays, alterations, failures in setting-out and coordination failures (Love et al., 1999a). In summary, the above technical, quality and human resource factors do not only lead to rework but equally compromise safety on construction sites.

2. Methodology

The methodology adapted was case-study research combined with system dynamics methodology. As noted by Yin (2003), case-study methodology investigates a phenomenon within its real-life context and this is particularly essential for safety research. Case-study research relies on multiple sources of
evidence and also benefits from prior theoretical prepositions (Yin, ibid.). The latter argument makes case-study research appropriate to system dynamics modelling which is based on the formulation of a dynamic hypothesis at the start of the modelling exercise. In this paper, the occurrence of accidents is hypothesised to depend on undiscovered rework. High levels of undiscovered rework lead to a high frequency of accidents on projects.

2.1 Case-Study Project:

The case-study project used in this paper was a failed hotel building complex in Busiro County, Wakiso District, Uganda. The choice of the hotel project as a case-study was largely due to its complexity in scope and design which made it suitable for system dynamics modelling. The hotel complex consisted of a high-rise apartment block, a hotel block, a queen’s suite, a swimming pool, cottages, a bar, an administration block, a health club, a conference centre and a shopping arcade. During construction, the apartment block which had reached third level suddenly collapsed (see Photos 1-2) resulting into the death of eleven workers and injuries to twenty-six others.


Following the accident, government appointed a nine-person technical committee to establish the cause of the accident. An investigation report by the committee revealed that the accident was largely due to lack of approved building plans and weak concrete columns (Mwakali, 2004). The columns were 50% of expected minimum size, had insufficient steel reinforcement which was less than 45% of the expected minimum steel and concrete was poorly mixed resulting into 30-78% of expected strength (Mwakali, ibid.).

Data collection included reviewing the project drawings to identify any design errors that could have resulted into failures. In addition to columns being undersize, five columns were omitted in the design and this greatly compromised the strength of the structure. There was also evidence of poor workmanship especially in the segregation of aggregates and honeycombing during the construction of columns (see Photos 3-4).
Through interaction with the Contractor and Wakiso District Engineering Office, project data including budgets, schedules and labour force was obtained. This data was used during the calibration of the developed model. Interviews were held with construction workers to gain insights into their skill levels and to study the safety practices on site before the accident occurred. It was observed that workers were not provided with basic safety gear and this contributed to the high incidence of fatalities and injuries which were registered when the building collapsed. Numerous variations were introduced without seeking approval by relevant departments as provided for by the laws governing the construction industry in Uganda.

Overall, based on the collected data, it was evident that the project was complex with magnificent architectural concepts and good investment ideas. However, the project was deprived of qualified consultants and contractors, and this contributed to its poor performance.

3. Model Formulation

3.1 Overview of the modelling process

Modelling is an iterative process, and the System Dynamics (SD) modelling process starts and ends with understanding the system and thus forms a loop. The essential stages of a typical SD modelling effort include problem definition, formulation of the dynamic hypothesis, formulation of the model, testing, and policy formulation and evaluation (Sterman, 2000).

The model presented in this paper builds on the classical project management model by Richardson and Pugh (1981). The classical model was formulated to address the problems of overruns in cost, time and personnel for large Research and Development (R&D) projects. Despite efforts by managers to avoid them, overruns in R&D projects persisted. This prompted Richardson and Pugh (1981) to develop a computer model to improve management of such projects in such a way as to eliminate or minimise overruns. Large R&D projects involve a sizeable number of people, a large number of detailed tasks and a relatively long time frame which are also characteristics of large-size construction projects. The model by Richardson and Pugh (1981) is largely hypothetical consisting of subsystems.
on workforce, scheduled time, project progress and rework. In this paper, the subsystem on safety is added and the model calibrated in a real world environment by taking a case-study of a hotel building complex in Uganda. The classical model developed in DYNAMO has now been implemented in POWERSIM STUDIO 8 software, an environment with advanced programming capabilities.

The formulation of the subsystem on safety is based on the dynamic hypothesis centred on the concept of undiscovered rework. The other causes of accidents that have been considered in this paper are the effects of schedule pressure and cost pressure on accidents frequency. Notably, high schedule and cost pressure increase the risk of accident occurrence. The occurrence of accidents is a measure of quality of practice on construction projects. Typically, the occurrence of accidents is an indicator that the design is defective and/or supervision of construction work is not effective enough to identify construction errors on time so that corrective actions are taken to avoid accidents.

3.2 Definition of terms used in causal loop diagrams

System Dynamics is an established body of knowledge with a common language of communication and for purposes of this paper, a number of terminologies require to be defined. These terminologies are stated below and mostly relate to feedback systems and causal loop diagrams.

Feedback systems:

Put succinctly, feedback is the transmission and return of information (Richardson and Pugh, 1981). Feedback systems characteristically form loops of interconnections (i.e. loops of causes and effects) and these interconnected sets of feedback loops define a feedback system (Richardson and Pugh, ibid.). In any system, all dynamics arise from the interaction of two types of feedback loops, positive (or self reinforcing) and negative (or balancing) loops.

Positive feedback loops (labelled as ‘R’ in Figure 2) tend to reinforce or amplify whatever is happening in the system. A typical example of positive feedback is the scenario of overwork observed on construction sites. Heavy assignments increase the backlog of work to do, causing anxiety to rise amongst workers and as a result making it more difficult for them to concentrate and complete any given task. The time it takes to complete a task rises and as a result the rate of completion of tasks slows down. Thus, the job backlog rises still further and so will anxiety and the inability to cope with tasks. Positive feedback loops usually make system behaviour to get worse and worse until there is some form of external intervention to break the vicious cycle.

On the other hand, negative feedback loops (labelled as ‘B’ in Figure 2) counteract and oppose change (Sterman, 2000). Negative feedback loops are goal-seeking and most control functions used in construction projects operate in this way by attempting to correct deviations in cost, time and resources, and return them to what was intended in the client’s brief (Chapman, 1998).
Polarity of feedback loops:

To use causal loop diagrams, it is important to have a good understanding of the concept of polarity. Within causal loop diagrams, individual links between two variables can be labelled positive or negative in order to express the nature of the relationship between the two variables. Loosely speaking, a plus sign indicates that the variables at opposite ends of the arrow tend to move in the same direction (i.e. direct variation) while a minus sign indicates an inverse relationship. Chapman (1998) illustrates that a causal link from A to B is positive (1) if A adds to B, or (2) if a change in A produces a change in B in the same direction (see Figure 1 below). Similarly, Chapman (1998) also states that a causal link from A to B is negative (1) if A subtracts from B, or (2) if a change in A produces a change in B in the opposite direction.

Figure 1: Polarity of feedback loops (adapted from Chapman (1998:239)

3.3 Causal loop structure of the safety model

The structure of the safety subsystem illustrated as a causal-loop diagram (see Figure 2) is linked to six main stocks (i.e. variables which accumulate over time) within the overall project model: undiscovered rework, known rework, work accomplished, accident costs, project costs and scheduled completion date. Figure 2 suggests that when accidents occur, known rework increases requiring an extra effort and time to correct the work hitherto perceived complete. The net effect of above events is an adjustment in scheduled completion date which builds up schedule pressure on the project. When working under schedule pressure human errors are bound to increase and this increases the possibility of recording more accidents. Similarly, accidents impose an unplanned extra-cost which over time builds cost pressure and increases the possibility of registering more accidents on the project.
The structure for rework presented in Figure 2 includes a variable on discovered rework probability which indicates the probability of undiscovered rework being uncovered by quality inspection. Discovered rework probability was estimated based on the judgments of project managers because it is impossible to assess it correctly. The other key variable in the model is the rework discovery rate which is modelled as a function of the time taken to detect unsatisfactory work in a project. Notably, the process of discovering and correcting rework reduces the level of undiscovered rework and as a result lowers the frequency of accidents. During model construction, the causal loop structure presented in Figure 2 was converted into a stock-flow structure which was implemented in POWERSIM STUDIO 8 simulation software.

4. Model Validation and Testing

Model validation is the process of building confidence in the usefulness of a model (Barlas, 1996). In the formal system dynamics methodology, although model validation is typically (and technically) defined to take place right after model construction and before policy analysis, in practice it exists at every stage of the methodology. Barlas (1996) observes that during model validation, it is not sufficient to test how “accurate” the output behaviour is; what is crucial is the validity of the internal structure of the model. Thus, the general logical order of validation is, first to test the validity of the structure, and then start testing the behaviour accuracy, only after the structure of the model is...
perceived adequate (Barlas, ibid.). Accordingly, validation and testing of the safety model was accomplished through conducting of structure and behaviour tests.

4.1 Structure tests of the safety model

Structure tests can be categorised as direct structure tests and structure-oriented behaviour tests. Direct structure tests assess the validity of the model structure by direct comparison with knowledge about the real system and structure-oriented behaviour tests assess the behaviour of the structure indirectly by applying certain behaviour tests on the model-generated behaviour patterns (Barlas, 1996). Direct structure tests are largely qualitative including checking dimensional consistency and extreme conditional tests in equations.

The structure-oriented behaviour tests were performed on the safety model by deactivating feedback loops responsible for behaviour and by replacing table functions with constants. For example, when the structure responsible for undiscovered rework was deactivated by setting the value of the parameter fraction satisfactory to 1 (literary meaning that all project work that is undertaken is satisfactory), the obtained results show that the accident frequency is zero throughout the simulation time, and there are no overruns in schedule and workforce. The above results illustrate that undiscovered rework has the power to cause the problematic behaviour of accident occurrence, and schedule and workforce overruns. Similarly, the structure responsible for accidents occurrence was deactivated by setting a very high value of average time to record an accident; this literally means that accidents cannot happen during the project life. The results obtained from this test revealed that when the average time to record an accident was set to an extreme value of 1,000,000,000 months, the scheduled completion date reduced from 63 months to 59 months and the workforce reduced from 58 to 54 persons at the close of the project. This means that by avoiding accidents, you minimise schedule and workforce overruns on projects.

4.2 Behaviour tests of the safety model

Behaviour tests measure how accurate the model can reproduce the major behaviour patterns exhibited by the real system (Barlas, 1996). As suggested by Richardson and Pugh (1981), the most common method of carrying out behaviour tests is through parameter sensitivity testing. Parameter sensitivity tests examine whether the patterns of behaviour exhibited by the model change with minor parameter value changes (Richardson and Pugh, ibid.).

During model testing, parameter sensitivity tests were carried out on the average time to record an accident and on discovered rework probability. The rationale was to select those parameters which have direct influence on the behaviour of the safety system. For example, when the value of discovered rework probability was changed from the default value of 0.5 (implying that there is a 50% chance that unsatisfactory work will be discovered by quality inspection) to 0.35 (a 30% reduction) the simulation results revealed that undiscovered rework increases (due to a reduction in discovered rework rate) and so does the accident frequency. Also observed is an increase in the scheduled completion date and a reduction in the workforce size. When the value of discovered rework probability is increased from the default value of 0.50 to 0.65 (a 20% increase), undiscovered rework
reduces (due to an increased rework discovery rate) and similarly does the accident frequency. Also observed is a reduction in the scheduled completion date and an increased workforce size. Overall, the parameter discovered rework probability is structurally insensitive but numerically sensitive.

5. Discussion of Model Results

The safety management model presented in this paper, in addition to presenting the dynamics of schedule and workforce overruns has developed an understanding of the possible structure and behaviour for safety as a quality factor on construction projects. The baseline data used to run the model was obtained from the baseline project plan of the case-study hotel complex presented in section 2 of this paper. According to the activity plan/gantt chart, the project was designed to be completed in 40 months with an initial scope of 1200 tasks. In the context of this paper, a task is defined as an activity which can be accomplished by a worker in one man-month of twenty man-days. As a result, activities with duration of more than twenty man-days were made up of more than one task. From the experience of similar past projects in the Ugandan construction industry, the productivity of workers was estimated to be 1 task per person per month. Therefore, the desired workforce at the start of the project is 30 persons. Figure 3 below presents an extract of the base run results obtained using the above project estimates.

![Base run results of the safety model](image)

Figure 3: Base run results of the safety model

During the first 20 months, the project is perceived to be on schedule, most of the unsatisfactory work is not detected and very few accidents do occur. The scope of the project does not significantly change and there is a small change in workforce size from 30 persons to 40 persons. Between 20 and 40 months, unsatisfactory work grows to high levels and many structure failures occur during this period. It also increasingly becomes evident that the project is behind schedule with only 57% of the work
completed after 30 months and 72% of the work completed after 40 months, supposedly the baseline planned completion date. The productivity of the workforce also drops to 0.90 tasks/person/month after 30 months and further to 0.82 tasks/person/month after 40 months. This means that management has to hire an even bigger workforce to put the project on schedule. Between 40 and 60 months, the effort of attaining adequate workforce pays off, more of the unsatisfactory work is detected and corrected, and the accident frequency significantly drops. Finally, the project is completed after 63 months with a workforce of about 58 persons.

