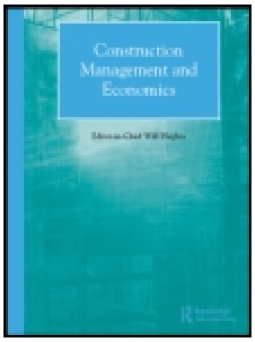

Construction Management and Economics

ISSN: 0144-6193 (Print) 1466-433X (Online) Journal homepage: https://www.tandfonline.com/loi/rcme20

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To cite this article: Andrew R. Atkinson & Rebecca Westall (2010) The relationship between integrated design and construction and safety on construction projects, Construction Management and Economics, 28:9, 1007-1017, DOI: 10.1080/01446193.2010.504214

To link to this article: https://doi.org/10.1080/01446193.2010.504214

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Construction Management and Economics (September 2010) **28**, 1007–1017

Routledge
Taylor & Francis Group

The relationship between integrated design and construction and safety on construction projects

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Received 15 February 2010; accepted 22 June 2010

The occurrence of accidents and injuries continues to be a major problem in construction worldwide. Even though accident statistics have been improving in most markets there are significant areas requiring further attention. The extent of integrated working between designers and constructors may be an instrumental factor. A comparison is undertaken of the accident performance of 55 large construction projects in the UK, with varying levels of design/construction integration as represented by procurement path. Although a statistical relationship between high levels of integration and low levels of accidents was weak, a follow-up interview study provided strong support, suggesting that a lack of significance was related to the unreliability of the statistics available. The interview study also indicated reasons for this link. A key element in improved safety was seen to be better communications and a more positive relationship between designers and constructors. Further research into designing for safety for all procurement paths is recommended.

Keywords: Safety, accidents, integrated working, architectural design.

Introduction

Construction is a dangerous industry. There were 72 deaths in construction in the UK for the year 2007–08 (Donaghy, 2009) and a fatalities rate of 3.4 per 100 000 workers (Health and Safety Executive, 2010). This rate is five times higher than rates in other manufacturing industries (Sawacha *et al.*, 1999). In other developed economies, the picture is similar or worse. In the USA, the construction industry accounts for about 6% of the workforce, yet contributes to 20% of fatalities (Behm, 2005). The rate in the USA has not significantly dropped in the last 10 years (Abudayyeh *et al.*, 2006) and approximates to 6–10 fatalities per day (Suraji *et al.*, 2001). Beyond the developed economies, the imbalance of statistics between construction and manufacturing is similar (Aksorn and Hadikusumo, 2008), but the rates of fatalities very much higher. The South Africa Construction Industry Development Board provides summary statistics (Table 1) for many developing and undeveloped countries, which show dramatically higher figures.

Although there have been some recent improvements, worldwide (Figure 1), safety performance is still poor in construction and attention should be given to improvement. As Rita Donaghy pointed out in her recent report for the UK Government: ‘A temporary lapse should not kill you. We should not accept that construction has to be a dangerous industry’ (Donaghy, 2009, p. 43).

Table 1 Occupational accidents by international regions (Construction Industry Development Board, 2009)

Region	Fatality rate per 100 000 workers
Established market economies	4.2
Former socialistic economies	12.9
Asia and Islands excluding China/India	21.5
Sub-Saharan Africa including South Africa	21.0
Latin America and Caribbean	17.2
Middle East	18.6
Singapore	9.8
South Africa	19.2

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Construction Management and Economics
ISSN 0144-6193 print/ISSN 1466-433X online © 2010 Taylor & Francis
http://www.informaworld.com
DOI: 10.1080/01446193.2010.504214

Figure 1 UK construction industry fatalities per 100 000 employees (Health and Safety Commission, 1993, 2000; Health and Safety Executive, 2010)

Rather, it is important that the reasons for any improvement be accurately identified and an evidence base of practical interventions be built up in striving towards a zero accident industry.

