Applied Ergonomics 36 (2005) 391–400

APPLIED ERGONOMICS

www.elsevier.com/locate/apergo

Accident patterns and prevention measures for fatal occupational falls in the construction industry

Chia-Fen Chi[a,*], Tin-Chang Chang[a], Hsin-I Ting[b]

[a]*Department of Industrial Management, National Taiwan University of Science and Technology, 43 Keelung Road, Section 4, Taipei, Taiwan 106*
[b]*CTCI Corporation*

Received 5 March 2004; accepted 13 September 2004

Abstract

Contributing factors to 621 occupational fatal falls have been identified with respect to the victim's individual factors, the fall site, company size, and cause of fall. Individual factors included age, gender, experience, and the use of personal protective equipment (PPE). Accident scenarios were derived from accident reports. Significant linkages were found between causes for the falls and accident events. Falls from scaffold staging were associated with a lack of complying scaffolds and bodily action. Falls through existing floor openings were associated with unguarded openings, inappropriate protections, or the removal of protections. Falls from building girders or other structural steel were associated with bodily actions and improper use of PPE. Falls from roof edges were associated with bodily actions and being pulled down by a hoist, object or tool. Falls through roof surfaces were associated with lack of complying scaffolds. Falls from ladders were associated with overexertion and unusual control and the use of unsafe ladders and tools. Falls down stairs or steps were associated with unguarded openings. Falls while jumping to a lower floor and falls through existing roof openings were associated with poor work practices. Primary and secondary prevention measures can be used to prevent falls or to mitigate the consequences of falls and are suggested for each type of accident. Primary prevention measures would include fixed barriers, such as handrails, guardrails, surface opening protections (hole coverings), crawling boards/planks, and strong roofing materials. Secondary protection measures would include travel restraint systems (safety belt), fall arrest systems (safety harness), and fall containment systems (safety nets).

Keywords: Fatal falls; Falls from height; Construction ergonomics; Construction site safety

1. Introduction

The construction industry has been identified as one of the most hazardous industries in many parts of the world and falls from height are a leading cause of fatalities in construction operations (Sorock et al., 1993). In Taiwan, Chi and Wu (1997) showed that falls contributed to more than 30% (377) of 1230 work-related fatalities. In seeking to understand the causes of these incidents, epidemiological analyses are of value in revealing the factors associated with fatal injuries. However, care is needed with the choice of classification scheme for the analysis as this can materially affect the outcome (Chi and Wu, 1997). Appropriately defined classification categories are also important in forming the basis for effective accident prevention programs (Hinze et al., 1998).

The research presented here developed a coding system to facilitate the categorization of fatal falls in terms of the cause of the fall, the fall location, individual factors, and company size, in order to determine the importance of contributing factors and to derive effective protection strategies. A total of 621 fatal falls were coded based on the classification scheme. The Finnish Multi-Linear Event-Sequencing Method (Aaltonen, 1996) and the Operationalized Model (Tuominen

*Corresponding author. Tel: +886 2 2737 6338; fax: +886 2 2737 6344.
E-mail address: chris@mail.ntust.edu.tw (C.-F. Chi).

0003-6870/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apergo.2004.09.011

and Saari, 1982), which treat an accident as a flow of events, were adopted to determine potential causes preceding the fall event (Chi et al., 2004).

1.1. Classification scheme

1.1.1. Cause of fall

Causes of accidents are not easy to isolate, especially in fatal accidents (Cattledge et al., 1996). Drury and Brill (1983) derived hazard scenarios in terms of the actors (individual), the prop (the tools, instruments and equipment), the scene (environment), and the action (task) from incident reports. They emphasized that each scenario suggested at least one feasible and effective intervention, but such an intervention strategy was appropriate only to that scenario. The current study adopted Drury and Brill's (1983) scenario analysis to characterize the causes of work-related fatal falls in terms of the individual, the task, tools and equipment used, and managerial and environmental factors. Each accident report was reviewed several times to itemize the detailed causes of fall under each factor. Individual factors included: bodily actions (e.g., climbing, walking, and leaning against), distraction, insufficient capacities, and the improper use of personal protective equipment (PPE). Task factors include overexertion and unusual control, poor work practices, and the removal of protection measures. Tools and equipment factors included mechanical failure, unsafe ladder and tools, or being pulled down. Management and environment factors included unguarded openings, lack of complying scaffolds, unauthorized access to hazard areas, contact with falling object, and harmful substances.