A unique scenario that was observed during model test runs was the case of accelerating the scheduled completion date. For example, when the baseline completion date was reduced from 40 months to 30 months, the accident frequency increased from 1.1 tasks/month to 1.6 tasks/month and the workforce at project completion increased from 58 persons to 65 persons. These results suggest that, when the scheduled completion date is reduced to an earlier date, more workforce is required to accomplish the work within a shorter period of time. However, with a bigger workforce a lot of unsatisfactory work is generated and as a result more accidents are registered on the project.

6. Conclusion

This paper set out to understand and model the dynamics of safety on construction projects. It was hypothesised that undiscovered rework is a critical factor that compromises safety on projects. Indeed, the results obtained using the developed model support this theory. From the results of this study, it is evident that the time to detect rework is a possible safety policy parameter. By strengthening quality inspection of a project, faults are detected and corrected early enough before they lead to accidents. In the case study hotel building project, the technical committee that investigated the accident noted that if the local authority had inspected the site, detected the faults in time and taken appropriate action, the accident could have been averted. The accident which was registered on the case-study building project was a result of design errors and poor construction practices. During the study, it was also observed that the tendency to accelerate projects can breed accidents on projects. Accelerated projects tend to experience high levels of unsatisfactory work compared to projects implemented following their planned schedule. From the management perspective, effective supervision of the design and construction process is recommended as the best strategy to avoid accidents. For further work, as a step towards developing a holistic view of safety, the safety model should be extended to capture the relationships between safety and equipment, safety and materials, and safety and labour.

7. Acknowledgement

The authors would like to acknowledge Swedish International Development Cooperation (Sida) for sponsoring this research and the School of Graduate Studies at Makerere University and the Centre for Banking and Finance, The Royal Institute of Technology (KTH), Sweden for coordinating the research fund.


Exploring the Influence of Construction Project Features in Accident Causation

Manu, P.
School of Engineering and the Built Environment, University of Wolverhampton, UK
(email: patrick.manu@wlv.ac.uk)

Ankrah, N.
School of Engineering and the Built Environment, University of Wolverhampton, UK
(email: nii.ankrah2@wlv.ac.uk)

Proverbs, D.
School of Engineering and the Built Environment, University of Wolverhampton, UK
(email: d.proverbs@wlv.ac.uk)

Suresh, S.
School of Engineering and the Built Environment, University of Wolverhampton, UK
(email: s.subashini@wlv.ac.uk)

Abstract

Health and safety (H&S) studies within the UK construction industry have revealed the complex and multi-faceted nature of accident causation. In this regard several causal factors have been identified resulting in the formulation of measures including legislation to mitigate these factors. In reporting the causal factors in construction accidents studies have only made passing reference to the causal influence of construction project features (CPF). However there is considerable evidence which demonstrate the causal link between CPFs and accidents. Through a critique of health and safety (H&S) literature within the UK construction industry, it emerges that CPFs such as the nature of project, method of construction, site restriction, project duration, procurement system, design complexity, level of construction, and subcontracting influence accident occurrence on projects. Beyond creating the awareness of the accident causal influence of CPFs, a simplified accident causation model illustrating the causal influence of CPFs is presented. It is argued that giving attention to this causal influence will be necessary if sustained improvement in construction health and safety is to be achieved. Project participants from whose decisions CPFs emanate would therefore have to take into consideration the accident causal influence of CPFs in their decision-making so as to positively influence the H&S outcomes of projects.

Keywords: accidents, decision-making, health and safety, literature review
1. Introduction

Inquiries into the causes of accidents within the UK construction industry have revealed the complex and multi-faceted nature of accident causation through the identification of several causal factors resulting in the formulation of mitigating and preventive measures. In laying bare the causal factors in construction accidents, studies have only made passing reference to the causal influence of CPFs. Nonetheless, there is considerable evidence which underscores the causal link between CPFs and accidents. This study reveals the causal relationship between CPFs and accidents. It begins by reviewing literature on accident causation in general and particularly within construction, focusing on the UK construction industry, the aim being to explore accident causes and the causal factors in construction accidents. It then proceeds to accentuate the causal relationship between CPFs and accidents through a discussion of the causal influence of CPFs. A simplified model of accident causation illustrating the accident causal influence of CPFs is subsequently presented.

2. Construction accident causation

An accident is an unplanned occurrence/event which results in injuries, fatalities, or ill-health to people, or loss of production or damage to property, equipment or materials (Raof, 1998; Health and Safety Executive (HSE), 2005). Following the seminal work by Heinrich (1930) there have been considerable efforts toward investigating how accidents occur and why they occur. These have resulted in the identification of several accident causal factors and accident causation models, generally with the overall objective of providing tools for better industrial accident prevention programmes which Heinrich et al. (1980) defined as a series of coordinated activities, directed to the control of unsafe personal performance and unsafe mechanical conditions, and based on certain knowledge, attitudes, and abilities. Among the various accident causation models are the Domino Theory by Heinrich (1930) which explains accident causation as a one-dimensional sequence of events; the Multi-causality of accidents (Reason, 1990) which indicates that accident causation is an interaction between latent and active failures; and the Human-Error Causation Model (Petersen, 1982) which indicates that human error is the main cause of accidents. In the construction industry worldwide, studies have similarly attributed various factors to accident causation, some of which have been illustrated in the form of models. In the USA, Hinze (1996) proposed the distraction theory, which puts forth the claim that the risk of accident may be generated by worker distraction caused by either physical hazards or mental diversion. Lam and Rowlinson (1997), in Hong Kong, reviewed a selection of government statistics and suggested that causes of (all types of) accidents included: employment of unskilled workers, lack of leadership from top management, and inadequate safety education courses. Kartam and Bouz (1998), in Kuwait, also reported the following factors as being the major causes of accidents: worker turnover and false acts; inadequate safety procedures; improper cleaning and unusable materials; and ‘destiny’. Again, in the USA, Abdelhamid and Everett (2000) presented the Accident Root Cause Tracing Model which proposes that construction accidents occur due to three root causes: failing to identify an unsafe condition that existed before an activity was started or that developed after an activity was started; deciding to proceed with a work activity after the worker identifies an existing unsafe condition; and deciding to act unsafely regardless of initial
conditions of the work environment. Behm (2005) explored the link between construction fatal accidents and the design for safety concept in the USA and concluded that of the 224 fatal accidents examined, 42% were associated with design factors. The author however recognized the complex and multi-faceted nature of accident causality and indicated that, it is incorrect to presume that implementation of the design for construction safety concept would automatically reduce construction industry fatalities, as other factors contribute to accidents. Although not all these were presented in the form of a causation model, they still provide essential information for formulating adequate preventive measures. They however do not indicate the pattern of causation and the inter-causal relationship between the causal factors. Similar to the above mentioned construction industries, the UK construction industry has equally been well investigated for the factors influencing accident causation.

2.1 Accident causation in the UK construction industry

The majority of research that have explored the causal factors in construction accidents within the UK construction industry have been commissioned by the Health and Safety Executive (HSE), e.g. Whittington et al. (1992), Suraji et al. (2001) and Haslam et al. (2005). Whittington et al. (1992) simplified the accident causation process into a sequence of failure initiation, classed as individual failures, site management failures, project management failures, and policy failures. Subsequent research by Suraji et al. (2001) and Haslam et al. (2005) further expounded the complex and multi-faceted nature of construction accidents by highlighting the various levels of causal factors and how they interact to influence accident occurrence. Their models were more extensive and included root causal factors upstream of the procurement process. Suraji et al. (2001) developed the constraint-response model which illustrates two major factors: the distal factors and the proximal factors. They explained that the proximal factors are those that can lead directly to accident causation while the distal factors are those that can, in the event of inappropriate responses by project participants, lead to the introduction of these proximal factors in the construction process. The proximal factors include inappropriate construction planning, inappropriate construction control, and inappropriate site condition. The distal factors are the constraint and responses above the proximal factors amongst which are client’s responses, designers’ responses, and project management responses.

Similar to the constraint-response model, is the causation model by Haslam et al. (2005). As explained by Haslam et al. (2005), the model describes how accidents arise from a failure in the interaction between the work team, workplace, equipment and materials, giving rise to the ‘immediate accident circumstances’. The operation of the worker, site and material/equipment factors in leading to (or precluding) an accident depends in turn on proximal influences, labelled as ‘shaping factors’. These shaping factors are then subject to more distal factors, labelled as ‘originating influences’, which includes the permanent works design, project management and client requirements. Recent investigation by Loughborough University (2009), recognizing the complex and multi-faceted nature of accident causation, grouped the causal factors into:

1. Macro - e.g. immature corporate systems; inappropriate enforcement; etc.
2. Mezzo - e.g. immature project systems and processes; inappropriate procurement and supply chain arrangements; etc.

3. Micro – e.g. ineffectiveness or lack of training and certification of competence; etc.

Within this same context of unearthing causal factors in construction accidents it is worthwhile to note that investigations have only made passing reference to the causal influence of CPFs, despite the considerable evidence underscoring the causal link between CPFs and accidents. For instance, from the studies by Suraji et al. (2001) and Haslam et al. (2005) it is apparent that CPFs, emanating from the distal/originating factors level (through strategic project decisions, project design, selection of technology, and project management decisions) and subsequently influencing the construction phase, do eventually influence accident causation. The causation models, particularly the ones by Suraji et al. (2001) and Haslam et al. (2005), therefore provide a key background for delving into the influence of CPFs in accident causation. With construction accident causation being complex and multi-faceted, attempts towards achieving substantial H&S improvements will require efforts targeted at identifying and redressing the multiple causal influences, which includes the causal influence of CPFs. It is thus imperative to also look into the accident causal influence of CPFs.

**2.2 The influence of construction project features in accident causation**

CPFs such as the nature of project, method of construction, site restriction, project duration, procurement system, design complexity, level of construction, and subcontracting influence accident causation on projects (cf. HSL (1999), McKay et al. (2002), Loughborough University and UMIST (2003), Gambatese et al. (2008) and HSE (2009)). These features are project characteristics/attributes (organisational, operational and physical) which emanate from the client’s brief, project management decisions and design decisions. Drawing on the accident causation models by Haslam et al. (2005) and Suraji et al. (2001), the accident causal influence of CPFs is distal to accident events. This distal causal influence of CPFs is demonstrated by the following critique of H&S literature within the UK. In exploring the causal influence of CPFs, it is acknowledge that the above enlisted CPFs may not be exhaustive. Other CPFs which inherently influence accidents may thus be identified to add unto this insight into the accident causal influence of CPFs.

**2.2.1 Nature of project**

The nature of project (i.e. new work, repair/refurbishment/maintenance and demolition) is usually determined by the client’s brief. The UK Office for National Statistic (ONS) (ONS, 2009) indicates that compared to new work, repair and refurbishment work constitute a fairly consistent proportion of approximately 45% of the industry’s output. The UK Health and Safety Executive (HSE) Construction Intelligence Report (HSE, 2009), however demonstrates that refurbishment and repair work constitutes a fairly consistent proportion of fatal accidents at around 50%. Refurbishment and repair work therefore accounts for a disproportionate percentage of fatal accidents. This trend is attributable to the fact that, the hazards during refurbishment are more uncertain, complex, and hence difficult to observe and evaluate than the hazards on new works (cf. Egbu (1999) and Loughborough
Like refurbishment work, demolition work shares similar attributes and is also a hazardous operation responsible for accidents (Hughes and Ferrett, 2008). Hazards such as falling debris, premature collapse of element/structures, dust and fumes, asbestos, noise and vibration, and electric shock are common in demolition and refurbishment work (Loughborough University, 2006; Hughes and Ferrett, 2008), and given that these hazards are uncertain and complex, it is only consequential that refurbishment work and demolition work are more dangerous than new work (Loughborough University and Milan Polytechnic, 2004; Loughborough University, 2006).

### 2.2.2 Method of construction

Studies have pointed to the contribution of method of construction to accident causation (cf. Gibb (1999, 2001), McKay et al. (2002), Loughborough University and UMIST (2003) and Wright et al. (2003)). This is influenced by manual handling, which is involved in over one-third of all construction injuries in the UK (HSE, 2009). Perttula et al. (2003) in a study conducted in Finland, similarly attributed manual handling to a third of the accidents in their study. The traditional/conventional on-site method, compared to pre-assembly construction (off-site fabrication), involves extensive manual handling and therefore introduces a lot of manual handling hazards and thus implying a causal link to accidents involving manual handling. A study by Gibb (2001) reported that because pre-assembly brought the construction site into the factory where the environment is more controllable, safety, productivity and quality could be improved. The Strategic Forum for Construction (2002), McKay et al. (2002), Loughborough University and UMIST (2003), and Wright et al. (2003) have similarly emphasized the H&S benefits of using pre-assembly construction.