Background

Ever since seminal work by the psychologist Jens Rasmussen in the 1980s (Rasmussen, 1983 quoted in Reason, 1990; Rasmussen, 1987; Rasmussen *et al.*, 1987) categorizing errors into slips, rule and knowledge based errors, it has been established that the occurrence of error is, more or less, inevitable. His overriding conclusion is that errors need to be managed or designed out of systems. There either have to be insignificant consequences related to errors, an opportunity for recovery, or complete elimination of the possibility of an error occurring. Otherwise 'Murphy's law'[1] will apply and, sooner or later, an error leading to injury will occur. The recognition that errors are inevitable has led to an initial emphasis on the managerial preconditions of errors. Reason (1990) used the term 'resident pathogen metaphor' to explain the idea that the preconditions of accidents may exist elsewhere in an organization or system long before an error occurs. Similar ideas are voiced from a variety of perspectives including psychology (Norman, 1988; Lourens, 1990), engineering (Petroski, 1985; Blockley, 1992) and sociology (Turner, 1978; Vaughan, 1990). In construction management, emphasis on the preconditions for accidents has developed progressively into three more or less distinct theories of error control: managerial, avoidance and integration.

Managerial theories

Managerial theories in construction are based on the role of managers within organizations in causing or avoiding accidents. Whittington *et al.* (1992) postulate a hierarchical model, which operates on four levels: company policy, project management, site management and individual. They report specific factors influencing accidents, including poor supervision, remoteness of responsibility, uncontrolled changes, poor communications, cost and time pressures. Similar models of error have been proposed by others, including Atkinson (1998), Loughborough University and UMIST (2003), Suraji *et al.* (2001) and Suraji *et al.* (2006). Atkinson (2002) also proposes a four-level model—*primary error* made at operative level, *managerial errors* related to such issues as controlling changes, communications and division of responsibilities, *organizational errors* related to system culture and attitudes, and *global pressures* including the economic and social environment. Both Whittington *et al.* (1992) and Suraji *et al.* (2001) introduce dynamic elements to their models showing how one precondition for error at a managerial level can influence and predispose systems to error later in the production sequence. Subsequent studies (including those by Kartam, 1997; Abdelhamid and Everett, 2000; Langford *et al.*, 2000; Saurin *et al.*, 2004) have supported the emphasis on managerial action.

In parallel with research emphasizing the importance of error management, legislative and policy initiatives in industry have laid a similar emphasis, from the Health and Safety at Work etc. Act 1974 to the European Directive 92/57/EEC[2]. These are backed up by practical information and guidance on policy, planning, measurement and auditing for safety (for examples, see Health and Safety Executive, 1997).

Avoidance theories

There is considerable evidence from the literature that building designers are influential, but do not know how to design for buildability and safety. As a consequence attention has more recently been given to detailed methods and processes of design. The general intention is to design out the possibility of error at the outset. Hinze and Weigand (1992), Behm (2005) and Gambatese *et al.* (2005) have all carried out studies investigating the influence of architectural design on construction accidents. Behm (2005) in examining 224 fatality investigation reports in the USA established a statistical link between a 'design for construction safety' concept and fatalities. He concludes, among other things, that hazards are unintentionally designed into construction projects as architects lack knowledge of the construction process.

Gambatese *et al.* (2005) note that design professions are willing to design for safety, but cite limitations of cost, time and restrictions on perceived 'architectural creativity'. However, they also note that some influential architects actively include construction safety management as a part of all programming and design activities. This contradiction suggests that creativity can accommodate safety in building. Gambatese *et al.* (2008) note the generally traditionalist designer view of safety—that it is the constructor's responsibility—but also cite instances where considerable design modifications were proposed to protect worker safety. Generally, however, design modifications noted were modest—provisions of fixings or rails as preventative measures for what remained dangerous activities, rather than radical rethinking of the installation process.

Matthews and Rowlinson (1999) among others note the role of tender and contract documentation in encouraging appropriate levels of safety, in both design and construction. This includes traditional contract clauses requiring safe practice, but also the use of explicit priceable items for safety organization. They expressly cite the Hong Kong Government Works Bureau 'Pay for Safety Scheme' of 1996, where provisional sums were to be included in bills of quantities for safety related elements.

