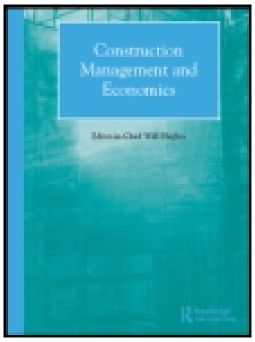

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Application of the Loughborough Construction Accident Causation model: a framework for organizational learning

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In order for the construction industry to improve its poor safety performance it needs to learn from its safety mistakes and put the lessons learned to good use. Incident investigation theories and techniques vary widely in the peer-reviewed literature. The Loughborough Construction Accident Causation (ConAC) model was applied to State Department of Transportation construction accidents, and is proposed as a tool to facilitate organizational learning in the construction industry. Details of the methodology utilized are described so that it can be duplicated in research and in practice. By investigating 27 DOT construction incidents, the research demonstrates how the model can be used both in research and in practice. The model yielded 6.63 causes/factors/influences identified per incident, and correlated the causes to determine relationships. Incident causality is complex and multi-faceted. The Loughborough model facilitates a holistic view of incident causality and thus organizational learning.

Keywords: Accident, organizational learning, safety.

Introduction

Safety scientists recognize that in order to prevent incidents it is essential to learn from previous accidents and near misses (Kletz, 2006; Lindberg *et al.*, 2010; Fahlbruch and Schöbel, 2011). Hopkins (2008) highlighted the inability to learn from previous safety incidents as a source for repeated accidents, most of which have similar systemic causes. While the opportunity to learn from previous incidents is available, many miss this opportunity. For example, Stoop and Dekker (2011) noted that accident investigations are criticized for their reactive nature and the lack of learning potential they provide. Kletz (2002) examined the missed learning opportunities from incident investigations because, in his review, they focus on a single, immediate cause like human error and on procedural changes rather than designs. Chua and Goh (2004) emphasized the value of learning from incidents in the construction industry. While learning from safety-related incidents is important, there are numerous approaches to and theories regarding incident causality. Kletz (2006) described this diversity by comparing incident reports to Rorschach inkblots: different people see different underlying causes. The inconsistency in incident investigation techniques is best described by Lundberg *et al.* (2009), who find that the causes of the incident discovered during an investigation reflect the assumptions of the incident model. They coined the acronym 'WYLFIWYF', meaning What You Look For Is What You Find. Accordingly, What You Find Is What You Fix, 'WYFIWYF'.

The aims of this research are to contribute to the body of knowledge in construction safety by demonstrating the utility of a previously developed construction accident causality model, and proposing it as a useful framework to facilitate organizational learning. The need for this case study was identified by a State Department of Transportation, in order to evaluate a

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new way of determining incident causes that could be applied within the organization. The Loughborough Construction Accident Causation (ConAC) model (Figure 1) was applied to analyse State Department of Transportation construction accidents. A rationale for selecting this particular model is explained. The methodology utilized is detailed and written so that a similar study could be repeated by researchers and utilized in practice by incident investigators. The ConAC model was developed in the United Kingdom and recently applied in Australia.

Literature review

Incident investigation

Incident investigation theories and techniques vary widely in the peer-reviewed literature. Heinrich (1969) proposed a domino theory focusing on human behaviour deficiencies. Bird (1974) modified Heinrich's domino theory by adding that management and organizational aspects are causal factors in incidents. In construction, Whittington *et al.* (1992) found that management errors were the major contributors to