### 2.2.3 Site restriction

Compared to an unrestricted site, a restricted site (provided by the client) would imply insufficient storage space and limited or congested working space for the operatives, plants, machines and equipment on site (cf. Loughborough University and UMIST (2003)). A restricted site would thus influence accidents as a result of the site congestion it introduces which has been a persistent cause of accidents (cf. Entec UK Ltd. (2000), Loughborough University and UMIST (2003) and Loughborough University (2009)). Congested site conditions would imply insufficient working space, constricted room for vehicle manoeuvrability and difficult access to drop-off points, possibly resulting in the need for double handling of materials, all of which have safety implications (Loughborough University and UMIST, 2003). These antecedents influence accidents such as a worker being struck by a moving vehicle or by a moving (including flying/falling) objects which are among the main causes of fatalities as demonstrated by the HSE (2009).

### 2.2.4 Project duration

During construction, it is possible that the anticipated/targeted construction duration set by the project planners may eventually not be exactly the actual duration spent as there could be time over-runs or early completion. However, this planned duration, as it represents a time span, has the potential to influence accident occurrence. A constrained duration set by the client or the project management team would introduce time pressure at the construction phase with subsequent problems such as trade
overlap, crowded work space, reduced attention to detail, and the prioritising of production over safety which influence accident occurrence (Mayhew and Quinlan, 1997; Loughborough University and UMIST, 2003).

2.2.5 Design complexity

The influence of design on accident causation has been well echoed throughout the UK construction industry (cf. Entec UK Ltd. (2000), Loughborough University and UMIST (2003), Wright et al. (2003) and Donaghy (2009)), hence the existence of the Construction (Design and Management) Regulations 2007. The findings of Loughborough University and UMIST (2003) indicated that an increased desire for aesthetic qualities inhibit the ease of building which in itself induces safety hazards. As part of the research informing the Donaghy Report (2009), Loughborough University (2009) again mentioned poor design for buildability as a causal factor in construction fatalities. Designs that are complex (having intricate aesthetic qualities) therefore tend to have a greater potential to influence accident occurrence as such designs inhibit buildability (Loughborough University and UMIST, 2003).

2.2.6 Subcontracting

Several studies within and outside of the UK construction industry have identified subcontracting as a causal factor in construction accidents. In countries such as Spain, Malaysia, Philippines, Poland, China, and Australia, subcontracting has been associated with adverse H&S outcomes in the construction industry (cf. Byrne and van der Meer (2001), ILO (2001) and Yung (2009)). Similarly in the UK, the accident causal influence of subcontracting has been reported over the years (cf. Mayhew and Quinlan (1997), HSL (1999), Loughborough University and UMIST (2003), Ankrah et al. (2007), Donaghy (2009) and Manu et al. (2009)). Subcontracting could emanate from the pre-construction phase (through decisions by the project planners and client) and/or during the construction phase (by a principal contractor/contractor and client/client representative). Subcontracting inherently fragments the workforce thus making it more difficult to manage H&S on site (Mayhew and Quinlan, 1997; Loughborough University and UMIST, 2003).

2.2.7 Procurement system

The UK construction industry is complex covering a large number of players (cf. ONS (2008)). In view of this, Entec UK Ltd. (2000) reported that there are organisational obstacles which impede H&S improvement in the industry. Interaction in the supply chain is often divisive rather than supportive and this impedes H&S improvement (ibid). Entec UK Ltd. (ibid) however indicated that, partnering is perceived as being able to enhance H&S improvement as it enables the building of close working relationships and it also provides opportunities for discussion, hazard identification and problem solving at the early stages of the project. Another procurement arrangement which is perceived as being able to enhance H&S improvement is design and build (cf. Loughborough University and UMIST (2003)). Loughborough University and UMIST (2003) reported that design and build procurement is perceived as enabling H&S improvement because the contractual arrangements place the responsibility for both design and construction within a single project team,
leading to shared goals, improved communication, and a better environment for new ideas to flourish. Evidently these procurement arrangements promote team integration which is essential for project success (Egan, 1998; Strategic Forum for Construction, 2002; Baiden et al., 2006). Contrary to partnering, and design and build procurement, a procurement arrangement that has been identified to have adverse H&S implications is management contracting (HSL, 1999). Management contracting is considered more problematic than the traditional mode of procurement when addressing the maintenance of good H&S (HSL, 1999). Evidently these latter procurement arrangements fragment the project team thus impeding effective management of H&S on project.

2.2.8 Level of construction

The level of construction, particularly multi-level/high-level construction involves working at height which accounts for falls from height which have been responsible for about 50% of fatal injuries from 1996/97 to 2007/08 (HSE, 2009). Thus comparing low-level construction to multi-level/high-level construction, multi-level/high-level construction contributes greater to accident causation. Research by Chua and Goh (2005) in Singapore revealed that underground construction has a higher rate of incidents than above-ground construction. Although Chua and Goh (2005) did not delve deep into the possible causes of the higher rate of incidents associated with underground construction, it is well known that underground construction involves working in confined space which accounts for adverse H&S outcomes (cf. Hughes and Ferrett, 2008) hence the existence of the UK Confined Spaces Regulations 1997.

The identified CPFs and the sources from which they have been extracted clearly demonstrate that the distal causal influence of CPFs is undeniably existent and has been reported to some extent, though in a segregated manner and not with the specific focus intended by this study. More importantly, they provide the opportunity to further build on previous construction accident causation models particularly underscoring where CPFs fit, how they influence accidents and the implications for accident prevention/mitigation and for further research.

3. A simplified model of accident causation highlighting the causal influence of construction project features

From the above discussion and also building on the causation models by Suraji et al. (2001) and Haslam et al. (2005), the following simplified accident causation model (Figure 1) illustrating the causal influence of CPFs is thus developed. The model (adapted from Suraji et al. (2001) and Haslam et al. (2005)) illustrates the causation pattern of how CPFs, arising from the client’s requirements, design decisions and project management decisions, influence accidents.
Figure 1: Accident causation model illustrating the influence of CPFs (adapted from Suraji et al. (2001) and Haslam et al. (2005))

As demonstrated by the review, for a CPF the causal influence could generally be considered as being adverse or less adverse/mitigating. For instance, for method of construction, traditional in-situ construction has an adverse causal influence whereas pre-assembly construction has a less adverse/mitigating causal influence in terms of the extent of manual handling associated with them. Also for procurement system, management contracting and traditional procurement have an adverse causal influence whereas design and build and partnering have a less adverse/mitigating causal influence. Project client, design team and project management team who determine CPFs (through the project brief and their decisions) would therefore have to take into consideration the accident causal influence of CPFs when making decisions. Where there is an opportunity to choose CPFs that have a less adverse/mitigating causal influence, it is thus recommended that such choices should be made over CPFs that have an adverse causal influence. This however in no way suggests that CPFs which have an adverse influence should or can entirely be avoided. In that regard, it should be recognised that some CPFs may be inevitable depending on the client’s requirements, the project management constraints and the design constraints as explained by Suraji et al. (2001). For instance, in a situation where the site available for the development is restricted or where the client wants the project completed within a very constrained duration or where the client wants a multi-level facility, such CPFs would be inevitable. Where the choice of CPFs which have an adverse causal accident influence is inevitable, appropriate mitigation measures should then also be considered. Apart from the model and its preceding discussion assisting project planners and designers with the choices of CPFs on the basis of their accident causal influence, it also provides the opportunity for further investigation into the accident causal influence of CPFs with the aim of obtaining deeper insight into how CPFs contribute to accident causation, the extent to which they contribute to accident causation, and the H&S risk implications. As demonstrated by Manu et al. (2010), such an investigation would contribute to efforts aimed at achieving a safer construction industry.
4. Conclusions

The consensus of research findings and statistics identified through the review of H&S literature within and outside of the UK clearly indicates that the accident causal influence of CPFs is undeniably existent and has severe ramifications. From the discussion a simplified causation model illustrating the accident causal influence of CPFs has been presented as further development on other construction accident causation models. Poorer H&S on construction projects is partly due to the accident causal influence of CPFs, especially when appropriate mitigation measures are not implemented. To ensure continuous H&S improvement in the UK construction industry it is thus important that the project participants from whose decisions CPFs emanate make decisions taking into consideration the accident causal influence of CPFs. Doing so would contribute towards achieving good H&S outcomes on projects.

References


The Evolution of Construction Accident Causation Models

Li, R.Y.M.
Department of Real Estate and Construction, the University of Hong Kong
(email: ritarec@hotmail.com)
Poon, S.W.
Department of Real Estate and Construction, the University of Hong Kong
(email: swpoon@hkucc.hku.hk)

Abstract

Construction accident rates have remained unacceptably high in Hong Kong. Despite huge sum of money in implementing safety tools by contractors and developers, the total compensation remains high. Likewise construction academics have developed many accident causation models in an attempt to finding out causes of accidents. This paper aims at reviewing the evolution of construction accident causation models in tandem with development in technology and procurement methods.

Keywords: evolution, construction accidents, accident causation model
1. Introduction

High accident rate in construction is a universal problem which needs to be tackled by all those concerned (Poon et al., 2008). Although in the last decade there is a downward trend in construction accidents in many places such as Hong Kong (Figure 1) due to implementation of numerous safety schemes (Figure 2), improvement in construction accidents record is still necessary. A previous research in Hong Kong has shown that an accident imposes huge cost to the society (Li and Poon, 2009a) and over $10 million of compensation was paid for non-fatal accidents each year during 2004-2008 (Table 1). The direct financial costs of accidents is only the tip of the iceberg when compared to the indirect ones. The injured employees and their families suffer from loss of earning and grief. Accidents on sites also lower staff morale, induce negative corporate image and lead to extension of time in project because of work re-arrangements (Li, 2006). This paper aims at studying and analyzing the evolution in accident causation models.

![Figure 1: Construction accidents per 1000 employees in Hong Kong (Tang and Poon, 1988, Poon et al., 2008, Lee, 1996, Hong Kong Labour Department, 2009).](image1)

![Figure 2: Construction Accident Rates and Safety Scheme (Rowlinson et al., 2009)](image2)
Table 1 Construction accident compensation in Hong Kong (Li and Poon, 2009b).

<table>
<thead>
<tr>
<th>Year</th>
<th>Total number of non-fatal accidents</th>
<th>Total PSLA ('000)</th>
<th>Total loss of earning ('000)</th>
<th>Total loss of earning capacity ('000)</th>
<th>Total Special damages ('000)</th>
<th>Total Future treatment ('000)</th>
<th>Total Deductions from ECC and victims’ faults ('000)</th>
<th>Total sum of compensation ('000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>29</td>
<td>6,779</td>
<td>26,964</td>
<td>267</td>
<td>610</td>
<td>584</td>
<td>4,005</td>
<td>32,443</td>
</tr>
<tr>
<td>2007</td>
<td>16</td>
<td>3,400</td>
<td>13,980</td>
<td>950</td>
<td>530</td>
<td>279</td>
<td>890</td>
<td>15,937</td>
</tr>
<tr>
<td>2006</td>
<td>19</td>
<td>7,260</td>
<td>20,234</td>
<td>875</td>
<td>1,378</td>
<td>2,669</td>
<td>7,640</td>
<td>39,643</td>
</tr>
<tr>
<td>2005</td>
<td>23</td>
<td>6,085</td>
<td>24,645</td>
<td>2,404</td>
<td>506</td>
<td>382</td>
<td>7,771</td>
<td>25,725</td>
</tr>
<tr>
<td>2004</td>
<td>14</td>
<td>2,940</td>
<td>11,283</td>
<td>431</td>
<td>211</td>
<td>116</td>
<td>5,174</td>
<td>10,998</td>
</tr>
</tbody>
</table>

2. Changes in construction industry 1960 – present

2.1 From low-rise building to tower of Babylon

In early 20th century, structural members were designed to carry primarily the gravity loads. Advances in structural design and building materials reduce building weight; taller building construction which can house more people has gained its popularity. Among the fifty tallest buildings in the World, only one was constructed in 60’s and the majority were constructed in 80’s and afterwards (Graven, 2009). Nevertheless, building slenderness increases also implies that lateral loads consideration becomes more important (Günel and Ilgin, 2007).