Integration theories

Integration theories stem from the fact that, in addition to having complex internal management structures, participants within the construction industry are often segregated. Segregation may be 'vertical' between initiation, design, production, use and maintenance, or 'horizontal' between participants with similar roles. Segregation complicates communications and obscures responsibilities between parties with complementary roles (for example, responsibility for failure of a component, between architects and constructors). It has long been recognized that this segregation is inefficient in business terms (see e.g. Latham, 1994) and there has been a consistent movement towards integrated working over the last 20 years internationally. However, many (Love and Gunasekaran, 1998; Hare *et al.*, 2006; Ankrah and Proverbs, 2009; Donaghy, 2009) consider that segregation, in particular between designers and constructors, compromises safety. Even where safety is not expressly mentioned, authors often refer to buildability improvements (and impliedly safety improvements) where integrated design and construction working is adopted (Black *et al.*, 2000; Bresnen and Marshall, 2000; Austin *et al.*, 2002; Baiden *et al.*, 2006).

The general criticism is that institutional separation between designers and constructors does not allow ready feedback. This may compromise safety because the design of parts of a building will influence their method of construction. Where the relationship between these two parties is organizationally close, as with design and construct contracts, communications are expected to be more rapid and frequent. Even where the relationship is not close (for example, with design and construct contracts where the designers are subcontractors), if the power relationships are such that designers are effectively employed by the constructor, the expectation is also that relationships will be more integrated.

Two issues arising from the reported benefits of integration are, first, that there is no real evidence base supporting the advantages of integration and, secondly, that integration does not guarantee that the necessary feedback will occur and that designers will actively modify their designs to improve safety. It is simply assumed that more account will be taken of construction considerations where integrated working is involved.

Field research

Using data from 55 UK projects within a single major construction company, a post-hoc statistical study was carried out. It worked from the hypothesis that projects delivered using integrated design and construction teams have a better safety performance than those using a fragmented approach. The statistical study was supplemented by a short interview study both to support this hypothesis and to illuminate the causal links between integrated working and safety.

Statistical study

The 55 projects ranged over 11 distinct sectors from highways and airports to speculative building developments and varied in size from approximately £1m to over £750m. This variability gives problems related to equivalence. The most important is the range in sizes of projects, but complexity may also be an important factor given the wide range of types of project. Conversely, using only one organization as the unit of analysis means that the overall approach and business culture is likely to be similar between projects (even though generalizing to other organizations may be more difficult). It is less necessary to control for these factors, but a 'common' business culture (especially a very 'safety oriented' one) is likely to give small differences in performance between the best and worst within the set and reduce the significance of any findings. It was possible to select a single time period (projects under construction in 2008), thus avoiding problems of changes in legislation and innovations occurring at different times during the projects' life cycles.

Variability in size was dealt with, first, by careful choice of dependent variable. The expectation was that safety performance (dependent variable) would be affected by level of integration (independent variable). Accident statistics are notoriously unreliable even without allowing for differences in project characteristics. The only reasonably reliable statistic is fatality, but, even in a dangerous industry such as construction, fatalities and major accidents are rare for individual projects to the extent that reliable statistical tests are impossible without using extremely large samples. Reportable serious accidents (those defined in the UK as involving more than three days' absence from work) (Health and Safety Executive, 1997) are more common, but are also subject to some under- or over-reporting depending on the attitude, economic circumstances and cultural expectations of worker, supervisor or senior manager. Minor accident occurrence is even more unreliable and may be considerably under-reported by certain sets of workers or supervisors, who either culturally or for financial reasons prefer not to report them.

Project size is traditionally controlled by using accident frequency rates per hour of work. For this study two rates were calculated: the accident frequency rate using the number of major and serious accidents divided by the number of hours worked per year (multiplied by 100 000 for ease of use) and the total accident frequency rate using the number of major, serious and minor accidents divided by the number of hours worked per year. The latter was included, though less reliable, to compensate for the rarity of fatalities, or major accidents on any individual project. To further examine whether size of project affects accident rates, the projects were divided on the median number of employed workers and two sub-sets with large and small workforces respectively, were compared with a simple student t-test. There was no significant difference between groups on all relevant dependent variables. The expectation is that variations in *complexity* between projects would be reflected in cost, so a third variable was used of number of major, serious and minor accidents divided by the contract value.

The unreliability of reported accident statistics has led some researchers (Duff *et al.*, 1994; Mattila, 1994; Jorgensen *et al.*, 2008) to develop 'safety scores', which are, effectively, proxies for accidents. For example, Mattila (1994) used a researcher scored safety checklist to determine the safety level of construction sites. The rationale for scoring safety rather than logging accidents and incidents is that, assuming that safety measures are effectively directed at prevention, enumerating their use will provide an adequate proxy measure of 'non-accident' occurrence. The advantage of this is that it is not necessary to wait for an accident to happen, the statistics are more reliable and the scores are predictive rather than reactive and therefore support preventive measures. In this study, a similar safety score was used, but based on inspection ratings provided by the company's own health and safety inspection team, rather than independent researcher rating. The inspection team is expected to act independently, but these scores should, nevertheless be treated with caution.