1.1.2. Accident event

The US Department of Labor (2003) has 11 categories for fatal falls. These include (1) falls from stairs or steps, (2) falls through existing floor openings, (3) falls from ladders, (4) falls through roof surfaces (including existing roof openings and skylights), (5) falls from roof edges, (6) falls from scaffolds or staging, (7) falls from building girders or other structural steel, (8) falls while jumping to a lower level, (9) falls through existing roof openings, (10) falls from floors, docks, or ground level, and (11) other non-classified falls to lower levels. These categories were used directly in this study.

1.1.3. Individual factors

Age was coded as in our previous study (Chi and Wu, 1997). Worker's experience was classified after Butani (1988) into six different levels to compare the relative risk of injuries for different levels of experience. These levels were $0<$ to $\leqslant 1$, $1<$to $\leqslant 5$, $5<$to $\leqslant 10$, $10<$to $\leqslant 15$, $15<$to$\leqslant 20$, and >20 years. Company size was coded according to the categories used by the Directorate-General of Budget Accounting and Statistics (1997).

2. Methodology

2.1. Accident report of fatal falls

The current study analyzed 621 case reports of work-related fatal falls occurring during 1994–1997. All accident reports were extracted from case reports that were published by the Council of Labor Affairs of Taiwan. Each accident report identified the type of industry, age, gender, experience level of the victim, the source of injury, the company size, as measured by number of workers employed, accident type and any other factors which were judged to be relevant. Following Drury and Brill's (1983) in-depth investigation, *individual factors* (gender, age, experience level of the victim, and use of PPE), *task factors* (performing tasks), *environmental factors* (fall location), *management factors* (company size measured by number of workers), and cause of fall were coded for each fatality report for analysis.

2.2. Statistical analyses

Standardized mortality ratios (SMR) for each stratified gender, age, and company size group were calculated, along with 95% confidence intervals (Kelsey et al., 1996), using the working population of the Taiwanese construction industry in 1994–1997 (Directorate-General of Budget and Accounting Statistics, 1994–1997) as the reference group for the calculations.

Cramer's V and Phi coefficient analysis, based on Chi-square, were used to examine the relationship between factors (Kurtz, 1999). Where expected frequencies were less than 5, Fisher's exact test was used in place of Chi-square (Mehta et al., 1992).

3. Results

3.1. Frequency analysis

Frequency analysis was performed on each coded variable. This indicated that the majority of victims were male (572, 92.1%), between 25 and 44 years old (319, 51.4%), worked for companies with less than 30 workers (164, 26.4%) (Table 1), and had less than 1 year of work experience (500, 80.5%) (Table 2). The SMRs of various population segments were taken to be significantly different when the 95% confidence intervals of their SMRs did not overlap (Chi and Chen, 2003). Significant differences in SMR were found among different gender, age and company size groups. Different categories,

Table 1
Frequency distribution and SMR for stratified gender, age, and company size, together with SMR groupings derived from the statistical analysis

Factor		Frequency	%	SMR	95%CI	SMR groupings
Gender	Male	572	92.1	1.05	(0.97–1.14)	B
	Female	49	7.9	0.64	(0.47–0.84)	A
Age	Under 24	70	11.3	0.89	(0.69–1.12)	B
	25–34	138	22.2	0.66	(0.55–0.78)	A
	35–44	181	29.1	0.91	(0.78–1.05)	B
	45–54	116	18.7	1.23	(1.01–1.47)	C
	Over 55	113	18.2	3.17	(2.61–3.81)	D
	Unknown	3	0.5	—		
Company size	<5	54	8.7	2.75	(2.07–3.59)	D
	5–9	60	9.7	2.13	(1.62–2.74)	D
	10–29	50	8.1	1.10	(0.81–1.44)	C
	30–49	11	1.8	0.60	(0.30–1.08)	B
	50–99	7	1.1	0.32	(0.13–0.65)	B
	100–499	1	0.2	0.03	(0.00–0.19)	A
	$\geqslant 500$	1	0.2	0.05	(0.00–0.26)	A
	Unknown	437	70.4	—		

according to the SMRs, are indicated by alphabetical letters (Table 1).

The SMR indicated that males are more likely to be victims for fatal falls in the construction industry. Our previous analysis of national and cross-sectorial study of occupational fatalities indicated that female workers in high-risk industries, such as construction, and mining and quarrying have a lower fatality rate than their male counterparts (Chi and Chen, 2003). Possible reasons for the difference may be that female workers work fewer hours (Messing et al., 1994), and females are seldom employed in outdoor jobs or in jobs with extreme conditions (Lucas, 1974). Female workers were more likely to suffer fatal falls when performing cleaning and housekeeping tasks (11 cases), or doing plasterwork of building interiors (8 cases).