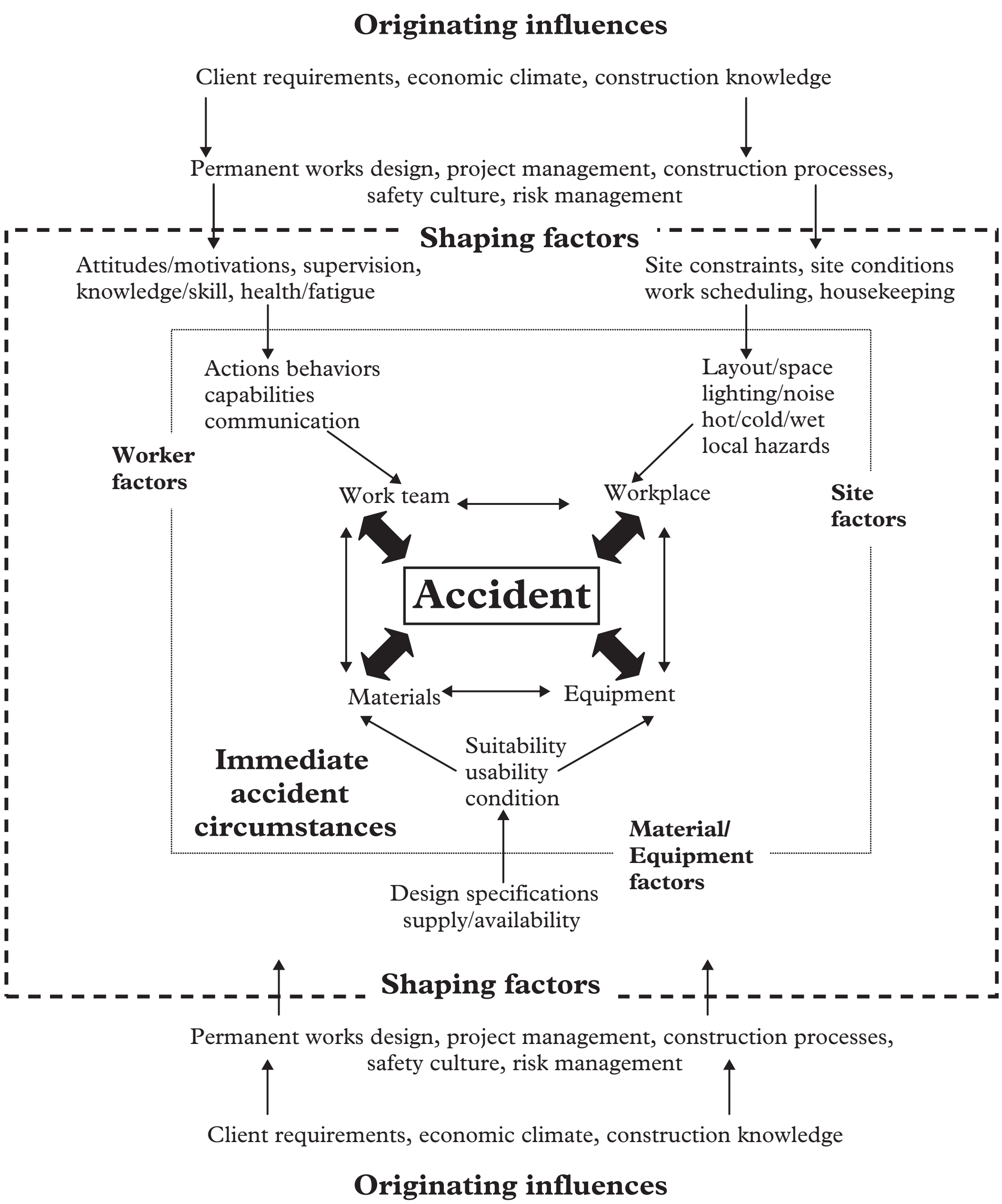

Figure 1 Loughborough Construction Accident Causation model (Haslam *et al.*, 2005)

incidents. Hinze (1996) proposed a distraction theory where the risk of a construction incident increased due to worker distractions. Abdelhamid and Everett (2000) developed a model that identified root causes of construction incidents as worker training, worker attitude and procedures. This model, while extremely useful at finding the immediate shortcomings at the worker level, ignores systemic root causes that might explain why worker attitude, for example, failed and subsequently caused the incident. Subsequent discussions raised this issue and recommended additional inquiries looking at culture, leadership, project management decisions and design inadequacies (Gibb *et al.*, 2001). Suraji *et al.* (2001) proposed an incident causality method by focusing on identifying proximal and distal factors in construction incidents. Proximal factors are those directly related to the incident cause while distal factors are those which lead to the introduction of proximal factors. Examples of distal factors would be time constraints or design complexity. Suraji *et al.* (2001) developed and validated 70 specific classifications of incident causes in the five broad categories of construction planning, construction control, construction operation, site condition and operator control.

The dichotomy in incident causation theories can be summarized by the person approach and the systems approach (Reason, 2000). The person approach focuses on the errors of individuals, blaming them for forgetfulness, inattention or moral weakness. The system approach concentrates on the conditions under which individuals work and tries to build defences to avert errors or mitigate their effects. The latter strives for a comprehensive management programme aimed at several different targets: the person, the team, the task, the workplace and the institution as a whole (Reason, 1997). The term 'root cause', is a very popular term in practice, but Dekker (2006) describes it simply as the place where you stop looking any further. Moreover, ending the investigation at employee-based causes can be attractive to management as internal investigators may be in a difficult position when they feel that an underlying cause of an incident is the organization's policy or culture (Kletz, 2006).

Investigating an incident should be undertaken like a research project, designed to extract the maximum amount of knowledge from the experience and to disseminate that knowledge so that no one need have such an experience again (Burgoyne, 1982). Katsakiori *et al.* (2009) suggest that a 'good' investigation method should also account for the specific context of the incident: this is why there exist methods best suited for aviation, or 'major' incidents, or 'offshore' incidents, etc. and others that are best suited for occupational incidents since the context is different. Seen from a safety scientist's view, Sklet (2004) suggests that the aim of incident investigations should be to identify the event sequences and all causal factors influencing the incident scenario in order to be able to suggest risk reducing measures suitable for prevention of future incidents.

Department of Transportation construction project incident causality

Much of the peer-reviewed research in the archival literature regarding Department of Transportation (DOT) construction project incident causality comes from the New York State DOT. Bryden and Andrew (1999) categorized NY DOT incidents as traffic and construction (non-traffic) incidents. They found that construction incidents accounted for four-fifths of all serious injuries and three-fifths of all fatalities. The categories were broadly classified as falls, struck by, and caught between. In follow-up research the same group (Bryden *et al.*, 2000) focused on traffic incidents within work zones. They found that pedestrian workers are at a greater risk of serious injury than non-pedestrian workers. Mohan and Zech (2005) provided additional descriptive research on NY DOT construction incidents, reporting that the top five DOT construction incidents are due to: struck/pinned by large equipment; trip or fall (elevated); contact with electrical or gas utility; struck by moving/falling load; and crane/lift device failure. These articles are descriptive of the incident classifications, but they do not evaluate the root causes of DOT type construction incidents from an investigatory standpoint. This research aims to fill that gap and to propose, for broader consideration, a model to facilitate organizational learning in the construction industry.

Recent use of the Loughborough ConAC model

Using the ConAC model, Cooke and Lingard (2011) explored the causes of 258 work-related deaths occurring in the Australian construction industry between 2000 and 2010 by utilizing data recorded in the National Coronial Information System, a national internet-based data storage and retrieval system for Australian coronial cases. They report that the Loughborough ConAC model is 'potentially useful in the causal analysis of work-related fatal incidents in the construction industry' (p. 287). However, Cooke and Lingard report on two specific limitations of the model. They are: '(i) that classification of factors was open to interpretation, which could lead to the identification of different causal pathways; and (ii) that not all incident scenarios were adequately represented by the "hierarchical" sequence of causal factors implied by the HSE model' (Cooke and Lingard, 2011, p. 287).

It is noteworthy that Cooke and Lingard's research was published after this project was proposed and undertaken. Two groups of researchers on different continents applying the same model to understand construction accident causality, without knowing of the other's work, lends credibility to both efforts, and to the model's potential utility. Cooke and Lingard recommended that, because different mechanisms of causation apply to fatal and non-fatal incidents, further research using richer data about the circumstances in which incidents occur be analysed. Our research does just that; the incidents in our dataset, as described in the methods section, include all non-fatal incidents, and even some near misses. This research complements the product of Cooke and Lingard's research, and adds further credibility to the model's applicability for organizational learning.