In summary therefore, the four dependent variables used in the study are as shown in Table 2. All data related to the year 2008 and assumed a standard working year of 2728 hours.

The independent variable was the level of integration between designers and constructors, but levels of integration are also difficult to determine for modern projects. One measure of integration is the method of procurement as represented by the type of contract, but using an 'integrative' procurement method is no guarantee that integration will actually be achieved. It is only an organizational device which allows the opportunity for integration. It is also often considered that levels of integration as defined by procurement paths are discontinuous, with projects being either fragmented (for example with traditional sequential design by consultants, then construction by main and subcontractors) or integrated (using design and construct or

Table 2 Dependent variables

(1) Accident frequency rate (AFR)	$\frac{\text{number of major and serious accidents}}{\text{total number of hours worked}} \times 100\,000$
(2) Total accident frequency rate (TAFR)	$\frac{\text{number of major, serious and minor accidents}}{\text{total number of hours worked}} \times 100\,000$
(3) Total accident frequency rate (TAFR) by contract value	$\frac{\text{number of major, serious and minor accidents}}{\text{contract value}} \times 100\,000$
(4) Scored inspection average (SIA)	

partnered procurement). The detailed picture is much more complicated. In the UK it is now relatively rare for major projects to be let using a fully traditional sequential process and of the 55 projects, only three projects were let on this basis. These were given an integration score of 1. Two further projects were let on a traditional basis, but with elements of the design being carried out by the main contractor, which thus gave opportunities for some integrated design/construction working. These were given an integration score of 2. Twenty-two further projects were let on a design and construct basis, but for a 'single project' only, where the client–design–construction team were unlikely to meet again in similar arrangements. Within this set, 12 projects used relatively adversarial and polarizing contract forms (integration score of 3) and 10 used a single project partnering arrangement or an acknowledged less adversarial contract (integration score 4). Eight projects were let on a design and construct basis, but with the contractor executing at least three projects for the same client (integration score 5), three projects made specific arrangements (within design and construct contracts) to involve the contractors early in the design process (integration score 6), six projects were let on a design and construction basis within a small framework[3] partnering arrangement (integration score 7) and 11 projects were within a larger framework partnering arrangement. The 55 projects were, therefore, divided into eight categories and given a corresponding 'integration score' as shown in Table 3.

Table 3 Criteria determining the integration score of each project

Integration score	Criteria
1	Traditional contract with no contractor design
2	Traditional contract with contractor designed elements
3	Design and build contract with a client for a single project only—polarized
4	Design and build contract with a client for a single project only—partnered
5	Design and build contract with same client for at least three project
6	Design and build contract with early contractor involvement
7	Design and build using small framework partnering arrangement
8	Design and build using large framework partnering arrangement

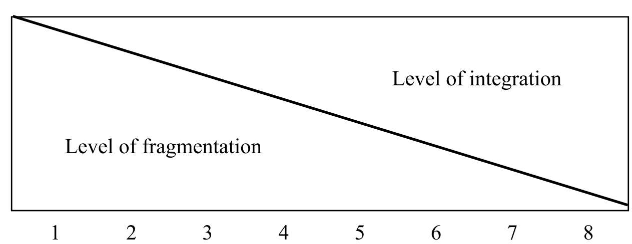

Figure 2 Integration continuum

From Table 3, it can be seen that projects sit on an 'integration' continuum, broadly where fully traditional arrangements are at the 'fragmented' end and large strategic partnering arrangements are at the 'integrated' end. Figure 2 illustrates this integration continuum, but even this may be misleading as it does not account for levels of fragmentation/integration further along the supply chain than the main contractor. Nor does it account for informal methods, which may be used by team members irrespective of the integration method used.