2.2 From traditional procurement to integrated procurement

Before 80’s, building firms enjoyed post-war expansion due to rebuilding, capital investment catch-up and increasing levels of immigration, which provided economic buoyancy. Clients were led by their design team -- they were not encouraged to be involved in a significant degree during decision making in design and construction, design and construction were separated (Smith et al., 2000). Between 1980 and 1999, traditional procurement method was losing ground (Franks, 1998), design and build gained popularity. The time, cost and quality became part of the construction service ethos. Since 1999 practitioners in Australia and UK, Latham stressed more on construction productivity and efficiency and multi-skilling of the trades to reduce disputes between unions and trades (Smith et al., 2000). Clients seek solutions rather than pure construction services (Rowland, 2001). Concept from manufacturing such as best practice, quality assurance benchmarking and re-engineering have influenced the construction industry, pre-qualification criteria for consultants, contractors and sub-contractors adopted. Integrated forms of procurement based on the principles of concurrent engineering (CE) which promotes cooperation and collaboration between project participants from the outset of a project have been advocated. Moreover, with the assistance of the client’s and project
advisor’s involvement during design development, the project team can jointly develop the project’s goals and objectives (Smith et al., 2000).

2.3 From conventional construction method to complicated ever changing digital and prefabricated construction

Construction industry has long been regarded as a labor intensive industry. Construction of bridges, buildings, dams etc are built by a great number of workers. International Alliance of Interoperability (IAI) founded in the USA in 1995 turned on the engine of digital construction, system-independent exchange of information between all stakeholders was developed (Moum et al., 2009).

In this ten years’ time since mid 90’s, information technology has changed the world of construction industry. CAD drawing has replaced handmade drawing, Video conferencing has replaced frequent freight face-to-face meeting, digital take-off has replaced traditional black and white take-off, and dynamic building information modeling has replaced static building design. Within this decade, man-made construction and design methods have been replaced by “n” kinds of software for quantity surveyors, architects, engineers, form workers and architects. If we view each of these from the system point of view, there are many new born subsystems each day in different parts of the globe. The World Wide Web even helps us to share the new building knowledge in a blink of an eye. All these technologies help us build faster but complicate the whole construction process at the same time – what the best method today does not mean it is the best for tomorrow. We are all trying to catch up with the latest technology.

Moreover, all the building services installations are carried out on site before 1980, with the help of modern technology, off-site fabrication of some building services components become possible (Hui and Or, 2005). Design of tall, asymmetric and specially shaped buildings has gained popularity (Steenbergen and Blaauwendraad, 2007). Building technical complexity has also increased (Joint Cooperative Committee AIA-AGC-CEC-VSPE, 2009), profound understanding of the force flow in these types of structures is not easy as the building plan is not constant along the height of the building (Steenbergen and Blaauwendraad, 2007).

3. Evolution theory

According to Darwin, “… each new variety, and ultimately each new species, is produced and maintained by having some advantage over those with which it comes into competition; and the consequent extinction of less favored forms almost inevitably follows” (Darwin, 1859). The evolution theory of Darwin and Wallance is based on the mechanism of natural selection where such process stresses that organisms better adapted survive and breed (Toole and Toole, 1999), evolution of human is one of the very good example (Advanced Theological Systems, 2009). Lamarckian Evolution states that a change in environment may lead to changed pattern of behavior which can necessitate new use of structures (Taylor et al., 1999). Academic researchers developed construction accident causation models as early as 1960 (Figure 3). Since then, many different accident causation models appear in journals and books. Changing in building complexity due to increase in building height, construction procurement and technology has led to a change in construction accident causation models over time.
Our building and construction environment has become more complicated, so as our accident causation models.

![Accident Causation Models, distribution of year of construction for the fifty tallest buildings in the world, procurement method and technology Timeline (Graven, 2009, Smith et al., 2000, Steenbergen and Blaauwendraad, 2007, Franks, 1998)](image)

**Figure 3: Accident Causation Models, distribution of year of construction for the fifty tallest buildings in the world, procurement method and technology Timeline (Graven, 2009, Smith et al., 2000, Steenbergen and Blaauwendraad, 2007, Franks, 1998)**

### 4. Accident causation model

#### 4.1 Energy model (1961)

Haddon suggested that accident happens when there is an excess energy transfer (Gibson, 1961). Accident causing agent such as electrical, mechanical and thermal, energy can lead to accidents. This model suggests that the occurrence of an accident basically follow the laws in Physics: it happens after there is an excess amount of uncontrolled energy and consequences depend on the amount of energy (Kjellen, 2000).

Yet this model has received some complaints from Lingard and Rowlinson (2005) who pinpoint that the abstract nature of this model fails to lay down a good foundation in identifying hazard in routine work. It also fails to suggest the appropriate safety measures under different circumstances (Kjellen, 2000).
4.2 Bird’ domino model (1974)

In 1974 Bird (1974) suggested that the accident can be viewed as the last domino in the ‘domino sequence’ where accident is the results of a sequence of events. The first domino falls on the second one and the second one’s fall lead to the fall of the third domino, so on and so forth. Bird suggested that workers will be safe so long as the first domino, i.e. site management does not fall (figure 4) (Kjellen, 2000). However, other researchers point out that there are many factors which lead to accidents. It is inappropriate to regard accidents as the last event in a sequence (Li, 2006). It can be the case like the last straw being placed on the camel.

![Figure 4: The Domino Sequence (Rowlinson, 1997)](image)

Bird’s contention was that these unsafe conditions were symptoms of management oversight and mismanagement in planning, organizing, commanding, coordinating and control (Fayol, 1949). Nevertheless, such model has failed to make a clear relationship between various relations between personal and organizational factors. Readers of domino sequence may misunderstand that personal factors and mental stress play the same role in accidents. Hence, such theory often leads to a false interpretation on the underlying accident causation factors. This is particularly true for those high rank officers who usually do not have really work on site and lack of safety knowledge in depth (Kjellen, 2000).

4.3 Heinrich’s axioms (1980)

Heinrich et al. (1980) proposed that more than one-fifth of accidents are caused by a series of unsafe acts which finally lead to accidents occurs. He further elaborates that the degree of injury is a matter of probability. Not in the camp of Henrich, Hopkins (1995) thinks that such model is too simple and cannot reflect the real life situation where accidents are caused by interaction between a handful of
causes. Moreover, Cooke (2003) points out that this model fails to show the effect of feedback in construction industry.

### 4.4 Potential accident subject model (1987)

Leather (1987) proposes that both endogenic and exogenic factors might affect the potential accident subject’s acts and thoughts which might lead to accidents in Potential Accident Subject (PAS) model. The PAS stresses the dynamic relationship between various stakeholders on accidents, e.g. workers, managers within the construction companies or even those people who work outside the construction companies. Under PAS model, any people even the victim himself can be PAS. Furthermore, people’s behaviors and attitudes are affected by reward, management systems, punishment, training, instructions given by seniors and so on. Some rewards for finishing task quickly may induce workers to take short cut and ignore the possible source of risks (Li, 2006).

![PAS model](image)

Figure 5: PAS model (Booth 2004)

### 4.5 Rasmussen's work behavior model (1994)

Rasmussen suggested that construction laborers’ work is shaped by economic, functional, safety related objectives and constraints. The model identifies three zones: safe zone, (where the workers’ behaviors are complied with safety rules) hazard zone and loss of control zone. Most of the construction managers on sites work along the cost gradient and the worker searches for the least effort gradient. All these end up with a systematic migration toward the boundary of acceptable performance only. In view of this, safety plan on sites are often designed to act against the pressures outlined in the model. Nevertheless, the pressures that push workers toward the safe zone require a continuous effort. Rasmussen therefore proposes that accident prevention should focus on error tolerant work systems development which make the boundary of loss of control reversible and visible (Mitropoulos et al., 2005).
4.6 Human information processing model (2000)

Kjellen (2000) sheds light on human and environment interaction from an operator’s point of view. Under this model, people are viewed as an information processor who makes their own judgment in response to environment risks, hazards or deviations. Accidents happen when people are unable to handle information under complicated circumstances. Accident analysis is one of the very good practice to identify and evaluate the safety risks on sites and provide suitable safety measures in turn.

Yet, this model suffers from two very major drawbacks. Firstly, the model only sheds light on ‘cold’ variables with regard to human’s cognitive processes which does not conform well with real life situation. In reality, emotional variables such as threat do affect people’s capability in problem solving and accident prevention. Secondly, internal information processes are absent. Interpretations by actual behavior observations and interviews become necessary which requires expertise. Because of the two aforementioned problems, application of this model is limited to in-depth investigation with experts participation (Li, 2006).

4.7 Epidemiological model (2003)

Conventional safety theorists put the lens on finding out accidents and injuries. There is, however, a trend in encompassing environmental factors which may be possible to cause an accident. Based on this idea, the Epidemiological model views accidents as a disease entity and arise as a product of interaction between the agent, environment and the host (Goetsch, 2003). Nevertheless, whether the agent in accidents can be meaningfully separated or not from its environment is in doubt (Hacker & Suchman 1963).
4.8 Systems Model of Construction Accident Causation (2005)

Building on Rasmussen’s model and various construction accident causation models in the past, this model identifies various variables which influence the probability of accidents during a construction activity. While the arrows in the figure indicate cause-effect relationships, the signs show the direction of the relationship between these factors. A positive sign indicates that when there are changes in factor X, the effect Y changes in the same direction. A negative sign signifies the effect of changes in an opposite way. This model proposes that unpredictable task and environment increase the likelihood of accidents as it increases the likelihood of errors hazardous situations and the production pressures (Mitropoulos et al., 2005).

![Figure 7: System model of accident causation (Mitropoulos et al., 2005).](image)

5. Conclusions

To conclude, all the seven writers suggest that accidents are not the result of bad luck. Accidents happen because of failure in one or more than one factors. Nevertheless, when we take a closer look at the changes of accident causation model over the years from 1961, we can see an interesting phenomenon: the models are getting more and more complicated. Accident causation models before mid 80’s were a lot simpler than model developed later on, i.e. complicated model “survive” in natural selection. It is predicted that future accident causation model will be more complicated when high technological tools are used on sites, construction procurement and height of buildings have changed i.e. Lamarckian Evolution also takes place in causation model.
Table 2 Changes in accident causation models

<table>
<thead>
<tr>
<th></th>
<th>Initial Accident Causation Models</th>
<th>Latest Accident Causation Models</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direction</strong></td>
<td>One</td>
<td>Multiple</td>
</tr>
<tr>
<td><strong>Categories</strong></td>
<td>Few</td>
<td>Multiple</td>
</tr>
<tr>
<td><strong>Factors</strong></td>
<td>Few</td>
<td>Multiple</td>
</tr>
</tbody>
</table>

References


ROWLINSON, S., YIP, B. & POON, S. W. 2009. *Safety Initiative Effectiveness in Hong Kong*, Hong Kong, CII-HK.


Abstract

Occupational health and safety is important to the design, construction, maintenance, refurbishment and demolition of buildings and facilities in all branches of industry, business and commerce. Health and safety issues have been a major consideration in construction. The numbers of people that get hurt, injured or die are still far too high even though the situation in many countries has improved through the years. This research project aims to investigate and improve the effectiveness of communication of health and safety information between all parties involved in a construction project. The main objective is to determine the flow of communication amongst construction players involved in a project (both new build and refurbishment projects). The overall research is being conducted in the UK based on a combination of qualitative and quantitative research methods including literature review, case studies and detailed surveys involving large and small construction companies. Observations on drawings and documentation along with interviews are used to investigate current industry practice. This paper focuses on the challenges in the communication of health and safety information in the design phase of construction projects. It characterizes the various aspects of collaborative communications at this stage and highlights the problem areas and presents the findings of interviews with members of the design team.

Keywords: Communication, construction, design, health and safety, inter-organizational relationships.
1. Communication of health and safety information in construction

The UK’s Construction, Design and Management (CDM) Regulations place a duty on all the principal stakeholders in a construction project to ensure safety during the course of a construction project. One of the key elements of this requires the communication of safety information between all parties. This is an issue in both new build and refurbishment projects. These regulations differ from those of many other countries outside Europe, particularly in the responsibilities that they give to clients (owners) and designers although interest world-wide is increasing (Gambatese et al., 2009).

The overall research project aims to investigate and improve the effectiveness of communication of health and safety information between all parties. The main objective is to determine the flow of communication amongst construction players involved in a project.

The first level of communication of project requirements is within the Client’s team, between the designer (or structural engineer) and the CDM Coordinator (CDMC), where health and safety problems need to be identified. A summary of duties under the revised CDM 2007 Regulations states that one of the responsibilities of a CDMC is to coordinate health and safety aspects of design work and cooperate with others involved with the project. Therefore, the communication of design information is vital for the CDMC to identify execution risks that can be reduced at design stage and this may result in modifications to parts of the design. In practice, the extent to which coordinators also contribute to solving health and safety problems rather than just acting as a ‘postal service’ varies considerably. Beal (2007) presents a critical review although his arguments are more personal than rigorous. It is certain however, that there is both good and bad practice.