Method

Methodological considerations of the model

In this research, the Loughborough ConAC model (Figure 1) was applied to State Department of Transportation incidents, where diverse construction activities are performed such as earth works, building construction, maintenance/repair, and non-routine project oriented tasks. The objective of this research project was to utilize the Loughborough ConAC model during retrospective investigations of a DOT incident subset, and describe its utility in assisting the investigators in determining multiple causes, factors and influences of DOT incidents. The model was developed in the United Kingdom by a research team drawing together the findings from focus groups and incident studies, and suggests a hierarchy of causal circumstances, factors and influences in construction incidents (Haslam *et al.*, 2005). The approach taken with the model reflects the inadequacy of deterministic, causal incident models when dealing with highly adaptive socio-technical systems, such as those found in construction (Haslam *et al.*, 2005). The Loughborough ConAC model and its development were detailed in a UK Health and Safety Executive report (2003), presented orally at an international construction safety conference (Gibb *et al.*, 2004), and presented formally in the archival peer-reviewed literature (Haslam *et al.*, 2005). This model allows the user to find solutions within a systems approach.

The Loughborough ConAC model was suggested to the State DOT for several reasons. First, the model calls for the consideration and analysis of various causes, factors and influences ranging from those immediate to the work back to supervision, management, planning and systemic influences. Secondly, the methodology by which this model was developed was readily available to be utilized and was described in sufficient detail to be duplicated (Health and Safety Executive, 2003). In reviewing other construction incident investigation models presented previously, those models were not explained carefully enough to be utilized in practical circumstances. For example, the Abdelhamid and Everett (2000) model focused solely on site conditions and worker actions or inactions. Suraji *et al.* (2001) included 70 classifications, and that proved to be too many for the practical purposes required to meet the State DOT's needs. Thirdly, the language within the Loughborough model was easy to understand and apply in practice; thus the researchers believed such a model could be applied broadly within a construction organization. That was a fundamental goal of this project. Lastly, the use of this model was reviewed and approved by the State DOT steering committee during the project scope's design.

Incident case selection

Through searching the DOT incident database 516 cases were found in the nine-month period before the project commenced. The focus on the investigation was on construction incidents as opposed to traffic incidents; thus 90 traffic incidents were eliminated, or 17%, a similar ratio of construction and transportation incidents as reported in research by Bryden and Andrew (1999). The sample set was further reduced by 203 cases eliminating geographic regions requiring overnight travel. Fifty-three incidents contained incomplete information. The database from which to sample was 170 cases. Based on recommendations from the project steering committee, to ensure a range of incidents representing the various types that occur within the DOT, the sample was stratified according to the nature of the incident. Every fifth case was selected for a total of 34 cases. In the research proposal, a goal was set to analyse 30 incidents, to be discussed in the next subsection. A criterion for case inclusion was that the employees (injured, work team, witnesses), supervisors, and the divisional safety engineer needed to be available to talk with the investigators. Owing to retirements, layoffs, and either the employee or supervisor not being available 12 data points were missing. The DOT steering committee assisted the researchers in selecting five additional incidents based on geographic diversity and adhering

Table 1 Type of the injury in 27 investigations

Type of injury	Frequency	Percentage
Strain/sprain	10	37
Contusion	6	22
None listed/near miss	4	15
Laceration	3	11
Foreign object—eye	2	7
Fracture	1	4
Puncture	1	4
Total	27	100

to the type of injury category. By the time all investigations were completed, 27 incidents were utilized in the research. The summary of the injury types is given in Table 1. The database contained four near misses (15%); the DOT recognized the benefit of collecting this information as did the researchers in the Health and Safety Executive (2003) study. Organizations can learn from their incidents and near misses without having to suffer the consequences of an injury-producing incident as proposed by Lindberg *et al.* (2010). Thirteen of the incidents investigated (45%) resulted in lost time ranging from 1 to 35 days, with an average of 5.7 lost work days. Ten of the incidents investigated (38%) resulted in medical only cases.

Sample size

One purpose of the research was to compare the utility of the Loughborough ConAC model to the current investigation model used by the DOT. It was hypothesized that the Loughborough model would produce a greater number of identified causes, factors and influences compared to the DOT. The previous research (Haslam *et al.*, 2005) found 4.5 causes, factors and influences per incident investigated. A cursory review of the DOT database in the planning stages of the research revealed they typically found one or two causes per incident, and occasionally three causes. Erring on the conservative side, it was estimated that the mean number of causes per incident found using the Loughborough model would be 3.5 and the mean for DOT would be 2.75, and the standard deviations would be 1.0; this yielded an effect size of 0.75. An alpha of 0.05 and power of 0.90. was used. G*Power 3.1.3 were utilized to calculate the sample size needed for these specifications to compare the differences between the two models with a dependent sample t-test; the result was a minimum of 21 incidents necessary for the statistical analysis. Thirty was chosen as a goal because it seemed appropriate to determine the model's practical utility across a suitable spectrum of DOT incidents and geographic regions. Further, the DOT steering committee agreed that 30 would be an appropriate number to determine the utility of the model in practice.

Utilization of the Loughborough model: operational definitions

From studying the previous research (Health and Safety Executive, 2003; Haslam *et al.*, 2005), it was apparent that there existed a need to create operational definitions for the 25 terms that make up the immediate accident causes, shaping factors and originating influences. The outer originating influences (economic climate, client requirements and construction knowledge) are indicated within the model; however, these are rarely able to be clearly indentified in incident investigations (Haslam *et al.*, 2005), and therefore this research endeavour did not attempt to trace incident influences to these outer originating influences. Cooke and Lingard (2011) also reported on the limitations of the operational definitions—'classification of factors was open to interpretation' (p. 287). In this research, the operational definitions were applied to ensure reliability throughout the investigation interviews. While some terms like worker behaviour are straightforward in their interpretation, other terms such as risk management and project management had to be defined so that they could be reliably utilized. The previous research reports (Health and Safety Executive, 2003; Haslam *et al.*, 2005) guided the development of these operational definitions. Provided below are three example operational definitions of project management, risk management and safety culture. These three terms are chosen as examples because they were the most ambiguous in communications with project staff about their meaning. All three are originating influences. Originating influences, because they are farther from or upstream of the immediate circumstances, were more difficult to identify and define. The definitions can also overlap with shaping factor and immediate circumstance terminologies.