The research divided the sample into fragmented or integrated projects on three bases, giving three separate studies. For study 1, all projects for a single client (integration score of 1–4), whether traditional or design and construct were treated as fragmented on the basis that there was no inter-project opportunity to build continuous relationships with the client. Projects where the same client was involved more than once were treated as integrated (integration score 5–8). For study 2, traditional sequentially procured projects only (integration score 1–2) were treated as fragmented on the basis that there was no inter-project opportunity to build continuous relationships at client–design–construction

Table 4 Results for three studies

	Study 1 Integration score		Study 2 Integration score		Study 3 Integration score	
	1 to 4	5 to 8	1 to 2	3 to 8	1 to 6	7 to 8
Number of contracts	27	28	5	50	38	17
Mean number employed	69	194	53	141	80	252
Mean contract value	£39.67m	£104.8m	£26.3m	£77.5m	£37.9m	£150.9m
DV1 AFR						
Mean	0.10	0.28	0.32	0.18	0.13	0.32
Variance	0.07	0.32	0.30	0.20	0.08	0.49
Probability of equal means			0.26			
DV2 TAFR						
Mean	4.12	4.50	7.88	3.96	4.14	4.69
Variance	19.24	18.61	54.52	14.63	16.50	24.43
Probability of equal means			0.03			
DV3 TAFR by contract value						
Mean	0.38	0.60	0.84	0.46	0.48	0.52
Variance	0.36	1.21	1.55	0.73	0.54	1.42
Probability of equal means			0.18			
DV4 SIA						
Mean	6.84	6.85	6.82	6.85	6.84	6.86
Variance	0.01	0.01	0.02	0.01	0.01	0.01
Probability of equal means	0.41		0.24		0.17	

interfaces. All other projects (integration score 3–8) were treated as integrated. For study 3, all projects (integration score 1–6) other than those within framework arrangements (integration score 7–8) were treated as fragmented on the basis that full integration between designers and constructors can only be developed over a number of projects with continuous cooperative working.

Data on accident rates, average numbers of people employed on the projects, contract values and safety scores were provided by the contractors' health and safety and operational departments and, because of their nature and the large sample size, were treated as parametric. Additionally, tests for normality of distribution (Q-Q plot) and homogeneity of variance were carried out to confirm suitability of data. Simple one-way student t-tests were run using dependent variable data for each independent variable condition (studies 1–3) and the results are as shown in Table 4.

From Table 4 it can be seen that for most measures of accident frequency there was no significant difference in numbers of accidents or inspection scores for any of the three splits between scored inspection categories. The exception was for study 2 on dependent variable 2. When a strict definition of fragmentation is adopted (to include as fragmented only projects let on a fully sequentially procured traditional basis with a separate design and construction team) and the dependent variable includes all accidents, there is a significantly lower accident rate for integrated projects ($P = 0.03$).

This company has a good safety performance and it is notable that, for many major projects, there were no major or serious injuries. This gives rise to the problem of using the accident frequency rate (AFR) mentioned above. However, it is possible to compare the number of projects with a zero accident frequency rate for the three studies. Results are given in Table 5.

Table 5 Number of projects with a zero accident frequency rate for each study

	Study 1 Integration score		Study 2 Integration score		Study 3 Integration score	
	1 to 4	5 to 8	1 to 2	3 to 8	1 to 6	7 to 8
Number of contracts	27	28	5	50	38	17
Number of contracts with zero AFR	22	15	3	34	28	9
Percentage of contracts with zero AFR	81	54	60	68	74	53

In this instance, for both study 1 and study 3, there were more fragmented than integrated projects with a zero accident frequency rate. It was only with study 2 that there were more integrated than fragmented projects with zero accidents.

Interview study

As a follow-up to the statistical study, three in-depth semi-structured interviews were conducted with senior project managers, two of whom worked for the contractor (at the general contractor level) and one for a large mechanical and services engineering subcontractor. These interviews were conducted for two broad reasons. First, the limitations of a purely statistical approach were anticipated. It was likely that unreliability of available data and the large number of intervening variables would make it difficult to establish a statistical link between levels of integration and measures of accident. Interviews would provide subjective evidence of the existence or absence of this link. Secondly, although it might be possible to establish the statistical link, this will not indicate cause.

The interview instrument posed open-ended questions, allowing interviewees freedom to develop their own ideas, but still generating specific information in order to meet the research objectives. Interviewees were selected to ensure they had a responsibility for site safety and had experience of working on a variety of projects, with different levels of integration.