The second level of communication is between the designer (architect or engineer) and the contractor. Project information has to be communicated in detail in order to share the architectural/engineering knowledge acquired during the design stage. The exchange of information has to be mutual because the contractor, through experience and skills, may add additional considerations to the project.

The third level of communication is within the contractor and subcontractor’s team. Project and safety information has to be communicated to the workforce and the site manager to ensure that they understand site rules and health and safety procedures related to the activities they are going to perform. Workers have also to be adequately instructed about not taking any initiative that has not been authorised by site managers. This requires workers to understand project and safety information and what they may find on site that could differ from what was foreseen by pre-construction investigations on the building to be constructed or refurbished.

This paper focuses on communication between architects as the lead of design team to other construction players in particular the design phase.
2. Literature review

Safety performance in the construction industry has lagged behind most other industries as evidenced by its disproportional high rate of accidents. Moreover, the existing systems of statistics collection are still not standardized and based only on post accident information and analysis. They provide factual information regarding the post accident situation, but ignore conditions existing prior to occurrence of the accident. This means the information can be used only for analyzing the post accident data and developing the statistics from it, not for contributing to a prediction of the risk of accidents in order to take appropriate action on site for accident prevention. Therefore, there is a need to have a mechanism to estimate the risk of accidents based on current safety practices and predict their effects on construction operations.

2.1 Industry trends and challenges

Safety in the contracted work environment is under pressure from a variety of industry trends. Downsizing and outsourcing of work, the increasing complexity of operating systems, increased specialization of equipment, and more potent chemical products create an environment ripe for accidents (Hislop, 1999). Jannadi (1996), said that the most important factors affecting construction safety are:

1. Maintaining safe work condition.
2. Establishing safety training.
3. Educating workers and supervisors.
4. Effective control by main contractor of the numerous subcontractors.
5. Maintaining close supervision of the workers.
6. Assignment of responsibility to all levels of management and workers.

Maintaining a range of employees with the technical expertise suited to attend to the construction, modification, maintenance, and also the operational requirements of the complex systems of today’s operations is an expensive venture that most organizations cannot invest in. As a result, the expertise of specialty contractors is needed to deliver construction work and to meet and specialized cyclical work requirements.

The changes and trends in construction have encouraged publication of many articles and research projects. Most papers discuss the aspects of construction and cost control. Health and safety issues have been a major challenge for construction. The numbers of people that get hurt, injured or die are still high even though they have improved through the years. In comparison to other industries, the construction industry still tops the chart in cases of accidents and deaths.
2.2 The importance of construction health and safety

Health and safety in construction is of utmost importance. Jannadi (1996) argued that construction safety is a serious concern to most construction companies since accidents not only reduce productivity and damage equipment, but also injure human beings. In the case of accident occurrence, or worse, accidents that result in fatality, the parties involved in the project will suffer loss in terms of additional cost and time. Damages payment to the victim contributes to this high cost. Employers will need to pay for the cost of lawyers and such if the case is taken to court. Other than that, accidents and fatalities may negatively affect a particular company’s image. This must be avoided, particularly considering tough competition in the construction industry.

2.3 Construction communication strategies

The construction industry is considered to be divisive and fragmented, where construction parties pay attention to conforming to contractual requirements. Eddie et al (2001) argues that all their different skills and backgrounds of the parties involved in construction representing different professions including architecture, structural engineering, quantity surveying, civil engineering, project management, building surveying etc., limit the scope of co-operation between them. The significant reason for this lies with problems in communication. At present, leading construction stakeholders are trying their best to improve the quality of project management in every aspect. One of the aspects given top priority is the communication system. A multitude of communication strategies may be employed to help good communication among all parties. Among them is developing and increasing the usage of IT in construction.

Thomas et al (2001) stated that the underlying perception of the UK construction industry is that of an industry which is highly fragmented, non-collaborative and distinctly unique. The industry needs to change its current culture towards one which supports continuous improvement by adopting collaborative working practices between clients and contractors, in order for the industry to improve its performance, and by association its image. Latham (1994) and Egan (1998) have argued that this collaborative culture should facilitate information sharing between projects and teams and across organizational boundaries (Egbu, 1997). Nevertheless, Faniran et al. (2001) stated that the evaluation of design/construction interactions has not been sufficiently addressed by research studies. Consequently, the mechanics and dynamics of design/construction interactions are considered to be not well understood.

3. Research methodology

The research for this paper investigated the flow of communication of health and safety information from the view of architects as designers throughout construction projects. It characterises the various aspects of collaborative communications at the entire construction stages from appraisal until practical completion as well as highlighting the problem areas. In the context of looking at overall health and safety communication process in construction, the communication flow is also examined. The authors
sought to understand the communication strength, challenges, barriers and also the media used for communication, including potential limitations presented by traditional and conventional design practices and the knowledge and understanding of architects as design professional related to design for safety. This is based on a combination of qualitative and quantitative research methods including literature review, case studies and detailed surveys involving large and small construction companies. Observations on drawings and other documentation along with interviews were used to investigate current industry practice. However, this paper presents emerging issues from the first stage of interviews. It is acknowledged that these interviews only present the designers’ perspectives and may include some degree of bias against other construction stakeholders. This will be addressed in further phases of this research.

3.1 Semi structured interviews with designer – architects’ companies

The study to investigate the communication of health and safety information in construction, the first author began with architects as those professionals who are involved at the very early design stage. Lead architects from four design companies in the UK’s East Midlands area were interviewed. They were contacted by telephone, followed by a formal letter with an invitation to join the study and the research abstract. Interviews were held in their premises and each lasting about one and a half hours. The intent of the interview was to investigate:

1. Health and safety communication flow in construction and the communication strength.
2. Communication media.
3. Communication barriers and challenges.

<table>
<thead>
<tr>
<th>Company</th>
<th>Industry</th>
<th>Typical Procurement Type</th>
<th>Position</th>
<th>Years of experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Construction</td>
<td>Traditional</td>
<td>Architect</td>
<td>7</td>
</tr>
<tr>
<td>B</td>
<td>Construction</td>
<td>Design and Build</td>
<td>Architect (Partner)</td>
<td>22</td>
</tr>
<tr>
<td>C</td>
<td>Construction</td>
<td>Design and Build</td>
<td>Architect (Associate Director)</td>
<td>10</td>
</tr>
<tr>
<td>D</td>
<td>Construction</td>
<td>Framework Agreement</td>
<td>Architect (Design Manager)</td>
<td>21</td>
</tr>
</tbody>
</table>
4. Findings and discussion

The findings of the interviews are discussed based on the research foci which are: health and safety communication flow, communication strength, communication media, communication barriers and challenges and suggestion to improve health and safety communication in construction. The Royal Institute of British Architects RIBA Plan of Work (RPoW) had been used to standardise the architect’s design services. The RPoW includes eleven stages; appraisal, strategic brief, outline proposal, detailed proposal, final proposal, product information, tender documents, tender action, mobilisation, construction to practical completion and after practical completion.

4.1 Communication flow and the strength of the communication

4.1.1 Appraisal, strategic brief and product information

From the architect’s point of view, the communication of health and safety comes into consideration as soon as a client approaches them with a proposal. At the first two stages; appraisal and strategic brief, based on traditional procurement type, interviewee A will communicate with the client, quantity surveyor, mechanical and structural engineers as well as CDMC, classifying this communication of health and safety at these two stages as ‘often’. Interviewee B and C who mainly work on design and build projects, communicate health and safety issues to the client and CDMC very frequently at these two stages. Apart from the client and CDMC, both interviewee B and C communicate health and safety to the quantity surveyor, mechanical and structural engineers, albeit ‘seldom’. From their experience, design engineers will be contacted if there seem to be issues in their work scope. Interviewee B mentioned that suppliers were rarely likely to be involved at these stages. Based on a framework agreement, interviewee D only communicates with the client and quantity surveyor at appraisal stage and expands the communication of health and safety to the CDMC and principal contractor at the second stage. At these two stages, the communication of health and safety could be classified as ‘frequent’ to the client and the quantity surveyor, whereas the communication of health and safety to the principal contractor and CDMC is described as ‘often’.

4.1.2 Proposal stages – outline proposal, detailed proposal and final proposal

In the proposal stages; outline proposal, detailed proposal and final proposal, interviewee A communicates health and safety to the CDMC a ‘great deal’. At this stage the health and safety issues are being highlighted and taken into account in the preparation of the tender documents. From experience, interviewee A finds that it is crucial to highlight health and safety issues at proposal stage to ensure that the proposed project will be constructed safely and the health and safety facilities are included in the budget and time frame. The communication with other disciplines is still ongoing at these stages for interviewee A but either ‘seldom’ or ‘very seldom’. Interviewees stressed that all parties would be kept informed of any updated health and safety information. Basically, the other parties have already given their input regarding health and safety information by this stage. CDMCs and architects record and compile the information in the preparation of tender documents and final drawings. At the proposal stage, interviewee B and C tend to communicate health and safety information to the client, CDMC, quantity surveyor, suppliers, mechanical and structural engineers.
For interviewee B and C, the communication involving all parties could be classified as ‘often’ at proposal stage. All parties involved are being contacted regularly. This is to ensure that all health and safety information is taken into account. The communication of health and safety is less significant in the final proposal stage as all the information is now compiled and inserted as part of the tender documents.

Architects will again review the health and safety plan at this stage to assess the design and ensure the initial concepts, ideas, risks and site restraints are all have been considered and the design is ready for construction. Using a framework agreement with the client, company D does not have the outline proposal stage. From the frozen layout, the proposal will be directly discussed in the detailed proposal stage involving the client, principal contractor, CDMC, sub-contractor, structural and mechanical engineers and quantity surveyor. The discussion will cover all aspects of construction of the project as well as health and safety issues. Usually the client would have approached them with a proposal and their responsibility is to enhance the proposal according to the standard and approved by the local authorities. According to interviewee D, in handling small projects, there are not many things to be considered. However, the communication of health and safety keeps ongoing in the detailed and final proposal stages. Internally, company D has their own four stage risk assessment system; feasibility risk assessment, design risks assessment, built risks assessment and maintenance risks assessment. These risk assessment stages are used to eliminate health and safety risks. In these stages, the communication amongst the parties involved with interviewee D could be classified as ‘often’.

In the product information stage, the three interviewees A, B and C all communicate health and safety issues with the client, CDMC, quantity surveyor, suppliers, mechanical and structural engineers. Basically, as the job goes on, the communication frequency between the designers and the client will become higher. For example, at the product information stage, the client has preferences of materials to be used and the designers and the other parties involved will provide the health and safety aspects in regard of the material chosen. The communication with the suppliers also becomes more frequent. The designers will have to check the quality of the materials and ensure that the criteria of the materials used suit the building regulations. For interviewee D, the product information has already been discussed in the final proposal stage.

4.1.3 Tender stages – tender documents and tender action

For the tender stages; tender documents and tender action, communication between interviewee A and the client, quantity surveyor, structural and mechanical engineers is very seldom. It is just a formality to keep them informed of what is going on at this stage. But the health and safety communication between interviewee A and the CDMC is ‘high frequency’ at this stage to ensure the health and safety issues have been taken into account and compiled in the tender document. At tender stages, the communication between interviewee B and C is less frequent but the communication is vital. For example, they typically have only one meeting with the CDMC but the health and safety issues discussed in the meeting are crucial and must be inserted in the tender document. Interviewee D does not practice tendering as they are in the long term framework partnership.
4.1.4 Construction stages – mobilisation, construction to practical completion and after practical completion

In the construction stages; mobilisation, construction to practical completion and after practical completion, architects still have role to play in the health and safety information. In mobilisation and construction to practical completion stages, the communication will expand to the principal contractor, contractors, sub-contractors and site agents. The communication to the principal contractor and the site agent is very important to ensure that they understand the risks that have been assessed throughout the design process. According to interviewee B, the pre-contract meeting is very important because at this meeting, designers, client and the contractor will meet face to face to discuss about the construction strategy. At this meeting, the relationship among all parties should be confirmed. This opinion is shared with interviewee A. A good relationship between parties involved is very crucial to ease communication. Based on A’s experience, communication of health and safety on site is better communicated verbally. To achieve the maximum effects of verbal communication, there should be good understanding between the parties. Therefore the pre-contract meeting is very important to be used as a platform to establish good client-designer-contractor’s relationships.

4.2 Communication media

4.2.1 Appraisal and strategic brief

Throughout the design process, all companies interviewed using the same method to communicate health and safety. Health and safety communication is being shared either verbally or written or through drawings. In the appraisal stage, the interviewees tend to have meeting with parties involved with them and record all the health and safety information. In normal cases, only communication between the architects and clients and CDMC are being recorded. Communication between the interviewees and the structural engineers and quantity surveyor at this stage is informal, mostly by telephone calls or informal emails to gain health and safety information and the budget from each discipline. The communication continues in the same pattern in the strategic brief stage. The interviewees keep communicating with the same parties involved, informally, either meeting individually or by telephone calls.