- *Project management* includes the safety oversight of the intricacies of the project and tasks to be performed. It includes contractor arrangements, subcontracting, labour supply, work scheduling, time management, time pressures, and individuals taking it upon themselves to do jobs/tasks. Usually substandard project management is indicative of poor long-term planning of the work to be performed.

- *Risk management* includes the following: improper, or a lack of formal or informal, risk assessments, work method statements, job hazard analyses; improper incident investigation, which includes not learning from past mistakes and/or failures; poor identification of proper remedial actions in respect of identified risks; lack of, or poor employee consultation and participation in identification of hazards and risks; conditions where recognizable hazards were not identified; and situations where recognizable risks were not properly anticipated and identified. Usually substandard risk management is indicative of poor short-term planning of the work to be performed.
- *Safety culture* is the way things are done around the organization and can be an organizational level, divisional and group (work team) level phenomenon. Safety culture affects workers' attitudes and motivation in relation to an organization's ongoing safety performance, communication, supervision, scheduling, and eventually work team behaviour regarding safety. It is unwritten and largely unspoken, but influences how projects and tasks are planned, when and how often risks are taken, what risks are acceptable, and what are not. For example, when employees take shortcuts it can be rooted in the safety culture of the organization or group in that they are encouraged either directly or indirectly to take those shortcuts to get the job done.

Interview protocol

Separate semi-structured interviews with the employee(s) involved in the incident, including witnesses, and their supervisor(s) were coordinated with the assistance of divisional safety engineers. The safety engineers were also interviewed. Interviewing multiple sources allowed triangulation of the data, ensuring validity. Each interview lasted approximately 30 minutes to two hours depending on the detail and complexity of the incident. The investigator utilized the Loughborough ConAC model as a guide during the interview, which was in an open-ended type format. A method to ensure consistency and reliability across all interviews was developed and it is described in the next section. The interviews started with the interviewee's account of the incident with the interviewer taking notes and relating information to the ConAC model keywords. When issues came up related to the immediate accident causes (work team, workplace, materials and equipment) they were followed up and discussed further to discover whether there were shaping factors and originating influences that could be identified as discussed in the next section.

Method for using the Loughborough ConAC model

The researchers developed the following method for use during the investigations. This model and the operational definitions of each cause, factor and influence enhanced model reliability across each investigation. Before the interviews, the researchers reviewed the DOT incident investigation forms to understand the basic information about and nature of the incident.

(1) Allow the interviewee to tell what happened and what caused the incident to occur. Start by identifying immediate accident circumstances and work out from the incident in the middle of the model.

(2) Treat the phrases within the model, immediate accident circumstance, shaping factors and originating influences as questions with dichotomous answers; either the cause, factor or influence was related (answer = yes), or it was not related (answer = no). For example, if worker actions and behaviours are identified to be an immediate incident cause (yes), then the affirmative response must be traced back through the model to the shaping factors associated with the work team. In the example of worker actions and behaviours, ask the following questions to determine any shaping factors:

   (i) Did the attitudes or motivations of the worker(s) shape the actions and behaviours of the worker(s)? If so, how?
   (ii) Did inadequate supervision contribute to the actions and behaviours of the worker(s)? If so, how?
   (iii) Did the health or fatigue of the employee(s) contribute to their actions and behaviours? If so, how?

(3) When any yeses are identified to these shaping factor questions, it means that an opportunity for improvement to reduce risk has been identified. Each is then traced back to the potential originating influences and similar dichotomous yes/no questions asked, thinking about a piece of Swiss cheese (i.e. Reason, 1997), where the holes

in the cheese represent gaps or the opportunities for improvement. For example, if inadequate supervision were detected as a shaping factor, then the investigator would ask questions about all originating influences, such as, does the safety culture of the organization encourage this type of inadequate supervision, and was the project managed successfully. The investigator must think critically about each influence and confirm any organizational issues that have affected the incident. If it cannot be confirmed then it cannot be listed as a 'yes'. Again, the data were triangulated to ensure validity by multiple interviews with the injured employee, witnesses, supervisors and safety engineers. We never suspected the interviewees were not telling the truth. However, the perspectives of the employees compared to their managers were at times conflicting. Because we were able to interview witnesses and the divisional safety engineers, we were able to ascertain and corroborate facts surrounding the events.

(4) Repeat the questioning sequence for each incident immediate circumstance (work team, work space, equipment and materials).

(5) When causes and influences are identified, they should be highlighted on the model (Figure 1) and written down. The research team created a spreadsheet with columnar headings for each cause, factor and influence, with explanations of how they were linked to the incident. See Figure 2.

(6) Originating influences may appear more than once in a single incident if there are multiple deficiencies or improvement areas found. For

	Factor/Influence	**How linked to accident**
■	Work team	
■	Communication	
■	Capabilities (knowledge/skill)	
■	Actions/behaviours	
■	Attitudes/motivations	
■	Supervision	
■	Health/fatigue	
■	Permanent works design	
■	Project management	
■	Construction processes	
■	Safety culture	
■	Risk management	
■	Workplace	
■	Local hazards	
■	Site conditions (layout/space)	
■	Working environment	
■	Site constraints	
■	Work scheduling	
■	Housekeeping	
■	Permanent works design	
■	Project management	
■	Construction processes	
■	Safety culture	
■	Risk management	
■	Materials/equipment	
■	Suitability—equipment	
■	Usability—equipment	
■	Condition—equipment	
■	Suitability—materials	
■	Usability—materials	
■	Condition—materials	
■	Design specs of material & equip	
■	Availability of material & equip	
■	Permanent works design	
■	Project management	
■	Construction processes	
■	Safety culture	
■	Risk management	

Figure 2 Loughborough Construction Accident Causation model documentation form

Table 2 Summary of immediate causes, shaping factors and originating influences in 27 incident investigations