Questions posed covered background information on the types of projects the interviewees had worked on, methods of communication and levels of contact throughout the project team. They also covered a number of factual issues about the instances of accidents on sites they had worked on, levels of feedback and transfer of learning within and between projects. Finally, they asked for a number of opinions on factors that determine safety on site, relationships with other project team members and the influence of team members on safety. Full details of the questions and related objectives are given in Table 6.

Questions 4 to 8 covered communications and relations between parties on different types of contract. The responses indicated that the amount of contact between contractors and designers on traditional contracts was considerably less than on design and construct contracts. For the latter, team meetings are far more frequent and there is much more communication between meetings.

The form of communication is also different on design/construct projects compared with traditional projects, with more verbal, open and face-to-face communication with the former. On traditional projects the communication was described as 'formal', 'often written' and 'contractual'. The relationships between the contractor and designer were perceived as markedly better on design/construct projects than traditional projects by all three interviewees. Words used when considering traditional projects included 'frustrated', 'contractual', 'invasive' and 'blame-oriented', indicating that the designers and contractors do not work well together. On design/construct projects more positive wording was employed including 'interactive', 'proactive', 'part of the family' 'closer' and 'integrated'. All interviewees described the way of working on design/construct projects as collaborative and that they were able to guide designers to improve buildability. Two interviewees also found the *client* more involved and supportive on design/construct projects than traditional.

Question 2, relating to key factors determining safety during construction, was posed early in the interviews to avoid leading the interviewees. However, answers were very consistent and followed the literature. All interviewees stressed the importance of the client's and designer's roles in safety during construction. A positive safety culture was crucial, driven from the top, with an emphasis on detailed planning for zero accidents and involving the whole project team from client to subcontractor to worker.

Responses to questions 9 and 10 (influence of clients and designers) covered some of the same ground mentioned above, but interviewees made numerous suggestions for designers to contribute to safer construction—the common theme was that if designers worked together with contractors this could have a massive impact on safety. Practical action designers could take included:

- asking the contractor how the works would be constructed;
- determining what were practical component sizes for safe installation;
- coordinating the design and construction programme for safe sequencing of the work on site;
- ensuring the contractor had an in-depth understanding of the design rationale.

In the experience of all interviewees, the contractor has far more opportunity to influence the designers on design/construct projects compared with traditional projects and could sometimes insist on design changes to improve safety. One interviewee indicated that using design/construct projects allowed the contractor to educate the designers to look at the design from a site safety point of view and not just as a box-ticking exercise to comply with Construction Design and Management Regulations 2007 (SI 2007/320) or similar regulations.

Table 6 Interview questions and objectives

	Question	Question objective
1	What type of projects (in terms of size, nature of contract, sector) have you been involved in?	Establish and record types of contract worked on (covering fragmented and integrated types). Interviewees were pre-selected for having worked on both.
2	In your opinion, what are the top three key factors determining safety during construction?	To establish the critical factors that determine safety performance.
3	Has there ever been a serious accident on a site you have worked on? What was it? What were the direct and root causes of the accident?	To provide evidence of root causes of specific accidents and probe whether the interviewee believed they could have been avoided through more integrated team working.
	For the following questions, answer for traditional (sequentially procured) and for design/construct projects you have worked on.	
4	How much contact do you and your team have with the designers?	To evaluate the relationships and level of communication between the contractors and the designers on different types of project.
5	How often are you involved in meetings with the client and/or designers?	To evaluate the level of face-to-face contact between the contractors and the designers on different types of project.
6	How do you communicate with the client and/or designers between meetings?	To evaluate the relationships—is the communication formal or informal, verbal or contractual?
7	In two words, how would you describe your relationship with the designers?	To determine whether there is a common theme to the relationships between contractor and designer on different types of project.
8	How involved is the client in projects?	To establish the commitment of clients to managing projects procured using different procurement methods or partnering arrangements.
9	Does the client have an influence on safety? To what extent? How do they influence safety?	To establish the role of the client in improving H and S performance.
10	Do the designers have an influence on safety? To what extent? How do they influence safety?	To evaluate the role of designers in improving H and S performance and establish whether the designers take a consistent approach to the CDM regulations on different types of projects.
11	Do the subcontractors have an influence on safety? To what extent? How do they influence safety?	To evaluate the degree integration between client, designer and contractor encourages supply chain integration and to what extent this improves safety.
12	Is the buildability/safety experienced during construction fed back to the designers? How is it?	To assess whether lessons learnt or possible innovations identified by the contractor are fed back to designers in order to improve the delivery of future projects.
13	Are improvements transferred to future projects? If so, how are they?	To evaluate whether particular types of project are more conducive to the transfer of knowledge and continuous improvement within the industry.