4.2.2 Proposal stages – outlined proposal, detailed proposal and final proposal

In the proposal stages, the pattern of health and safety communication in construction continues to be the same. The method of communication is verbal and written at this stage but more formal. More meetings are held and the health and safety information is recorded. On rare occasions, according to interviewee B, suppliers are also contacted to get some information regarding the materials that will be used in the construction. In the final proposal stage, according to interviewee A, basically it is not easy to pin down the communication of health and safety because it is very dynamic and it is not being recorded all the time. They have discussion and meeting regarding the project, and simultaneously health and safety information would be taken into account and they highlight the information in risk assessments. At proposal stages, all four interviewees agreed that the
communication goes on and becomes more condensed but the communication of health and safety is not a major topic. Since all the parties involved in proposal stages are coordinating the design together, they would be thinking of health and safety as part of their discussions. According to interviewee B, the architects would have separate meeting with the CDMC and review the health and safety information in depth.

During the product information stage, the communication of health and safety continues in a more formal way than the previous stages. All four interviewees would have more formal meetings, sending emails, fax and letters and conversation via telephone calls with the client, suppliers, engineers, quantity surveyor and the CDMC.

4.2.3 Tender stages – tender documents and tender action

All the health and safety information will be recorded and included in the risk assessment form and compiled in the tender document. During tendering stages, according to interviewee A, B and C, the communication in general is still going on and they keep in regular contact with the other parties but the communication of health and safety is low. All the considerations have been made in the previous stages. According to interviewee B, they would have only one meeting with the CDMC but the meeting is considered as very important to review the health and safety risks. This is to ensure that all information is gathered and the design is safe to be constructed.

4.2.4 Construction stages – mobilisation, construction to practical completion and after practical completion

Communication expands widely in the construction stages. By this time, the principal contractor, contractors and subcontractors have been appointed. As the lead designer, the responsibilities of interviewee A, B, C and D towards health and safety become more vital. Interviewees claimed that communication between the architects and the contractors is very frequent, communicating health and safety information via meetings, telephone calls, faxes, emails and drawings. The exchange of information has to be mutual because the contractors, through experience and skills may add additional health and safety considerations for the project. In some cases, they could be changes in the design. In this case, the communication with the other parties will also be very frequent as they have to revise and improve the design.

Interviewees stressed that it is very important to appoint a competent contractor as well as establishing good relationships among the team members. According to interviewee A, at this stage the informal verbal communication between the designers and the contractor is very important to remind the site staff of health and safety issues and to ensure that they take health and safety issues seriously. Interviewee D has different experience with projects in the retail sector where they are using a framework agreement as the base of the project. In the framework agreement style, there is no further communication between the designer and the contractor as the design has to be released straight away, therefore construction could start quickly unless there were changes in the design. In small scale projects, according to interviewee D, there are not so many issues to consider. They would only have one meeting with the contractor for the briefing of the design and the next meeting with contractor is
to handover the project. Therefore the communication between the designer and the contractor is limited. Company D communicates the design using a system on the intranet where all the drawings are in the system so they can be accessed by all parties involved in the project.

### 4.3 Communication barriers and challenges

One of the challenges to communicate health and safety is to get the most health and safety input from the client, as agreed by all four interviewees. According to interviewee B, health and safety information must be collected from the earliest point of the design stage. This is very important to ensure health and safety are being considered in the design. This view is shared with interviewee D that, based on experience, the investigation of health and safety risks should be done as soon as the client approaches the designer with a project proposal. For example, the investigation of asbestos existence in a construction site should be carried out before or in the appraisal or strategic brief stage so that, in the proposal stage, the precautionary steps to minimise the risks of asbestos could be included or considered as the design of the project develops. If the existence of asbestos is not established until the final proposal stage, they would have to revise the design and this will take longer time to finalise the design. In a worst case scenario, if asbestos is only found during the construction phase, this could put the workers or site agents at risk. Therefore it is very important to carry out site investigation and compile the health and safety information before the design starts to minimise risks at any point.

In regards to the client, all four interviewees also have much the same opinion on the clients’ knowledge of construction. If the client comes from a construction background, they are likely to understand the importance of highlighting the health and safety risks. Problems would arise if the client is from a different discipline or has very little knowledge about construction. Some of the clients that interviewee A and D dealt with did not know about the CDM regulations. Therefore, it is not easy to gain health and safety input from them and they would hesitate to spend more money hiring specialists for site investigations or land surveying. Interviewee B mentioned that some clients might have their own health and safety standards but related to their businesses rather than construction. Therefore it is crucial for the designers to communicate with these clients regarding the outline of health and safety requirements and regulations for construction projects. In other situations, clients who have little knowledge about construction would rely on the CDMC to advise them about health and safety in construction. However, according to interviewee A, the problems occur when clients became too dependent on CDMCs. A lot of decisions must be made by the clients such as budget approval for health and safety facilities, changes in design to coordinate health and safety information and so on.

The interviewees also agreed that too much documentation would lead to missed crucial health and safety information. The most important aspect of the ‘pre-construction information’ for each project is to highlight the specific residual risks that the designers have not been able to ‘design-out’ rather than including all the generic risks. Interviewee B thinks that it is human nature to avoid reading thick documents such as tender documents. Therefore, vital information such as health and safety information should only point out the specific potential risks which should also be communicated
verbally and visually. At some point in a project, there could be changes in the design, budget or time scale. The representatives from each discipline should be senior enough so that they could make decisions when a problem needs immediate attention. Interviewees identified some cases where meetings were attended by junior representatives from other disciplines, which meant that the problems could not be adequately addressed.

Interviewee C finds it difficult to record all the health and safety information and send all the information to other disciplines. Some of the conversations held were via telephone calls. Facing the same challenge, interviewee D would record every single bit of health and safety information because through experience, information, or the lack of it, might be used ‘against them’ later when a problem occurs. Interviewee C pointed out that the CDMC should be more proactive in coordinating health and safety information and ensure the parties involved get the same information. This aspect of the CDMC’s role remains contentious, despite clarification efforts revised in the CDM 2007 regulations.

5. Suggestion towards more effective health and safety communication

Clients should be more aware of the importance of health and safety information by giving more input to the team members. Budget allocation should take health and safety matters into account in order to provide the designers and the contractors with proper results of various site investigations and tests. According to interviewee B, clients should provide health and safety information in the early stage of a project therefore all of the considerations will be included in the design. Simultaneously, this could avoid clients spending money on avoiding risks that will not occur. Interviewee D stressed the need for clients’ willingness to spend more money on health and safety facilities and understand their roles and responsibilities to ensure that the project being planned and constructed safely. This is crucial to avoid accidents, fatal injuries and death during construction.

The CDMC should play larger role in recording all the health and safety information and ensure all the parties obtain the same information. Interviewee G suggests that the CDMC should be actively involved in every stage right from the beginning of the appraisal stage until completion. Communication becomes greater in construction phase. Interviewees felt that it was ‘almost impossible’ to keep track of all the health and safety information communicated by different contractors, subcontractors, site agents and workers. Verbal communication is very important to ensure that every person involved is aware of particular issues. To produce effective verbal communication, the stakeholders must establish good relationships from the very beginning of the project. In this regards, all four interviewees agreed on focusing on specific potential risks rather than the generic risks.

According to the interviewees, the designers should also cooperate with the CDMC in reinforcing the health and safety regulations. Regular communication should be made within the team members either verbally, written or visually to remind them of their roles and responsibilities in health and safety. Interviewee A suggests that the principal contractor should be involved from the early design stage, because their knowledge and experience, they will provide additional health and safety input.
Contractors have great responsibilities on site with regards to health and safety. Therefore, they have to ensure that the subcontractors, site agents and the workers get all the health and safety information and understand the work they are doing. Interviewee C emphasised the need for site agents and workers to have proper health and safety training.

Communication between team members and suppliers and subcontractors is also vital. Suppliers could be from a range of backgrounds and each product they supply to the construction site has different specifications. Subcontractors also come from different sectors.

6. Conclusion and further research

Communication between the designers in the design stage is essential and fairly straightforward. Health and safety information should be recorded and filed for the team members to keep and use whenever necessary. Cooperation among team members helps to produce a design that can be constructed safely. However, communication between designers and clients needs to improve. There should be more understanding about each other’s roles and responsibilities. The volume of communication increases significantly in the construction phase. The contractors should also ensure that the site agents, directly employed workers and subcontractors obtain the same health and safety information. The next phase of the research is to interview clients and contractors to gain their views on communication of health and safety information in construction. The findings from the interviews will be used to develop a framework on communication of health and safety in construction.

References

Beal, A. (2007), CDM Regulations: 12 years of pain but little gain, Civil Engineering, The Institution of Civil Engineers, Vol. 160, Issue 2, pp. 82-88


Airport Security: Structural Zoning in Developing Countries

Elzawi, A.
The University of Salford, UK
(email: a.a.d.elzawi@pgr.salford.ac.uk)
Eaton, D.
The University of Salford, UK
(email: d.eaton@salford.ac.uk)

Abstract

Civil aviation has often been an area of terrorist interest and activity. Long before the events of 11 September 2001, terrorists targeted airports and aircraft. The Rome and Vienna massacres of 1985 were launched against airports themselves. The hijacking of TWA 847 that same year, together with a variety of attacks occurring before and after those events served to identify aviation with terrorism in the public mind. For the terrorist, civil aviation assets remain high-value targets. Therefore, a safe and secure civil aviation system is a critical component of the nation’s overall security, physical infrastructure, and economic foundation. Billions of dollars and a myriad of programs and policies have been devoted to achieving such a system. The security measures employed in the airport environment involves screening passengers and their possessions, control of access to the aircraft and secured areas of the airport, and the inspections of baggage and cargo carried aboard the aircraft. This research paper sheds light on security zones in airports. The study focuses on identifying the main security zones in airports. These areas are: outside the airport and surrounding area; drop zones; lobby; boarding passes and check document zones; etc. The final contribution of the paper displays transit areas which may be vulnerable to breaches and terrorist attacks and identifies the relationship among of these areas. This research paper is entirely based on a literature review.

Keywords: performance measurements, security zones, airport security.
1. Introduction

Civil aviation has often been an area of terrorist interest and activity. Long before the events of 11 September 2001, terrorists targeted airports and aircraft. The Rome and Vienna massacres of 1985 were launched against airports themselves. The hijacking of TWA 847 that same year, together with a variety of attacks occurring before and after those events served to identify aviation with terrorism in the public mind. For the terrorist, civil aviation assets remain high-value targets. Therefore, a safe and secure civil aviation system is a critical component of the nation’s overall security, physical infrastructure, and economic foundation. Billions of dollars and a myriad of programs and policies have been devoted to achieving such a system.

However the link between aviation and the development of societies have been investigated in only a small number of studies. These have generally emphasised the importance of airport security in reforming standards of aviation security in developing countries. The studies also indicated that developing countries including Libya are facing economic, cultural and social problems related to the implementation of enhanced airport security. Therefore, these developing countries are looking to establish strategies that will help them in the improvement of social and economic development rather than aviation security.

The security measures employed in the airport environment involve inter alia: screening passengers and their possessions; control of access to the aircraft and secured areas of the airport, and the inspections of baggage and cargo carried aboard the aircraft; this is typically done by structural zoning of the airport.

The study focuses on identifying the main security zones in airports. These areas are: outside airport and surrounding areas; drop zones; lobby; boarding passes and check document zones; etc. The final contribution of the paper displays transit areas which may be vulnerable to breaches and terrorist attacks and identifies the relationship amongst these areas.

2. General aviation terminology

This section clarifies important terms such as Security, Airport, and Airport Security, etc., which are closely related to Aviation and will repeatedly be used in this research:

Security: Noun (pl. securities) (1) - the state of being or feeling secure. (2)- the safety of a state or organization against criminal activity such as terrorism or espionage, etc. (Ask-oxford dictionary);

Airports: Airports are key economic factors in the cities and regions, which they serve. The dynamics that relate to the development, construction, maintenance and operation of airports, therefore, deserve adequate study. As noted by Wiley, (1986) much of the literature on airports focuses on technical subjects, such as planning, design, construction, legal and environmental issues, while very little academic attention is focused on their management. The research by Wiley, (1986) is one of the few exceptions.
Airport threats: Aviation security staff deal with air rage, drunkenness, assault, smuggling and crime, as well as the threat of international terrorism – highlighted since the events of 9/11 such as underlined in the UK in the last couple of years. Other security concerns include stowaways, espionage, human trafficking, illegal immigration, theft, sabotage, hijack and environmental protest. Heightened security, including the deployment of sky marshals, continues to make headlines. The threat posed by knives and other relatively unsophisticated weapons has most certainly increased the number of potentially lethal items being impounded at airports.