A U-shape relationship was found between age and SMR ($p<0.05$), indicating that age (or most likely experience) was beneficial to workers for a certain period of time, but became less of an advantage over a certain age (Laflamme and Menckel, 1995). Fatal falls of aging workers (aged 55 and above) could have been caused by reduced sensory capability (e.g., decline of vision and hearing), and reduced physical strength and flexibility. Young workers (<24 years old) were suspected to suffer fatal falls due to inexperience and carelessness (Chi and Wu, 1997).

The SMRs in the analyses related to the number of workers are estimated. The estimates are based on the number of workers employed for companies that had fatalities in 1994, and the number of workers employed in all construction companies in 1996. This is because the Directorate-General of Budget Accounting and Statistics (1997) only had 1996 data. There was a significantly increasing SMR with decreasing company size ($p<0.001$) as with Buskin and Paulozzi (1987). Possible reasons for the greater risk with decreasing company size might be due to smaller companies' inability to afford safety programs and personnel, or because smaller companies are less likely to be inspected by relevant government agencies and often perform inherently riskier work (Buskin and Paulozzi, 1987).

Approximately 87% (537 cases) of the accident events can be classified as falls from scaffolding, staging, from existing floor openings, from building girders or other structural steel, from roof edges, through roof surfaces, from ladders, falls down stairs or steps, falls while jumping to a lower floor, and from existing roof openings (Table 2). Causes for fatal falls were also evaluated. More than 40% of the cases could be attributed to lack of complying scaffolds (160) and unguarded openings (104). Lack of complying scaffold was coded into lack of platform (58), lack of scaffold (55), and lack of fixed barrier (47). Being pulled down was coded with respect to the agent that caused the pulling. There were cases of being pulled down by heavy objects (21), hoists (9), trolleys (6), collapsing materials (2) and ladders (1). Inappropriate protection was coded into unfixed covers (15), insecure barriers (11), broken PPE (6), ineffective safety nets (2) and lack of secure anchors (1). Harmful substances and environment were coded into bad weather (rain, strong wind, thunder, and earthquake) (13), bumpy and restricted walkways (7), poor lighting and ventilation (3). Removal of protection measures was also coded into removal of barriers to facilitate materials handling (15) and the release of anchors after finishing a task (6).

3.2. Association between factors and between levels of factors

The Cramer's V coefficients indicate that significant associations exist between gender and cause of fall

Table 2
Frequency distribution of other contributing factors

Factor			Frequency	%
Experience	Under 1 year		500	80.5
	1–5 years		84	13.5
	5–10 years		18	2.9
	10–15 years		4	0.6
	Over 15 years		9	1.4
	Unknown		6	1.0
Accident event	Fall from scaffold, staging		189	30.4
	Fall through existing floor opening		128	20.6
	Fall from building girders or other structural steel		70	11.3
	Fall from roof edge		65	10.5
	Fall through roof surface		44	7.1
	Fall from ladder		26	4.2
	Fall down stairs or steps		11	1.8
	Jump to lower level		2	0.3
	Fall through existing roof opening		2	0.3
	Fall from floor, dock, or ground level		51	8.2
	Fall to lower level		33	5.3
Cause of fall	Unguarded opening		104	16.7
	Bodily action		62[a]	10
	Poor work practices		44[a]	7.1
	Improper use of personal safety equipment		23[a]	3.7
	Hurt by falling objects		22	3.5
	Overexertion and unusual control		16[a]	2.6
	Unsafe ladders and tools		7	1.1
	Distraction (carrying other tasks)		6[a]	1
	Insufficient physical and mental capacities		5[a]	0.8
	Unauthorized access to hazard area		5[a]	0.8
	Mechanical failure		3	0.5
	Lack of complying scaffold	Lack of platform	58	9.3
		Lack of scaffold	55	8.9
		Lack of warning barrier	47	7.6
	Being pull down	Heavy object	21[a]	3.4
		Hoist	9[a]	1.4
		Trolley	6[a]	1
		Collapsing materials	2[a]	0.3
		Ladder	1[a]	0.2
	Inappropriate protection	Unfixed floor cover	15	2.4
		Insecure warning barrier	11	1.8
		Broken personal protective equipment	6	1
		Ineffective safety net	2	0.3
		Lack of secure anchor	1	0.2
	Harmful substances and environment	Poor weather	13	2.1
		Bumpy and restricted walkway	7	1.1
		Poor lighting & ventilation	3	0.5
	Removal of protection measure	Removal of barrier	15[a]	2.4
		Release of safety belt	6[a]	1
	Others		6	1
	Unknown		40	6.4
		Total	621	100

[a]Unsafe acts of persons.