	Immediate circumstances (work team)			Shaping factors (work team)			Immediate circumstances (workplace)			Shaping factors (workplace)			Immediate circumstances (materials and equipment)						Shaping factors (M&E)		Originating influences				
Incident #	Worker actions and behaviours	Worker capabilities (including knowledge and skills)	Communi-cation	Attitudes and motivation	Immediate supervision	Worker health/ fatigue	Local hazards	Site conditions (layout/ space)	Working environment (lighting/ noise/hot/ cold/wet)	Site constraints	Work scheduling	House-keeping	Suitability of materials	Usability of materials	Condition of materials	Suitability of equipment	Usability of equipment	Condition of equipment	Design specs of equip. & matls.	Availability of equip. & matls.	Permanent works design	Project management	Construction processes	Safety culture	Risk management
1		✓					✓		✓	✓						✓	✓	✓	✓				✓		✓
2	✓		✓	✓	✓		✓			✓						✓					✓	✓	✓	✓	✓
3	✓		✓	✓	✓																	✓			✓
4	✓			✓			✓			✓															✓
5		✓					✓																		✓
6	✓	✓		✓													✓			✓					✓
7	✓	✓	✓	✓		✓											✓	✓							✓
8		✓			✓		✓			✓											✓	✓			
9	✓	✓		✓														✓			✓			✓	✓
10		✓				✓																			
11		✓														✓	✓		✓		✓				✓
12	✓						✓	✓													✓	✓			
13	✓			✓			✓			✓		✓										✓		✓	✓
14							✓	✓	✓																
15		✓					✓	✓	✓																✓
16	✓			✓																				✓	✓
17	✓			✓					✓	✓									✓	✓	✓				
18	✓			✓									✓							✓				✓	✓
19	✓	✓	✓																			✓			✓
20	✓	✓	✓	✓	✓		✓		✓	✓												✓		✓	✓
21	✓						✓			✓						✓				✓		✓			✓
22		✓	✓		✓																	✓	✓	✓	✓
23		✓								✓											✓				
24	✓		✓		✓		✓	✓		✓	✓					✓	✓			✓	✓	✓	✓	✓	✓
25		✓			✓	✓			✓	✓												✓			✓
26		✓	✓			✓	✓									✓			✓	✓			✓		
27	✓	✓		✓	✓				✓													✓			
Tot.	17	16	8	12	8	4	13	4	7	11	1	1	1	0	0	6	6	3	4	6	8	12	5	8	18

Note: 81 Immediate circumstances; 47 shaping factors; 51 originating influences.

Accident description: Employee was trying to lift 100-pound chain hoist when he felt pain in his right shoulder.

Root causes identified by division: Solo attempt to manhandle hoist. Counselled employee.

Were immediate causes and shaping factors identified by DOT? Yes.
Were originating influences identified by DOT? No.

Research investigation summary
The employee was told to take the hoist down off the ferry. It weighs approximately 100 pounds. This is not a one-person task. The employee suggested to the superintendent that perhaps they should use the forklift. The superintendent declined this idea and told the employee to get the job done or go home for the day. The employee noted that this was an uncommon task for him to remove the hoist. The employee felt pain and decided to wait it out a few hours before seeking medical attention. He was out of work for three days. After this injury, they began to utilize the forklift rather than use manpower when they need to remove the hoists.

Immediate causes and shaping factors
Communication—Supervisors not listening to employee input on the hazards and risks and possible countermeasures.
Capabilities—One worker is not capable of doing this task safely with a minimal degree of risk particularly given the fact that a forklift was available.
Supervision—The employee was not adequately supervised. He was told to do the job or go home.
Knowledge/skills—It was an unfamiliar task. There was a lack of knowledge by the supervisor and the employee.
Attitudes/motivation—The employee had no choice but to do the task or else be sent home. The attitude of the supervisor is identified as a shaping factor.
Local hazards—Slick/wet deck identified.
Layout/space—There were trip hazards and a lack of space faced when reaching to get hoist.
Site constraints—There was a minimal work area causing a limited range of motion.

Originating influences
Project management—There were time pressures (do it or go home), communication issues, that lacked management understanding of safety risks.
Safety culture—Instead of using available equipment (forklift) they used manpower to complete the task. Upon hesitation the employee was threatened with being sent home. This signals a lack of a positive safety culture within the workgroup or some part of the larger organization.
Risk management—The risks were not adequately identified by management. They were deemed acceptable even though the employee suggested otherwise.

Figure 3 Sample vignette 1, incident 20

example, an originating influence such as project management may affect the manner in which equipment is scheduled and may also affect supervision and the work team.

Limitations

Because the research team was not part of the DOT staff, it had the advantage of looking at the incidents through a more critical lens. Kletz's (2006) comments on the difficulty faced by internal investigators were discussed previously, but that difficulty is worth noting again here as a limitation especially with our comparison of the internal DOT findings to the research findings. As external researchers, there was nothing to lose; therefore, it was uncomplicated to identify areas for improvement that focused on the organization and management. Internal investigators have more at stake. For example, Schröder-Hinrichs *et al.* (2011) reviewed maritime incident reports and found that organizational factors were not identified to the extent expected but rather contributing factors at the sharp end (worker level) are over-represented. Similar findings are reported here, but this is also a limitation to utilizing the model in practice.

Results

Investigation results

Using the Loughborough ConAC model, 179 total causes, factors and influences were identified within the 27 incidents reviewed for an average of 6.63 causes/factors/influences identified per incident. The top six causes and influences identified using the Loughborough model, with the number of times linked to the incident in parentheses, are: risk management (18); worker actions and behaviours (17); worker capabilities, including knowledge and skill (16); local hazards (13); project management (12); and attitude and motivation (12). Eighty-one immediate causes, 47 shaping factors, and 51 originating influences were identified. A summary of each incident's immediate causes, shaping factors and originating influences is provided in Table 2.