Airport security: Until the 1960s, airport security was relatively simple, requiring nothing more than civilian police to provide protection against conventional crimes such as theft, pick pocketing, vandalism, and breaking and entering. However, in the 1960s civil aviation became a recognized target for politically motivated crimes. These crimes came to include general acts of terrorism, such as mass shootings and bombings and, especially, aircraft hijacking. (Encyclopaedia Britannica, 2009).

Wells and Young (2004) mentioned that the most significant issues facing by the airport in the 21st century is airport security. Airport security concerns all areas and all users of the airport, not limited to travelers, airport police force etc. To guarantee airport safety, different procedures are designed to detect, prevent and respond to chemical acts.

Security is different from safety. Security is means criminal activity, including hijacking, terrorism or any other unexpected criminal acts. Many parties are involved in securing the airport, including the airport administration body, the government, airlines, police and military force and so on.

It is clear that airport security therefore refers to an array of techniques and methods used in protecting airports and aircraft from crime. Large numbers of people pass through airports. Such gatherings present a target for terrorism and other forms of crime. Similarly, the high concentration of people on large airliners, the potential high mortality rate of attacks on aircraft, and the ability to use a hijacked airplane as a lethal weapon provide an alluring target for terrorism.

But the airport is primarily the place where passengers and their baggage can be controlled before boarding an aircraft. Preventing dangerous objects from being brought on board an aircraft is a significant step to prevent all acts of unlawful interference during a flight.

Moreover, airport security provides defence by attempting to deter would-be attackers from bringing weapons or bombs into the airport. If they can succeed in this, then the chances of these devices getting on to aircraft are greatly reduced. As such, airport security serves two purposes: to protect the airport from attacks and crime and to protect the aircraft from attack.

Airport security controls are governed by local regulations that have a genesis in national and international standards. For example; at Heathrow Airport; regulations control the drop off and pick up points at the concourse of each terminal, whereas in Khartoum Airport, a heavy presence of armed police and military personnel standing outside the airport is a scene similar to a military base. In Tripoli Airport, Libya; there is a drop off and pick up zone sited outside the airport concourse area
and special coaches run between this point and concourse. All these controls are legislated by
governments, local government and airport authorities.

Gileard and Yiqun. (1999) believe that security of promises is part of facility management. In other
words facility management consist of property services such as maintenance, restricted area,
commune areas, security, etc.

According to the above statement, it is safe to say that airport security is part of facility management
of an airport, and facility management is part of airport management, therefore security airport is part
of airport management.

### 3. Performance measurement

Performance measurement’s origins can be traced back to the Progressive era reform movement,
during which reformers were preoccupied with making government more efficient. Frederick Taylor’s
(1912) work exemplified the reform movement’s concern with efficiency and measurement. His
scientific management approach proposed that knowledge about a process could be reduced into laws
and formulae resulting in the most efficient method or “the one best way” to accomplish a task. Then,
as now, reformers were most concerned with efficiency, that is, how to produce the most output using
the least amount of inputs. Measuring inputs and out-puts was the main idea behind Taylor’s seminal
approach at improving managerial efficiency.

Enoma and Allen, (2007) argue that measurement is still one of the critical aspects of today's
management, just as it has been in the past being a key aspect of scientific development since the
seventeenth century. The concept of performance measurement has been embraced by facilities
managers and project managers, who increasingly use it as a benchmark against which effectiveness
can be measured, and a basis for which improvement can be determined.

The link between airport management and performance measurement can be displayed as follows:

Sinclair and Zairi(1995) claim, reveal the need for measurement in enabling good planning and
control, continuous improvement, resource allocation, motivation and long-term focus judging it to be
a valid management tool.

Moreover, Varcore(1996) says that applying the disciplines of performance measurement helps
managers and operators alike to determine those issues that crucially important to the overall
organisation and its success, also those issues that similarly are crucial to the successful delivery of
the specific function or operations concerned.

Thus, there is a strong relation between airport management and performance measurement. It is
required to shed light on performance measurement for its importance and vital role and as an
effective tool can be used by managers.
4. Aviation Performance Measures (APM)

Doganis et al. (1992) discuss that Airport Performance Measurement (APM) is a critical management activity at both the individual airport and the wider system levels. Airport managers and governments measure airport performance for three main purposes: to measure financial and operational efficiency; to evaluate alternative investment strategies; and to allow governments to regulate airport activity.

Gosling et al. (2000) notes that airports are complex and dynamic organizations that consist of many interacting parts, which include passengers, airlines, handling agents, ground transportation service providers, other aviation-related activity, and the interests of the regional and national economy. The range of different performance measurements reflects this complex nature. There has been a tendency to search for measures to simplify airport performance so that league tables can be drawn up and comparisons made.

Humphreys et al. (2008) argue that there is often the significant failure to recognize this underlying context with existing performance measures. Airports serve vastly different passenger types, all of whom have different needs and wants, which in turn impose a range of different demands on the airport’s resources.

Jacobson et al (2003) introduced APM for baggage screening systems. These performance measures can be used to formulate models for designing optimal aviation security systems. To describe these measures, several definitions are needed. Station is a set of airport facilities that share security resources. For example, a station could be an entire small airport or one airline’s terminal within a larger airport. All passengers are designated as either selected or non-selected, based on passenger-specific information that is processed and evaluated through a computer expert system.

Finally, the literature reveals that airport security is related to highly sensitive political decisions. These political decisions; if they were wrong may affect relations among countries involved in a negative way which determine the future relations of these countries. For example, in 2004, a Libyan airplane was hijacked by a group of Eritreans and forced to land in Sudan. The fundamental question is how did the group of the Eritrean hijackers get the weapons on the airplane? Yet, the decisions made by the Sudanese government affected the relations among the governments in Sudan, Libya and Eritrea.

In 1988, Lockerbie Pan AM flight 103 incident shocked the world greatly even before 9/11 (Sweet, 2004). Several countries where involved, and their political relations deteriorated to a level where sanctions were imposed on the suspected country. The problem was eventually solved in 2004; 16 years after the incident. This argument highlights the importance of airport security and how significantly it affects governments, politics, economics, and future relations.

It is important to mention that literature is so scarce and not up-to-date on airport security; however it is available in abundance on the incidents of hijacking and smuggling issues. It appears that revealing or setting examples of airport security in a country is not a desirable or perhaps acceptable matter.
Advanced countries such as the USA, Britain, Europe, Japan, etc., are so strict on airport security systems and the industry is controlled and regulated because it is related to their national security.

Written literature sources are hard to find because as it mentioned previously; airport security is related to national security of a country and is highly sensitive issue. Therefore, the research resorts to primary techniques.

5. Incidents of airport security

This section sheds light on the problems facing airport security and how it could affect the performance of the industry worldwide. The discussion highlights general approaches and practices of airport security.

The following table displays the number of incidents between 1999-2001 in the USA. The data in table 1 below is old; unfortunately, recent and new data and information are not available because of the recent development in the aviation industry after 9/11 incident worldwide.

Table 1: Incidents and breaches occurring in airport security in the USA (Oman, 2002):

<table>
<thead>
<tr>
<th>Airport</th>
<th>Date</th>
<th>Delay Minutes</th>
<th>Passengers Affected</th>
<th>Flights Affected</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austin-Bergstrom Intl.</td>
<td>2/5/00</td>
<td>25</td>
<td>500</td>
<td>5</td>
<td>Man set off alarm and ran—not found</td>
</tr>
<tr>
<td>Chicago O’Hare</td>
<td>8/25/99</td>
<td>Many hours</td>
<td>6000</td>
<td>221</td>
<td>Man bolted past security checkpoint—not found</td>
</tr>
<tr>
<td>Cleveland Hopkins Intl.</td>
<td>2/5/00</td>
<td>45</td>
<td>200</td>
<td>12</td>
<td>Women set off metal detector and did not wait for security</td>
</tr>
<tr>
<td>Los Angeles Intl.</td>
<td>3/1/01</td>
<td>120</td>
<td>1800</td>
<td>20</td>
<td>Man barged through exit door</td>
</tr>
<tr>
<td>Los Angeles Intl.</td>
<td>12/19/99</td>
<td>180</td>
<td>9000</td>
<td>66</td>
<td>Man ran with laptop rather than turn it on</td>
</tr>
<tr>
<td>Los Angeles Intl.</td>
<td>5/21/99</td>
<td>30</td>
<td>Not specified</td>
<td>Not specified</td>
<td>Individual entered without being properly screened</td>
</tr>
<tr>
<td>McCarron Intl. Las Vegas</td>
<td>3/20/00</td>
<td>Not specified</td>
<td>7000</td>
<td>Not specified</td>
<td>Man set off alarm and ran—not found</td>
</tr>
<tr>
<td>San Francisco Intl.</td>
<td>5/19/00</td>
<td>120</td>
<td>Not specified</td>
<td>8</td>
<td>Man late for flight, jumped security checkpoint, not found</td>
</tr>
</tbody>
</table>

Frederickson & La Porte, (2002) discuss the use of high technology security in airports and the role of security in aviation. Moreover, Lazarick (2001) described terrorist attacks on many different targets in different nations. Over the years, the world such as the USA, Britain, Israel, Libya, Russia, Canada, Norway, Germany, etc. has experienced acts of terrorism directed at civil aviation, in the form of numerous hijackings and high-visibility aircraft bombincidents. The effects of example breach incidents at US airports are shown in (Table 1). For example; on 2nd of May 2000, in Austin-
Bergstrom International Airport there was 25min delay, 500 passengers affected, 5 flights affected because a man set off alarm and ran. On 19th Dec 99, Los Angeles International Airport, there was 180 min delay, 9000 passengers affected, 66 flights affected because a man ran with laptop rather than turn it on, etc.

6. Airport security zones

Generally, the security measures employed in the airport environment involves screening passengers and their possessions, control of access to the aircraft and secured areas of the airport, and the inspections of baggage and cargo carried aboard the aircraft. Lazarick (2001) cited examples of security breaches at airports and how they might be prevented. For example, the entry of a terrorist through an exit lane into the passenger-loading area could be blocked by a one-way revolving door; a coded strip could be attached to a suitcase when it is accepted at the passenger-ticket desk, only baggage with strips would be loaded into the airplane; airport employees who have access to airplanes normally carry a card with a photograph, a high-level encrypted portrait could be embedded in the card, so that a terrorist with a forged card could not pass the entry gate.

Civil Aviation Annual Report; Hong Kong (2005) suggests that in order to ensure the security of passengers, they need to take time to pass through different security zones check. Therefore, passengers have to pass through metal detection and their luggage have to be checked through x-ray machine then sometimes require additional checks before passengers get on board, it will take even more time. Moreover, at present time some airports asking passengers to pass through the body search or the x-ray. As a consequence; some passengers may think it is an encroachment on their privacy. The security process as a whole could be considered a keeping the balance between the security and privacy.

Figure 1: Airports security Breaches (Elzawi, 2009)
Figure 1 illustrates the areas of airport security needed to be addressed by airport management and decision makers. It is clear that airport security is divided into five major areas. The first is outside it airport and surrounding area; it includes the entry, dropping zones, and parking places which lead to the airport. This area is the outside zone where airport security commences. The second is the lobby, boarding passes and check document zones. This area is second in order and the first inside airport buildings. These areas are highly congested and crowded with passengers and other visitors. It also consists of all the rest areas, shops, restaurants, airline offices, etc. It is a very hard zone to control because of this overcrowding and all sort of people in different ages are there. The third zone is check-in points. This zone is the most crucial zone. Security personnel, police dogs and advanced security and screening equipment are present in this area. The fourth zone is the waiting gate zone. This area is for passengers only and some other administrative and security staff. Passengers have already been checked, scanned and screened. The final zone is inside the airplane. Only passengers with boarding cards are allowed to enter the plane with flight staff (Pilots, Crew and Stewards). All of these airport security zones are important and they are like organs in a healthy body. Any organ becomes ill affects the performance of other organs and eventually leads to chronic illness of the body.