($V = 0.222$, $p<0.05$) and between accident event and cause of fall ($V = 0.273$, $p<0.001$) (Table 3). The significant association between gender and cause of fall (Table 4) indicated that female workers were more likely to fall from heights due to inappropriate protections (6 cases, $\varphi = 0.084$, $p<0.05$) and the removal of protection measures (5 cases, $\varphi = 0.110, p<0.05$) as compared with their male counterparts. However, the data show that male workers were more likely to have fatal falls. They suffer a larger number of fatalities from falls and the SMR shows that males are at greater risk.

Case reports of female victims show 6 inappropriate protection cases. There were 3 with unfixed floor coverings, 2 insecure warning barriers, and one case of broken PPE. All 5 cases where there was a removal of protection measures involved the removal of barriers to facilitate materials handling. The authors suspected that female workers were less protected because they communicated less frequently with the male workers. Females may not have been informed of safety concerns, such as the proper use of PPE or the removal of barriers similar to those incidents caused by poor communication within work team as in Haslam et al. (2005).

The significant associations between cause of fall and accident event (Table 5) reveal the likely cause of fall for each accident event. Lack of complying scaffolds (82 cases, $\varphi = 0.267$, $p<0.01$) and bodily actions (26 cases, $\varphi = 0.083$, $p<0.05$) were the main causes of falls from scaffolds or staging. Unguarded openings (53 cases, $\varphi = 0.337$, $p<0.01$), inappropriate protection (23 cases, $\varphi = 0.272$, $p<0.01$), and removal of protection measure (11 cases, $\varphi = 0.147$, $p<0.01$) were the main causes for falls through existing floor openings. Bodily actions (14 cases, $\varphi = 0.119$, $p<0.01$) and improper use of PPE (10 cases, $\varphi = 0.200$, $p<0.01$) were the main causes for falls from building girders or other structural steel. Bodily actions (11 cases, $\varphi = 0.079$, $p<0.05$) and being pulled down (11 cases, $\varphi = 0.150$, $p<0.01$) were the main causes of falling from roof edges. Lack of complying scaffold (43 cases, $\varphi = 0.454$, $p<0.01$) was the main cause for fall through roof surfaces. Overexertion and unusual control (4 cases, $\varphi = 0.169$, $p<0.01$) and unsafe ladders and tools (4 cases, $\varphi = 0.282$, $p<0.01$) were the main causes for falls from ladders. Unguarded openings were likely to cause falls down stairs or steps (6 cases, $\varphi = 0.136$, $p<0.01$). Poor work practice was the main cause for falls while jumping to lower floors (2 cases, $\varphi = 0.206$, $p<0.01$) and falls through existing roof openings (2 cases, $\varphi = 0.206$, $p<0.01$).

4. Discussion

This research developed a classification scheme to code 621 fatal fall from height accidents in terms of contributing factors. The causes for the falls and the nature of accident events were classified. Accident scenarios were then developed with the intention of proposing prevention measures.

A limitation of the study is that the fatalities considered occurred several years ago, during the period 1994–1997. This presents the possibility that construction methods and practices in Taiwan may have developed during the intervening period, reducing the validity of the findings. Although the extent of any change is uncertain, the results nevertheless give a useful cross-sectional indication of the patterns of fatal falls and their causation in construction operations. It is interesting that fall incidents caused by unguarded openings, inappropriate usage of a safety harness, and poor communication with work team, were also reported in Haslam et al.'s (2005) analysis of British construction accidents. It is also argued that the classification scheme and analytical approach used by the study, mostly based on existing literature and an ANSI standard, has relevance for the analysis of fatal falls more widely.

When comparing the proportion of accident events with those reported by Hoyos and Zimolong (1988), it is apparent that falls through existing floor openings accounted for a greater proportion of fatal falls in our study. This will be connected to exposure to risk, ie the presence of floor openings and the safety protection afforded, and mostly likely has its origins in different construction practices between Taiwan and Hoyos and Zimolong's study context. Another interesting observation is the proportion of the causes of falls in terms of unsafe acts and unsafe mechanical or physical conditions as defined in Henrich et al. (1980). When the unknown and other unclassified causes are excluded, unsafe acts (e.g., as arising from bodily action, poor work practices, improper use of safety equipment, overexertion and unusual control, distraction, insufficient physical and mental capacities, unauthorized

Table 3
Cramer's V for six factors.