In comparison, the DOT incident investigations yielded 32 total causes/influences identified from the 27 incident investigations, or an average of 1.21 causes/influences per incident. Comparing this with the Loughborough model the result is significantly

Accident description: Employee was holding bent signpost for backhoe to grab with back jaw bucket. As the backhoe grabbed the bent post, it twisted and hit the employee in the head and arm. Employee was knocked to ground. Backhoe crew was removing debris from a large pipe on a state road. The crew was attempting to remove blockage from pipe with several signposts that had been bolted together. The signposts could not be taken apart with a wrench because the post and bolts had been bent while attempting to remove the blockage. The assembled posts were too long to transport back to work yard. Therefore, the backhoe was used to break the posts apart. Employee was holding the bent signpost for the backhoe to grab with the back jaw bucket. As the backhoe grabbed the bent post, it twisted hitting the employee in his left arm and side of head, causing the employee to flip and fall to the ground.

Root causes identified by DOT: Employee should have left the backhoe jaw bucket to grab the post off the ground instead of employee holding the post. Employee was standing too close to work area while equipment was in operation. Follow a written operating procedure that the operator should be aware of employees and others on foot in work zones and be sure area is clear of personnel before lowering stabilizers or moving the boom. The ground man (injured employee) was counselled on paying attention to surroundings and staying clear of operating range of equipment.

Were immediate causes and shaping factors identified by DOT? Yes.
Were originating influences identified by DOT? No.

Research investigation summary
A home owner called DOT that a pipe was blocked in front of their property by the state road. This could be a potential emergency situation for the public as rains had come and heavier rains were forecasted; the state road could have become flooded due to the blocked pipe. Management scoped the job and it was scheduled for the next day. The supervisor stated that a 30-gallon PVC drum was stuck because the pipe got smaller as there was an addition on to this pipe that was not added on by DOT. The driveway was modified and a contractor added smaller pipe on to the existing pipe originally installed by DOT. This enabled the blockage of the 30-gallon PVC drum. Four road signposts were bolted together to act as a battering ram to jar the PVC drum loose from the pipe or damage it enough so that the water could drain. The backhoe held the signposts at one end and rammed it into the blockage. The crew stated that they like to use a tree as the ram and would have in this instance but there were no trees in close proximityto the driveway. This is very normal procedure to use the signposts and trees. They got the job done and were rushing to get cleaned up so they could get the prison inmates, who were helping them, back for the day. This is when two of the signposts could not be separated with a wrench because they were damaged. The crew and supervisor decided to break them using the backhoe and the injured employee decided to hold the signposts for the backhoe. They needed to separate the posts or break them so they could haul them back to the work yard in the pick-up truck, as they would not fit bolted together.

Immediate causes and shaping factors
Worker factors/actions/behaviours/attitudes/motivation. Employee holding the signposts was in the danger zone of the backhoe. He knew this was a mistake but did it anyway.
Worker factors/actions/behaviours/supervision. Overseeing this task to use the backhoe was a decision of the crew leader.
Worker factors/communication. There was poor communication between employee and backhoe operator, and also between the crew and the supervisor.
Workplace/layout/site constraints. The pipe was 30' long and the drum was stuck at the end so they had to un-jam this from a distance of close to 30'. This distance made the job more difficult and contributed to the damage in the signposts and the difficulty in getting them apart.

Figure 4 Sample vignette 2, incident 24

Workplace/local hazards/work scheduling. There was an immediate need to get this job done or there was a potential public hazard due to the road flooding with the forecasted rains. They also needed to get the prison inmate helpers back at a designated time.
Equipment/suitability and usability/supply/availability. Is bolting signposts together a suitable work method? Is there a better work method with more suitable equipment to do this job?

Originating influences
Construction processes. The supervisors and employees claim there is a Jet Rodder, a machine designed to remove grease and debris from the smaller-diameter sewer pipes with high-velocity jets of water. It is also called a high-pressure cleaner, hydraulic cleaner, hydro jet, or jet cleaner, but it is expensive. A neighbouring DOT Division has one. They could rent one but it is $275 per hour.
Project management (work scheduling). They had to get this job done or there was a potential public hazard due to the road flooding with the forecasted rains. Should the project have been managed more thoroughly given the constraints?
Project management (equipment). Is bolting signposts together a suitable work method? Is there a better work method with more suitable equipment to do the job? Could this have been managed better to reduce risk? Could the machine described or other machine be utilized?
Permanent works design. The re-design addition of the smaller pipe was something that DOT could not control, but it is worth mentioning to understand how it influences other aspects. Recognizing design influence can enable better judgments for specifying equipment and how jobs are planned.
Safety culture. Safety could have been considered more thoroughly in the planning phase of this task. The risk of rushing the job and rushing to get done for the day was acceptable, and still would be according to the interviews, as long as no one gets hurt. The culture within the organization is certainly affected by the public's perception. As one witness stated, 'the public doesn't care if a DOT worker gets hurt, just so their roads are fine and always passable'. This statement really sums up the pressure that DOT is faced with, particularly in jobs that will negatively affect public transportation if not completed in a timely manner.
Risk management. Recognizable hazards and risks were not properly anticipated and identified in terms of the methods to open the clog in the pipe.

Figure 4 (*Continued*)

different ($p < 0.001$). Most of the identified causes (13) were assigned to employee behaviour and actions. Seven were deemed due to local conditions, such as road conditions, ground conditions, etc. Two of the incidents investigated by the DOT did not identify any causes on the investigation form.

For each incident investigated a vignette was created which discussed the incident and the investigation including how the causes, factors and influences were related. The decision to provide vignettes and the protocol in their development again followed the previous research (Health and Safety Executive, 2003; Haslam *et al.*, 2005). Two vignettes are provided as examples (see Figures 3 and 4).

Correlations

On each pairing of the 25 variables, a correlation was performed. Using the nominal correlation coefficient, phi, it was analysed if any of the 25 dichotomous variables correlated with any other variables. There are no widely accepted criteria for defining a strong, moderate or weak correlation (Portney and Watkins, 2000). In construction research, Touran (1993) and Ranasinghe (2010) chose correlation coefficients of 0.15 (midpoint of 0–0.3) for weak, 0.45 (midpoint of 0.3–0.6) for moderate, and 0.8 (midpoint of 0.6–1.0) for strong correlations. Some of the significant correlations ($p < 0.05$) are discussed here.