The five structural security zones illustrated in Figure 1 is important for airport security and believed to enhance the security performance in airports in the developing countries. This is because that there is big number of airplane hijackings which indicates the lack of security in airports worldwide. Examples on the rise of airplane hijacking cases are such as the Transportation Security Administration reported 1,442 security breaches at the nation's 450 commercial airports in the fiscal year ended Sept. 30, 2004, according to the Government Accountability Office report. Reported breaches jumped to 2,073 in fiscal year 2005, 2,258 in fiscal 2006, 2,758 in fiscal 2007 and 2,819 in fiscal 2008 (Fontaine, 2010). Moreover, Wells and Young (2004) state that in June 1985, Lebanese terrorists diverted a TWA plane leaving Athens for Beirut. One passenger was murdered during the 2-week ordeal; the remaining 155 were released. This hijacking was an upsurge in Middle East terrorism, resulted in several U.S. actions, among them the International Security and Development Cooperation Act of 1985 that made federal air marshals a permanent part of the FAA workforce. Wells and Young (2004) add that on December 21, 1988, a bomb destroyed Pan American flight 103 over Lockerbie, Scotland. All 259 people aboard the London-to-New York flight, as well as 11 on the ground were killed. Investigators found that a bomb concealed in a radio-cassette player had been loaded on the plane in Frankfort, Germany. The security measures that went into effect for U.S. carriers at European and Middle Eastern airports after the Lockerbie bombing included requirements to x-ray or search all

7. Conclusion

In the aftermath of 9/11 many new security systems and devices were proposed or implemented. While greater scrutiny is required, the question of which new methods are the most effective remains to be studied. Furthermore, enhanced airport security and implementation of the new technologies will cost billions of dollars and will drive up the cost of tickets and increase taxes. Governments worldwide have introduced new drastic measures to assess and minimise risk in aviation and airports as it is an important part of national security. These recent measures include background checks of employees, stringent passenger screening, baggage matching and x-ray scrutiny, secure cockpits, and
sky marshals. Prior to entering the gate area, passengers must pass through metal detecting devices and subject their carry-on bags to examination through an x-ray machine. Trace detection of explosives on carry-on bags can be achieved by use of a swab. Immigration checks could be processed automatically, and that frequent fliers could expedite processing by providing detailed, personal information and their travel plans to the airline. This information could also be stored on an embedded chip on a Smart Card. The economic impact of these costly measures and the ensuing airport delays has resulted in significant loss of revenue for air carriers; thus it has become imperative to consider the importance of these new security measures.

Finally, this research paper has also contributed to airport security by providing a theoretical model of the major zones to be considered in airport security. This will make the process of controlling airport security much easier because it gives governments and authorities the step-stone or perhaps the starting point in airport security control.

**Bibliography**


Britannica Encyclopaedia Online (2009), ULR: http://www.britannica.com/EBchecked/topic/456811/philosophy


John D. Gilleard and Pan Yiqun, (1999), Challenge and opportunity: facility management in Shanghai,
http://www.emeraldinsight.com/Insight/viewPDF.jsp?contentType=Article&Filename=html/Output/Published/EmeraldFullTextArticle/Pdf/0690170305.pdf

Lazarick, R (2001), Applications of Technology in Airport Access Control, U.S. Federal Aviation Administration (FAA), Aviation Security R&D, pp. 85-95, Downloaded on August 27, 2009 at 10:04 from IEEE Xplore.


Salter M. (2007), SeMS and Sensibility: Security Management Systems and Management and Risk in the Canadian Air Transport; Security Authority, Science Direct Journal, Accessed 09/09/2009, ULR: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VGP-4PPFT5C-1&user=10&rdcu=1&_fnt=&_orig=search&_sort=d&_docanchor=&view=c&_searchStrId=1006339286&_rerunOrigin=google&acct=C000050221&_version=1&_urlVersion=0&md5=332b91b5ca1e6ec7737641bd7c3c47b2


CIB's mission is to serve its members through encouraging and facilitating international cooperation and information exchange in building and construction research and innovation. CIB is engaged in the scientific, technical, economic and social domains related to building and construction, supporting improvements in the building process and the performance of the built environment.

CIB Membership offers:
- international networking between academia, R&D organisations and industry
- participation in local and international CIB conferences, symposia and seminars
- CIB special publications and conference proceedings
- R&D collaboration

Membership: CIB currently numbers over 400 members originating in some 70 countries, with very different backgrounds: major public or semi-public organisations, research institutes, universities and technical schools, documentation centres, firms, contractors, etc. CIB members include most of the major national laboratories and leading universities around the world in building and construction.

Working Commissions and Task Groups: CIB Members participate in over 50 Working Commissions and Task Groups, undertaking collaborative R&D activities organised around:
- construction materials and technologies
- indoor environment
- design of buildings and of the built environment
- organisation, management and economics
- legal and procurement practices

Networking: The CIB provides a platform for academia, R&D organisations and industry to network together, as well as a network to decision makers, government institution and other building and construction institutions and organisations. The CIB network is respected for its thought-leadership, information and knowledge.

CIB has formal and informal relationships with, amongst others: the United Nations Environmental Programme (UNEP); the European Commission; the European Network of Building Research Institutes (ENBRI); the International Initiative for Sustainable Built Environment (iISBE), the International Organization for Standardization (ISO); the International Labour Organization (ILO), International Energy Agency (IEA); International Associations of Civil Engineering, including ECCS, fib, IABSE, IASS and RILEM.

Conferences, Symposia and Seminars: CIB conferences and co-sponsored conferences cover a wide range of areas of interest to its Members, and attract more than 5000 participants worldwide per year.

Leading conference series include:
- International Symposium on Water Supply and Drainage for Buildings (W062)
- Organisation and Management of Construction (W065)
- Durability of Building Materials and Components (W080, RILEM & ISO)
- Quality and Safety on Construction Sites (W099)
- Construction in Developing Countries (W107)
- Sustainable Buildings regional and global triennial conference series (CIB, ISBE & UNEP)
- Revaluing Construction
- International Construction Client's Forum

CIB Commissions (August 2010)
TG58 Clients and Construction Innovation
TG59 People in Construction
TG62 Built Environment Complexity
TG63 Disasters and the Built Environment
TG64 Leadership in Construction
TG65 Small Firms in Construction
TG66 Energy and the Built Environment
TG67 Statutory Adjudication in Construction
TG68 Construction Mediation
TG69 Green Buildings and the Law
TG71 Research and Innovation Transfer
TG72 Public Private Partnership
TG73 R&D Programs in Construction
TG74 New Production and Business Models in Construction
TG75 Engineering Studies on Traditional Constructions
TG76 Recognising Innovation in Construction
TG77 Health and the Built Environment
TG78 Informality and Emergence in Construction
TG79 Building Regulations and Control in the Face of Climate Change
TG80 Legal and Regulatory Aspects of BIM
TG81 Global Construction Data
W014 Fire
W018 Timber Structures
W023 Wall Structures
W040 Heat and Moisture Transfer in Buildings
W051 Acoustics
W055 Construction Industry Economics
W056 Sandwich Panels
W062 Water Supply and Drainage
W065 Organisation and Management of Construction
W069 Housing Sociology
W070 Facilities Management and Maintenance
W077 Indoor Climate
W078 Information Technology for Construction
W080 Prediction of Service Life of Building Materials and Components
W083 Roofing Materials and Systems
W084 Building Comfortable Environments for All
W086 Building Pathology
W089 Building Research and Education
W092 Procurement Systems
W096 Architectural Management
W098 Intelligent & Responsive Buildings
W099 Safety and Health on Construction Sites
W101 Spatial Planning and infrastructure Development
W102 Information and Knowledge Management in Building
W104 Open Building Implementation
W107 Construction in Developing Countries
W108 Climate Change and the Built Environment
W110 Informal Settlements and Affordable Housing
W111 Usability of Workplaces
W112 Culture in Construction
W113 Law and Dispute Resolution
W114 Earthquake Engineering and Buildings
W115 Construction Materials Stewardship
W116 Smart and Sustainable Built Environments
W117 Performance Measurement in Construction
Publications: The CIB produces a wide range of special publications, conference proceedings, etc., most of which are available to CIB Members via the CIB home pages. The CIB network also provides access to the publications of its more than 400 Members.

Recent CIB publications include:
• Guide and Bibliography to Service Life and Durability Research for Buildings and Components (CIB 295)
• Performance Based Methods for Service Life Prediction (CIB 294)
• Performance Criteria of Buildings for Health and Comfort (CIB 292)
• Performance Based Building 1st International State-of-the-Art Report (CIB 291)
• Proceedings of the CIB-CTBUH Conference on Tall Buildings: Strategies for Performance in the Aftermath of the World Trade Centre (CIB 290)
• Condition Assessment of Roofs (CIB 289)
• Proceedings from the 3rd International Postgraduate Research Conference in the Built and Human Environment
• Proceedings of the 5th International Conference on Performance-Based Codes and Fire Safety Design Methods
• Proceedings of the 29th International Symposium on Water Supply and Drainage for Buildings
• Agenda 21 for Sustainable Development in Developing Countries

R&D Collaboration: The CIB provides an active platform for international collaborative R&D between academia, R&D organisations and industry.

Publications arising from recent collaborative R&D activities include:
• Agenda 21 for Sustainable Construction
• Agenda 21 for Sustainable Construction in Developing Countries
• The Construction Sector System Approach: An International Framework (CIB 293)
• Red Man, Green Man: A Review of the Use of Performance Indicators for Urban Sustainability (CIB 286a)
• Benchmarking of Labour-Intensive Construction Activities: Lean Construction and Fundamental Principles of Working Management (CIB 276)
• Guide and Bibliography to Service Life and Durability Research for Buildings and Components (CIB 295)
• Performance-Based Building Regulatory Systems (CIB 299)
• Design for Deconstruction and Materials Reuse (CIB 272)
• Value Through Design (CIB 280)

Themes: The main thrust of CIB activities takes place through a network of around 50 Working Commissions and Task Groups, organised around four CIB Priority Themes:
• Sustainable Construction
• Clients and Users
• Revaluing Construction
• Integrated Design and Delivery Solutions

CIB Annual Membership Fee 2010 – 2013
Membership will be automatically renewed each calendar year in January, unless cancelled in writing 3 months before the year end

<table>
<thead>
<tr>
<th>Fee Category</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM1 Fee level</td>
<td>11837</td>
<td>12015</td>
<td>12195</td>
<td>12378</td>
</tr>
<tr>
<td>FM2 Fee level</td>
<td>7892</td>
<td>8010</td>
<td>8131</td>
<td>8252</td>
</tr>
<tr>
<td>FM3 Fee level</td>
<td>2715</td>
<td>2756</td>
<td>2797</td>
<td>2839</td>
</tr>
<tr>
<td>AM1 Fee level</td>
<td>1364</td>
<td>1384</td>
<td>1405</td>
<td>1426</td>
</tr>
<tr>
<td>AM2 Fee level</td>
<td>1133</td>
<td>1246</td>
<td>1371</td>
<td>1426</td>
</tr>
<tr>
<td>IM Fee level</td>
<td>271</td>
<td>275</td>
<td>279</td>
<td>283</td>
</tr>
</tbody>
</table>

All amounts in EURO

The lowest Fee Category an organisation can be in depends on the organisation’s profile:

FM1 Full Member Fee Category 1 | Multi disciplinary building research institutes of national standing having a broad field of research

FM2 Full Member Fee Category 2 | Medium size research Institutes; Public agencies with major research interest; Companies with major research interest

FM3 Full Member Fee Category 3 | Information centres of national standing; Organisations normally in Category 4 or 5 which prefer to be a Full Member

AM1 Associate Member Fee Category 4 | Sectoral research & documentation institutes; Institutes for standardisation; Companies, consultants, contractors etc.; Professional associations

AM2 Associate Member Fee Category 5 | Departments, faculties, schools or colleges of universities or technical Institutes of higher education (Universities as a whole can not be Member)

IM Individual Member Fee Category 6 | Individuals having an interest in the activities of CIB (not representing an organisation)

Fee Reduction:
A reduction is offered to all fee levels in the magnitude of 50% for Members in countries with a GNIpc less than USD 1000 and a reduction to all fee levels in the magnitude of 25% for Members in countries with a GNIpc between USD 1000 ~ 7000, as defined by the Worldbank. (see http://siteresources.worldbank.org/DATASTATISTICS/Resources/GNIPC.pdf)

Reward for Prompt Payment:
All above indicated fee amounts will be increased by 10%. Members will subsequently be rewarded a 10% reduction in case of actual payment received within 3 months after the invoice date.

For more information contact
CIB General Secretariat:
e-mail: secretariat@cibworld.nl
PO Box 1837, 3000 BV Rotterdam,
The Netherlands
Phone +31-10-4110240;
Fax +31-10-4334372
Http://www.cibworld.nl
DISCLAIMER

All rights reserved. No part of this book may be reprinted or reproduced or utilized in any form or by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying and recording, or in any information storage or retrieval system without permission in writing from the publishers.

The publisher makes no representation, express or implied, with regard to the accuracy of the information contained in this book and cannot accept any legal responsibility or liability in whole or in part for any errors or omissions that may be made.

The reader should verify the applicability of the information to particular situations and check the references prior to any reliance thereupon. Since the information contained in the book is multidisciplinary, international and professional in nature, the reader is urged to consult with an appropriate licensed professional prior to taking any action or making any interpretation that is within the realm of a licensed professional practice.