Contributing factors	Gender	Age	Experience	Company size	Accident event
Age	0.122				
Experience	0.091[a]	0.104			
Company Size	0.221[a]	0.189	0.139[a]		
Accident event	0.178	0.154	0.118	0.212	
Cause of fall	0.222*	0.153	0.208	0.320	0.273**

*Significant at 0.05.
**Significant at 0.01.
[a]Fisher exact test is used instead of Cramer's V when the expected frequency for any cell is smaller than 5.

Table 4
Phi coefficients between gender and cause of fall

Cause of fall	Gender	
	Female	Male
Lack of complying scaffold	13 0.005	147 −0.005
Unguarded opening	12 0.061	92 −0.061
Bodily action	2 −0.058[a]	60 0.058[a]
Poor work practices	1 −0.058[a]	43 0.058[a]
Being pulled down	3 −0.002[a]	36 0.002[a]
Inappropriate protection	6 0.084[a,+]	29 −0.084[a,*]
Harmful substances and environment	0 −0.057	23 0.057
Improper use of PPE	1 −0.026[a]	22 0.026[a]
Hurt by falling object	2 0.009[a]	20 −0.009[a]
Removal of protection measure	5 0.110[a,+]	16 −0.110[a,*]
Overexertion and unusual control	1 −0.010[a]	15 0.010[a]
Insufficient physical and mental capacities	0 −0.024[a]	5 0.024[a]
Unsafe ladders and tools	0 −0.031[a]	7 0.031[a]
Distraction (carrying other tasks)	1 0.032[a]	5 −0.032[a]
Unauthorized access to hazard area	0 −0.026[a]	5 0.026[a]
Mechanical failure	0 −0.020[a]	3 0.020[a]

In each cell, the three numbers are the number of cases, φ, and level of significance, respectively.
++ φ value is positive and significant at 0.01.
** φ value is negative and significant at 0.01.
+ φ value is positive and significant at 0.05.
* φ value is negative and significant at 0.05.
[a] Fisher exact test is used instead of φ when the expected frequency for any cell is smaller than 5.

access to hazard area, being pulled down, removal of protection measures) accounted for only 35.6% (221) of the total number of fatal falls (621 cases). This contrasts with the 88% suggested by Henrich et al. (1980). It is possible that this difference can be attributed to the liability litigation focus from the insurance company in Henrich et al. (1988) versus the accident prevention emphasis in our study.

The Fall Protection Guidelines proposed by the Manitoba Labor and Immigration Division MLID (2003) suggested six categories of fall protection measures. These included (1) surface protections (non-slip flooring), (2) fixed barriers (handrails and guard-rails), (3) surface opening protections (removable covers and guardrails), (4) travel restraint systems (safety line and belt), (5) fall arrest systems (safety line and harness), and (6) fall containment systems (safety nets). Bobick et al. (1994) classified protective measures as either primary or secondary. The first three categories of protection measures, were considered active or primary because they physically prevent falls to a lower level from occurring. The last three categories were referred to as passive or secondary since they inhibit or minimize injury after an already initiated fall to a lower level. Secondary measures include safety nets and lifelines. MLID (2003) stated that it is preferable to provide a fixed barrier to prevent a worker from falling, than PPE (such as a safety harness and lifeline), and the selection of the particular fall protection measure is dependent upon the circumstances and the job task.

We originally attempted to categorize tasks into 24 task categories (adopted from Koningsveld and Molen, 1997) and then select appropriate protection systems for each general task category. However, the linkage between the general task category and protection systems was not as obvious and sensible as expected. The same can be said of linkages between causes for falls and protection measures. For this reason, the authors chose to categorize feasible prevention measures by accident event (Table 6).

For falls from scaffold or staging, based on a study of scaffold accidents performed by the US Department of Labor (1981), Helander (1984) suggested that the number of scaffolding accidents could be reduced dramatically by using guardrails. However, prior to the installation of guardrails, and even after their installation, safety harnesses and an independent lifeline should be properly secured to an adequate anchor and used by those who may be exposed to any open edge or risk of falling (MLID, 2003). Safety nets should be used in places where it is difficult or impossible to install guardrails or to provide a proper anchoring and lifeline system for fall arrest. Also, visual markings such as warning signs or warning tape should be used to mark off the hazard area for places where a guardrail is temporary removed (MLID, 2003). Surface protection (non-slip flooring) is excluded from Table 6 because it is mainly for prevention of slips and falls on the same level.

To prevent falls from building girders or other structural steel, fall arrest systems and fall containment systems are essential since fixed barriers become impossible to implement at hazard areas. However, in our analysis, 10 victims died from the improper use of personal protection equipment. This is a reminder that activities such as safety training, to improve recognition of hazards and dangers, and the enforcement of the use of fall protection systems, as well as the inspection and testing of protection systems, tools, and inspection of the facility and environment, and other administrative interventions should not be neglected (Janicak, 1998).