Worker actions and behaviours were negatively correlated with worker capabilities, including knowledge/skills ($r = -0.48$, $p = 0.011$), which indicates that these immediate causal factors acted separately as causes of incidents. It was either one or the other in most cases, but not both. Worker actions and behaviours were correlated with attitudes and motivations ($r = 0.69$, $p = 0.001$). When the work crew's actions or behaviours were identified as a causal factor, someone's attitude or motivation to work safely was usually also identified. This could be the injured employee, a crew mate, a supervisor, or manager. Attitudes and motivation were also correlated with safety culture ($r = 0.40$, $p = 0.039$). Defining safety culture within an organization is a complex task (Molenaar *et al.*, 2009). Mohamed (2003) and Cooper (2000) viewed safety culture as a sub-facet of organizational culture, which affects workers' attitudes and behaviour in relation to an organization's ongoing safety performance. The operational definition used for safety culture to maintain reliability was given in the methods section and was derived from the previous research (Health and Safety

Executive, 2003), and the work of Molenaar *et al.* (2009), Mohamed (2003) and Cooper (2000). Worker actions and behaviours were correlated with availability of equipment and materials ($r = 0.41$, $p = 0.034$). This suggests that even though equipment and materials may not be available, workers believed they should go ahead and attempt to complete the tasks assigned.

Site conditions were correlated with work scheduling ($r = 0.47$, $p = 0.013$), and work scheduling was correlated with construction processes ($r = 0.41$, $p = 0.033$). Site conditions are varied and sometimes unknown. Despite this, DOT jobs had urgency; they had to be done. Sometimes, if the job was not completed it would negatively affect public safety. This phenomenon affected the safety of DOT employees. Sometimes the equipment utilized to complete the job was not suitable and often traceable to the construction process ($r = 0.66$, $p = 0.001$). Sample vignette 2 is an example of this observation.

Discussion

The Loughborough ConAC model is not a checklist style incident investigation model. It is based on Reason's (1997) 'Swiss cheese' model, which seeks to span the entire incident sequence from organizational to individual levels. The model's purpose is to diagnose incident causation by looking beyond the immediate causes of incidents. Incident causation models that focus solely on individual level factors (i.e. immediate factors in the Loughborough model) lose a great deal of diagnostic information especially if the goal is organizational safety improvement. Consider a model that focuses solely on employee acts and/or unsafe conditions. Specifically consider the incident described in vignette 1. The DOT investigation stopped at the employee action, and the corrective action was to counsel the employee. However, the employee already knew the task was a risk, but the supervisor insisted he do the task or 'go home'. Lingard *et al.* (2010a) recommend that the development of safety leadership capability in first-level supervisors may yield significant improvements in safety performance, and that supervisors are an important conduit through which top management support safety. The other point is that organizational learning can occur, but only if the organization and the investigator want to learn. The internal investigator in this example was too close to the organization and ended the investigation at the employee which was attractive to management, just as Kletz (2006) warned us about. The underlying causes of this incident lie within the organization's culture that allows a supervisor to make such decisions and demands without considering worker safety and health. This was not the first time the supervisor made such demands as 'do it, or go home' to his employees. Rather the culture of the micro-organization in that department could be that of an authoritarian rule which compromises safety. Learning about the organization from incident investigations can also reveal other useful improvement opportunities. Thinking about safety as a people problem, highlighted in this example, does nothing to prevent the same type of incident from occurring again in the future. If it's not 'lift that or go home', it could be 'get in that confined space or go home' or 'make that critical lift with the crane or go home'. Identifying originating influences like poor safety culture and risk management in relatively minor incidents (like this example of three days' lost time) can produce information to prevent major incidents. This finding complements the findings of, and the call for future inquiry made by Cooke and Lingard (2011).

Consider another incident investigated during the research where employees hit an overhead electrical line with a backhoe. In this incident a focus on the employees would certainly reveal that they got too close to the overhead wires and this is in violation of work rules that they admittedly understand. This is what the DOT found in its internal investigation. However, if an incident investigator stops at this point, the organization can reprimand the employees and then run the risk that the employees become frustrated with the safety effort because there was more to the incident than a simple focus on the employees' acts. Through the research investigation it was revealed that management did not scope and plan the job properly nor did they conduct a thorough risk assessment. Saurin *et al.* (2004) found that planning and control failures were identified as major root causes of the lack of safety. In relation to the overhead wires, employees were told to 'be careful', because the job had to be completed and a smaller piece of equipment to safely manoeuvre below the power line was not available that day.

An incident investigation is only as good as what is revealed by the people involved and the information revealed must be factual. The Loughborough ConAC model allows the investigator to critically think about influences that affected the particular incident under investigation but also to think about factors that might influence organizational aspects. In the overhead electrical line example, there was clearly a lack of communication between employees and supervisors. Knowing this should prompt the investigator to consider other aspects where poor communication increases risk; the organization should consider ways to improve safety communication between employees and management. One way is to improve safety culture. Again, safety culture was noted as an originating influence in this incident because clearly there is a culture of disagreement when it comes to safety planning and communication. Lingard *et al.* (2009) recommend that the development of a positive safety culture should be one of the most important aims for those who wish to improve safety performance. Choudry *et al.* (2007) found that safety culture will ascertain and reflect the effectiveness of a safety management system at any construction site. Guldenmund (2000) posits that when a given safety culture or climate has been assessed and needs improvement, then the next question will certainly be 'so what?'. As regards many originating influences, it will be difficult for an organization to understand them and develop methods for improvement, but we suggest that it is worth the effort within the construction industry. An organization interested in improving employee safety would investigate further as to whether this is an isolated clash or if there is more disagreement about safety at the group or organizational level. Lingard *et al.* (2010b) found that developing a strong consensus within workgroups about the importance of safety relative to other project objectives is important to overall site safety performance. A focus on the employees' acts would likely prevent this group of employees from doing the same type of unsafe act in the short term. It might also prompt workgroups within the division to not perform unsafe acts when working around overhead power lines. However, it might not if the other groups thought that this particular workgroup just got unlucky that day or if they were not informed of the conditions surrounding the incident. Nevertheless, what about the long term and what about organizational learning from this incident across the other DOT divisions? Discussions with divisional safety engineers revealed two other incidents where equipment struck overhead power lines. Is this is a work rule violation that needs to be corrected at the employee level through training and enforcement or is this an organizational issue where risk could be minimized through better planning of the work, proactive communication, a building of trust between employees and management, and potentially other originating influences identified? The latter will enhance organizational safety in working with and around overhead power lines safely. That's the solution to Guldenmund's 'so what' question. Furthermore, identifying these originating influences will ultimately affect other work issues (apart from power line safety). Consider if the organization, because of this new knowledge, decides to focus on better work planning. This would potentially include a large gamut of DOT construction activities, not just working on or around overhead electrical lines. Hallowell *et al.* (2011) found that being able to proactively identify high risk periods and communicate risks with construction crews are very important matters for successful safety management. To meet those needs, Cameron and Hare (2008) developed safety tools that can be integrated into the construction planning process. Utilizing a framework like the Loughborough ConAC model for organizational learning will allow the organization to uncover these systemic issues and highlight them as areas for improvement. The aggregated data provided in Table 2 can help an organization with knowledge management and learning by providing focus in prioritizing safety interventions. For example, efforts to identify local hazards unique to the specific jobs DOT must conduct will yield a greater risk reduction than would a focus on housekeeping based on the number of times each was identified in the investigations.