In their response to question 3 (occurrences of serious accidents on site) two interviewees described an accident, each of which had occurred on projects they had been working on. The root causes of both included poor supervision of the works. However, both emphasized that a change in the design could have completely eliminated the risk of an accident occurring.

Question 11 covered influences on safety further down the supply chain and all interviewees indicated that there was more interaction between designers and subcontractors on design/construct projects than on traditional ones. This had a positive influence on safety.

The aim of questions 12 and 13 was to investigate transfer of knowledge and continuous improvement. From the responses, there was no evidence on traditional projects of feedback from contractor to designer or means of transferring improvement on to future projects. There was, however, only limited evidence of this on design/construct projects, although one interviewee noted that designers were more willing (than for traditional projects) to go out on site and discuss difficulties experienced during construction. Another interviewee noted that lessons learned are readily transferred from one project to another with framework projects.

Discussion and conclusions

The theoretical contributions of the research are twofold and relate to both the methods used to investigate safety in construction and the substantive findings. With respect to the former, the findings reported here illustrate some of the problems associated with carrying out research into safety management in industry. Many interventions are proposed which either anecdotally or logically improve safety performance, but a firm evidence base is demanded for concerted action at policy, regulatory or executive levels. The evidence demanded is often in the form of objectively determined statistics showing that the intervention is associated with performance. However, for interventions in project and construction management, there are considerable problems of enumeration and identification of both independent and dependent variables. There are also likely to be a large number of intervening variables, which act to confound any association. For the current study, a statistically significant link was noted between one measure of integration and injury occurrence, but this was among 12 tests and is a weak endorsement for the overall hypothesis that integrated working improves performance. The danger with these results is that the research hypothesis will be unjustifiably rejected and the opportunity for safety improvements missed.

It follows that for studies in managerial subjects, problems with quantitative research using inferential statistics should be anticipated and alternatives designed into the research programme. It is valid that objective quantitative statistically based studies are attempted, because strong statistical support accelerates acceptance of valid proposals. However, these should be used in conjunction with a triangulation methodology perhaps combining qualitative interviewing techniques, or surveys. For the latter, qualitative and quantitative techniques can be further combined, by quantifying data and opinions from survey returns.

With respect to the second theoretical contribution, although the statistical study gave weak support to the proposition that integrated working between designers and constructors improves safety performance, the small interview study supported it. It also revealed mechanisms by which integration did this. A key element of this was related to the relationship between the designer, contractor and subcontractors. Integrated working appears to make this relationship closer, more positive and constructive and allows the designer to design more proactively for safety. Integrated techniques of partnering and design/construct contracting may be associated with better *opportunities* for safe working (for example by providing opportunities for safety reviews early in design). What integrated working does not do is to guarantee that these opportunities are constructively and actively used by designers.

Future research work should, therefore, be directed towards examining in more detail how designers can contribute to safety. Current regulations, while requiring that designers acknowledge the safety implications of their designs, do not and probably could not actively require that they design out accidents. Some research is currently progressing in this direction (Gambatese *et al.*, 2005, 2008), but most design initiatives to improve safety appear to be quite limited. Anecdotally, some architects have active buildability and safety oriented design reviews and are considering far more radical approaches to safety sensitive building elements (for example roof design). Further work should attempt to capture these initiatives.

Future work should also consider improving the design–construction interface for traditionally sequentially procured projects. Although integrated working may improve safety performance, the key element is communication and cooperation between design and construction. Given that it is likely that many projects, particularly of a smaller and routine type, will continue to be procured by traditional means, it is important that lessons learned from the design–construction interface, wherever they originate, are transferred in this direction.

Notes

1. Anything that can go wrong will go wrong.
2. Council Directive 92/57/EEC of 24 June 1992 on the implementation of minimum safety and health requirements at temporary or mobile construction sites (8th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) [1992] OJ L245/6.
3. Framework arrangements involve one contractor being selected to carry out a series of contracts for the same client.

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