Table 5
Phi coefficients between cause of fall and accident event

Causes of fall	Accident event								
	From scaffold, staging	Through existing floor opening	From building girders or other	From roof edge	Through roof surface	From ladder	Down stairs or steps	Jump to lower level	Through existing roof opening
Lack of complying scaffold	82 0.267^{++}	6 -0.246^{**}	7 -0.128^{**}	6 -0.129^{**}	43 0.454^{++}	4 -0.050	1 -0.051^{a}	0 -0.033^{a}	0 -0.033^{a}
Unguarded opening	6 -0.240^{**}	53 0.337^{++}	13 0.017	10 -0.012	0 -0.124^{**}	0 $-0.094^{a,*}$	6 $0.136^{a,++}$	0 -0.025^{a}	0 -0.025^{a}
Bodily action	26 0.083^{+}	4 -0.117^{**}	14 0.119^{++}	11 0.079^{+}	0 $-0.092^{a,*}$	1 -0.043^{a}	0 -0.045^{a}	0 -0.019^{a}	0 -0.019^{a}
Poor work practices	15 0.022	6 -0.048	5 0.001	4 -0.012^{a}	0 $-0.076^{a,*}$	0 -0.058^{a}	0 -0.037^{a}	2 $0.206^{a,++}$	2 $0.206^{a,++}$
Being pull down	10 -0.027	9 0.016	1 -0.071^{a}	11 $0.150^{a,++}$	0 -0.071^{a}	2 0.012^{a}	1 0.016^{a}	0 -0.015^{a}	0 -0.015^{a}
Inappropriate protection	3 -0.116^{**}	23 0.272^{++}	3 -0.021^{a}	1 -0.061^{a}	0 -0.067^{a}	1 -0.016^{a}	0 -0.033^{a}	0 -0.014^{a}	0 -0.014^{a}
Improper use of PPE	4 -0.056	1 -0.079^{a}	10 $0.200^{a,++}$	1 -0.039^{a}	1 -0.021^{a}	1 0.002^{a}	0 -0.026^{a}	0 -0.011^{a}	0 -0.011^{a}
Removal of protection measure	1 -0.104^{*}	11 $0.147^{a,++}$	3 0.018^{a}	0 -0.064^{a}	0 -0.052^{a}	2 0.050^{a}	0 -0.025^{a}	0 -0.011^{a}	0 -0.011^{a}
Overexertion and unusual control	6 0.025^{a}	2 -0.033^{a}	2 0.006^{a}	1 -0.022^{a}	0 -0.045^{a}	4 $0.169^{a,++}$	0 -0.022^{a}	0 -0.009^{a}	0 -0.009^{a}
Unsafe ladders and tools	2 -0.004^{a}	0 -0.054^{a}	0 -0.038^{a}	0 -0.037^{a}	0 -0.029^{a}	4 $0.282^{a,++}$	0 -0.014^{a}	0 -0.006^{a}	0 -0.006^{a}

Note: Only causes of falls with significant φ coefficients are listed. See legend in Table 4.

For preventing falls through existing floor openings and through existing roof openings, openings must be protected with guardrails or adequate coverings, e.g., secured wood or metal covers that are capable of supporting subjected loads and warnings which indicate that there is an opening below (MLID, 2003). Also, only workers wearing a whole body safety harness with a lifeline secured to a proper anchorage should have access to unprotected openings more than 2.5 m above a lower floor (MLID, 2003). For preventing falls down stairs or steps, MLID (2003) suggests the use of proper handrails on open sides of stairs, ramps and other similar means of access. These not only act to prevent falls from open sides but also serve as a support to workers moving up and down the access way. In our case reports, falls from stairs or steps were also associated with unguarded openings, so protection systems to prevent falls in these situations should also be applied.

To prevent workers falling from roof edges due to bodily actions (sloping roofs are an especial hazard), workers should use a fall-arrest system or a safety belt with a lanyard attached to a secure anchor (even when guardrails are installed at roof edges) (Helander, 1981). Our analysis showed that of the 11 incidents where people were pulled down and then fell from roof edges, 4 workers were pulled down by loose and falling hoists with these being overloaded in 2 of the 4 cases. Two workers were pulled down by the hoisting materials (bricks and hanging bucket); and another 5 were pulled down by plywood and hand tools they were handling or manipulating on the rooftop. In order to prevent hoisting related falling accidents, The Division of Building Safety in Idaho (2004) suggested that each worker in a hoist area should be protected from falling to lower levels by guardrail systems or personal fall arrest systems. If guardrails are removed to facilitate the hoisting operation (e.g., during landing of materials), and an employee must lean through the access opening or out over the edge of the access opening (to receive or guide equipment and materials), that the worker should be protected from fall hazards by a personal fall arrest system.