Table 3 highlights the comparison of this research to Cooke and Lingard (2011). A higher number of immediate circumstances, shaping factors and originating influences were, on average, found in this research compared to that of Cooke and Lingard. A possible explanation for this is in the methodology for data collection. The methods for this research utilized semi-structured interviews with multiple personnel, whereas Cooke and Lingard analysed the content of retrospective data reports. In fact, they could not analyse 26% of the original database because of insufficient data in the coronial reports. Further, the coronial database they used was not originally established for the purpose of injury surveillance. Cooke and Lingard (2011) recognize these two features and highlight that 'many coronial investigations may focus predominantly on immediate circumstances surrounding an incident and may not identify the extent to which these immediate factors arise as a result of shaping factors or originating influences that are known to contribute to the causation of safety

Table 3 Comparison to Cooke and Lingard (2011), average per incident

	Immediate circumstances	Shaping factors	Originating influences	Avg. no. found
Cooke and Lingard (2011)	1.82	1.07	0.61	3.50
This research	3.00	1.74	1.89	6.63

incidents in the construction industry' (p. 284). Therefore, it is not surprising that this research found a greater number of circumstances, factors and influences.

Conclusions

Safety-related incidents are complex and multi-faceted; successful construction organizations will appreciate these characteristics in order to better understand incidents within their control so that they can make sound financial decisions on risk countermeasures. The Loughborough ConAC incident investigation model provides researchers and practitioners with a useful thought process to identify immediate causes and latent conditions/organizational oriented influences. Further, the causes, factors and influences that can be identified can have influence beyond the individual incident that is being investigated. The model was successful as a framework to lead the investigation in identifying multiple causes and influences. If risk reduction efforts could be channelled in the direction of these more frequent and organizational causes and influences, the DOT may experience fewer incidents overall. Further, the causes, factors and influences can be analysed to understand how they are co-related in a group of incidents. This can help explain how originating influences affect worker action, behaviours and work conditions more globally within construction companies.

The model can be utilized as a tool and a source for organization safety learning. Hopkins (2008) suggests that organizations need to learn from incidents, and also be proactive, and not wait until incidents occur, for organizational learning. The Loughborough ConAC model is not limited to DOT type incidents, but is generalizable to a variety of construction work. DOT has a wide assortment of construction, maintenance, work zone and short-term tasks and the data included a variety of incidents in a variety of situations. The model is specific in its approach but yet flexible to use within the broader construction industry. The results complement the recent research inquiry and findings of Cooke and Lingard (2011) by evaluating non-fatal injuries and by supporting the use of the ConAC model as a framework for organizational learning.

At the conclusion of the research project, the DOT was satisfied with the amount of organizational learning that could be obtained by the Loughborough ConAC model and the vignette for each incident. However, at the practical level, utilizing the ConAC model and the forms that were developed at the initial investigation level by the supervisors and managers seemed too cumbersome to the DOT. The investigation research process was in-depth and lengthy; the DOT felt that the length and depth made it impractical for its supervisors and managers to utilize correctly even with training and examples. It was pleased with the organizational learning but realistically it could not commit to the time and depth required as was allowed for during the research endeavour. Organizations will also need to invest in the time needed to perform in-depth incident investigations. Burgoyne (1982) recognized that in practice, there is little incentive for the company to spare the time and effort and that the ideal investigation will often be curtailed through considerations of time and cost. Jørgensen (2011) recognized that the amount of time and resources required for mapping and analysing accidents is a considerable obstacle for companies who want to use investigation tools.

This research also supports the suggestion of Burgoyne (1982) that incident investigations should be undertaken like a research project and designed to extract the maximum amount of knowledge from the experience and to disseminate that knowledge. Construction industry professionals should consider the Loughborough ConAC model as a tool for organizational learning. However, it is cautioned that when using the tool, and any incident investigation tool for that matter, the investigators should be able to examine incidents without fear of what will happen if they reveal organizational and management issues. The Loughborough ConAC model helps construction organizations find a variety of causes, factors and influences, and thus a variety of areas in which to seek improvement. Nevertheless, Lundberg *et al.* (2009) were correct—'What You Look For Is What You Find' and 'What You Find Is What You Fix'.

Future research

It is suggested that future researchers reproduce this study with a variety of construction industry populations to further examine the Loughborough ConAC model's utility. In particular, the ratios and relationships between immediate causes, shaping factors and originating influences that this study and Cooke and Lingard found are potentially interesting. For example, it would be interesting to know, via larger databases and random sampling for instance, the approximate number of originating influences and shaping factors there are for every unsafe act. Any incident investigation is a reactive process. It is hypothesized that the Loughborough ConAC framework could be utilized proactively in a construction organization's safety management systems to identify levels of unacceptable risk.

This is a future research area that could have particular impact on the construction industry.

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