Various researchers have suggested a fundamental approach to prevent falls through roof surfaces. These include the suggestion that manufacturers should use roofing material that are strong enough not only to support workers and equipment (Helander, 1981) but also the dynamic loading during walking, falling against or sitting on the material (Bobick et al., 1994). Wide and properly secured support platforms (crawling boards and planks) should be provided for any roof under construction. In our analysis, falls from ladders were associated with overexertion and unusual control and

Table 6
Feasible prevention measures for each accident scenario

Accident event	Cause of fall	Frequency	Primary					Secondary		
			Fix barriers		Surface opening protection		Strong roofing material	Travel restraint systems	Fall arrest systems	Fall containment systems
			Guardrails (toe board) Handrails,	Warning, barrier warning sign and tape	Floor coverings	Crawling boards, planks		Safety belt	Safety harness	Safety nets
Fall from scaffold, staging	Lack of complying scaffold	82	X	X					X	X
	Bodily action	26	X	X					X	X
Fall from building girders or other structural steel	Bodily action	14							X	X
	Improper use of PPE	10							X	X
Fall through existing floor opening	Unguarded opening	53	X	X	X			X	X	
	Inappropriate protection	23	X	X	X			X	X	
	Removal of protection measure	11	X	X	X			X	X	
Fall through existing roof opening	Poor work practices	2	X	X	X			X	X	
Fall down stairs or steps	Unguarded opening	6	X	X	X			X	X	
Fall from roof edge	Bodily action	11	X					X	X	X
	Being pulled down	11	X						X	
Fall through roof surface	Lack of complying scaffold	43				X	X		X	
Fall from ladder	Overexertion and unusual control	4								
	Unsafe ladder and tool	4								
Jump to lower level	Poor work practices	2								X

unsafe ladders and tools. Cohen and Lin (1991) define three major approaches: (1) choosing the right equipment, (2) the safe use of ladders and (3) regular inspection and maintenance of the ladders. If these approaches had been used, the accidents would have been prevented.

Two workers died while jumping to a lower level. One worker intended to jump across an aisle to another building but fell into the aisle. The other worker jumped from a disassembled crane structure. Both accidents could have been prevented if the workers had not underestimated the risk of jumping. The second worker could have followed a safe work practice for disassembling the crane structure. Safety nets could have, perhaps, saved both workers. However, selection and training were probably more important in these two cases.

Prevention measures are useful only if they are implemented by the company and applied by the workers. Thus, safety performance measures of the company, e.g., experience modification rate as in Hoonakker et al. (2004) and applying to workers, e.g., unsafe working behavior as in Haslam et al. (2004), should be collected and monitored for motivation and feedback.

In conclusion, this study has undertaken a statistical analysis of 621 fatal fall accidents in the construction industry in Taiwan. A framework for the analysis was developed, based on the US Department of Labor's categories for falls and Drury and Brill's (1983) scenario analysis. Inexperienced workers and those working for smaller companies were found to be at greatest risk of fatal falls. As might be expected in a male dominated profession, the victims in most fatalities were male, although female workers appear to be vulnerable in situations where inadequate physical protection measures are in place on site to prevent falling from height. Older workers, aged over 55 years, were represented disproportionately in the sample of incidents, and it is suggested that declining physical and sensory capabilities are a factor in this. Prevention measures have been proposed that would have prevented many of the falls examined. Although the measures are straightforward, significant commercial and cultural barriers will need to be overcome to achieve their widespread acceptance and adoption by construction employers and their workers.

References

Aaltonen, M.V.P., 1996. Occupational injuries in the Finnish furniture industry. Scand. J. Work Environ. Health 22, 197–203.

Bobick, T.G., Stanevich, R.L., Pizatella, T.J., Keane, P.R., Smith, D.L., 1994. Preventing falls through skylights and roof openings. Professional Safety 39, 33–37.

Buskin, S.E., Paulozzi, L.J., 1987. Fatal injuries in the construction industry in Washington State. Am. J. Ind. Med. 11, 453–460.

Butani, S.J., 1988. Relative risk analysis of injuries in coal mining by age and experience at present company. J. Occup. Accid. 10, 209–216.

Cattledge, G.H., Schneiderman, A., Stanevich, R., Hendricks, S., Greenwood, J., 1996. Nonfatal occupational fall injuries in the West Virginia construction industry. Accid. Anal. and Prev. 28 (5), 655–663.

Chi, C.-F., Wu, M.-L., 1997. Fatal occupational injuries in Taiwan—relationship between fatality rate and age. Safety Sci. 27, 1–17.

Chi, C.-F., Chen, C.-L., 2003. Reanalyzing occupational fatality injuries in Taiwan with a model free approach. Safety Sci. 41, 681–700.

Chi, C.F., Chang, T.C., Hung, K.H., 2004. Significant industry-source of injury-accident type for occupational fatalities in Taiwan. Int. J. Ind. Ergon. 34, 77–91.

Cohen, H.H., Lin, L., 1991. A scenario analysis of ladder fall accidents. J. Safety Res. 22, 31–39.

Drury, C.G., Brill, M., 1983. Human factors in consumer product accident investigation. Hum. Factors 25 (3), 329–342.

Directorate-General of Budget, Accounting & Statistics, 1994–1997. Annual Bulletin of Manpower Statistics Taiwan Area, Executive Yuan.

Directorate-General of Budget, Accounting & Statistics, 1997. The Report on 1996 Industry, Commerce and Service Census Taiwan Area, Executive Yuan.

Haslam, R.A., Hide, S.A., Gibb, A.G.F., Gyi, D.E., Pavitt, T., Atkinson, S., Duff, A.R., 2005. Construction safety: lessons from 100 studies of accident causation. Appl. Ergon. (Ed.), accompanying paper in this special issue.

Helander, M. (Ed.), 1981. Safety in construction. Human Factors/Ergonomics For Building and Construction. Wiley, New York.

Helander, M., 1984. A review of research on human factors and safety in building/construction. Proceedings of the 1984 International Conference on Occupational Ergonomics, pp. 95–104.

Henrich, H.W., Petersen, D., Roos, N., 1980. Industrial Accident Prevention. McGraw-Hill, New York, pp. 57–58.

Hinze, J., Pedersen, C., Fredley, J., 1998. Identifying root causes of construction injuries. J. Constr. Manage 124, 67–71.

Hoonakker, P., Loushine, T. Carayon, P. Kallman, J., Kapp, A., Smith, M., 2004. The effect of safety initiatives on safety performance: a longitudinal study. Appl. Ergon. accompanying paper in this special issue.

Hoyos, C.G., Zimolong, B., 1988. Safety studies with special emphasis on high risk technologies. In: Occupational Safety and Accident Prevention: Behavior Strategies and Methods. Elsevier, New York (Chapter 6).

Janicak, J.A., 1998. Fall-related deaths in the construction industry. J. Safety Res. 29, 35–42.

Kelsey, J.L., Whittemore, A.S., Evans, A.S., Thompson, W.D., 1996. Methods in Observational Epidemiology. Oxford University, New York 177pp.

Koningsveld, E.A.P., Van Der Molen, H.F., 1997. History and future of ergonomics in building and construction. Ergonomics 40, 1025–1034.

Kurtz, N., 1999. Statistical Analysis For The Social Sciences. Allyn & Bacon, MA 316pp.

Laflamme, L., Menckel, E., 1995. Aging and occupational accidents: a review of the literature of the last three decades. Safety Sci. 21, 145–161.

Lucas, R.E.B., 1974. The distribution of job characteristics. Rev. Econ. Stat. LVI, 530–540.

Manitoba Labour and Immigration Division, 2003. Fall Protection Guidelines. http://www.oshforeveryone.org/wsib/default.html.

Messing, K., Courville, J., Boucher, M., Dumais, L., Seifert, A.M., 1994. Can safety risks of blue-collar jobs be compared by gender? Safety Sci. 18, 95–112.

Mehta, C.R., Patel, N.R., Senchaudhuri, P., 1992. Exact stratified linear rank tests for ordered categorical and binary data. J. Comput. Graph. Stat. 1, 21–40.

Sorock, G.S., Smith, E.O., Goldoft, M., 1993. Fatal occupational injuries in the New Jersey construction industry, 1983–1989. J. Occup. Med. 35, 916–921.

The Division of Building Safety in Cooperation with the Idaho Industrial Commission, 2004. 074 fall protection. http://www2.state.id.us/dbs/safety_code.

Tuominen, E., Saari, J., 1982. A model for the analysis of accidents and its application. J. Occup. Accid. 4, 263–273.

US Department of Labor, Bureau of Labor Statistics, 2003. Occupational Injury and Illness Classification Manual, Section 2. http://www.bls.gov.

US Department of Labor. Bureau of Labor Statistics, 1981 Survey of scaffold accidents, 1978. Unpublished Report, Washington, DC.