Development of Causal Model of Construction Accident Causation

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Abstract: Accidents occur in all types of construction activities. The accident causation process is complex. Accident prevention requires a comprehensive understanding of this complex process. This paper proposes a conceptual, but practical, model of accident causation for the construction industry, highlighting the underlying and complex interaction of factors in the causation process. The model describes the constraints and responses experienced by the parties involved in project conception, design, and construction, which may affect accident causation. This paper details theoretical findings of research currently being conducted at UMIST. Both proximal and distal factors are considered (for example, operative factors, site environment and systems of work, and project management and organizational issues). A study of 500 accident records provided by the U.K. Health and Safety Executive shows that accidents in construction projects involve inappropriate construction planning (28.8%), inappropriate construction control (16.6%), inappropriate construction operation (88.0%), inappropriate site condition (6.0%), and inappropriate operative action (29.9%). Data currently available are, in some respects, inadequate and will need to be supplemented, in the future, by extended accident investigations.

INTRODUCTION

In most countries, the incidence rate for fatal accidents in the construction industry is higher than any other industry (Alves Diaz 1995; Suraji 1997a; Duff 1998). Snashall (1990) found that, on average, five construction workers were killed every 2 weeks and one member of the public was killed every month by construction activities in the United Kingdom. Across the European Union, 67% of workers in the construction sector believe that they are at risk of having accidents [Commission of European Communities (CEC) 1992]. Recent figures show 6–10 fatalities occur on construction sites every working day throughout the United States (Lucker 1996). It is a great challenge for all those involved in the construction industry to improve this situation by taking effective action to minimize the risk of accidents and ill-health.

This, however, is not an easy task because it requires thorough investigation of two vital questions: How do accidents happen? and Why do accidents happen? In explaining accident causation, these two fundamental, but different, questions need to be addressed prior to determining appropriate accident mitigation strategies. The complexity of the accident causation process is likened by Groeneweg (1994) to a marble standing on a rough plateau of which the undermining mechanism likely to cause its moving and dropping is unpredictable. An accident causation model needs to deal with both the event area (i.e., the direct causes or the ''how'' of accident causation) and the circumstances preceding the event area [i.e., the underlying factors of accident causation (Groeneweg 1994)]. The answers to the ''why'' question are concerned with identifying the root causes of accidents. Only by understanding these can the determination of fully effective and appropriate preventative actions be achieved. There is little work in the current literature about the construction industry that attempts to model the contribution of the underlying factors in the accident process. Efforts to reveal interrelated patterns between the underlying causal factors involved in the causation process could give valuable guidance for effective risk reduction strategies.

This paper proposes a conceptual but practical model of accident causation for the construction industry, which includes management and organizational aspects of accident causation. The model addresses the distal and proximal factors that may generate situations or conditions that increase the risk of accidents. The objectives of the model are to improve understanding of the accident causation process, assist in the structured investigation of accidents, and offer guidance on effective accident prevention measures. Finally, an analysis of approximately 500 reports of construction accidents, prepared by inspectors of the U.K. Health and Safety Executive (HSE), is reported, in which the frequency of occurrence of all proximal factors found in these reports is determined.

PAST ATTEMPTS AT DEVELOPMENT OF CAUSATION MODELS

Early attempts to model accident causation for all industries include several domino theories (Heinrich 1969; Bird 1974). Heinrich's domino theory, first proposed in the 1930s, considers that human behavior deficiencies, preceded and influenced by social and environmental factors, might lead to an unsafe state, accident, and injury. The modified domino theories proposed by Bird (1974) suggest that management and organizational aspects are fundamental underlying factors in accident causation.

Nishishima (1989) introduced a fishbone model to describe the accident causation process, in which four related factors generate unsafe states and unsafe behaviors. These are classified as human, equipment, work, and management. Reason (1990) proposed the tripod model, which represents the interconnection between accidents, unsafe acts, and resident pathogens. Resident pathogens are latent failures in technical systems that, when combined with situational triggering factors such as technical faults, errors, or violations, may lead to an accident. Latent failures can be generated by fallible decisions by top management, line management deficiencies, and psychological precursors of unsafe acts. The psychological precursors of unsafe acts are defined by Reason (1990) as latent states, such as high workload, undue time pressure, or inappropriate perception of hazards. The tripod model is concerned with underlying mechanisms of accident causation called general failure types, rather than simply the ''event area'' in which the accident happens (Groeneweg 1994). The classification of

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Note. Discussion open until January 1, 2002. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on March 3, 2000; revised October 25, 2000. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 127, No. 4, July/August, 2001. ©ASCE, ISSN 0733-9634/01/0004-0337–0344/$8.00 + $.50 per page. Paper No. 22189.

general failure types includes design, hardware, procedure, error enforcing conditions, housekeeping, training, incompatible goals, communication, organization, maintenance management, and defenses. The defenses represent safety tools to prevent foreseeable accidents. These can induce unsafe acts, conditions, and operational deficiencies on the production site. Bellamy and Geyer (1992) proposed a sociotechnical pyramid model of accident causation, which consists of five causal factors: engineering reliability, operator reliability, communication and feedback control, organization and management, and psychological climate.

In the construction industry, Whittington et al. (1992) asserted that poor management decision making and inadequate management control are major contributors to many construction accidents. They simplified the accident causation process into a sequence of failure initiation, classed as individual failures, site management failures, project management failures, and policy failures. In contrast to previous models, Hinze (1996) proposed a distraction theory, assuming that the risk of accident may be generated by worker distraction caused by either physical hazards or mental diversion. The theory addresses, using a descriptive analysis, the interrelationships between probability of injury occurrence, efficiency of work accomplishment, and mental distraction experienced by the worker.

All these models are generally more concerned with theoretical description than with practical investigation. These models do not deal with the extent to which causal factors may be eradicable, reducible, or avoidable. No attempts have been made to structure the organizational and operational factors, which may increase the risk of accidents. Previous models only represent causal factors of accidents in general. There is still a lack of explanatory detail in these models about which factors make a significant contribution to construction accidents. The effective mitigation of causal factors requires better knowledge of which factors are most influential, who may reasonably be expected to control those factors, and how such control may most effectively be achieved. The research reported here is the first stage in a comprehensive attempt to obtain this knowledge. This has involved the development of a more extensive behavior modeling approach to construction accident causation and analysis of past accidents to identify principal causes (i.e., causes near to or leading directly to the accident). It is being followed by further collaborative work between UMIST and Loughborough universities, supported and financed by the U.K. HSE, in which 100 recent accidents will be investigated in detail, applying the same causal modeling approach.

PRINCIPLES OF CONSTRAINT—RESPONSE MODEL

As with other researchers, it is assumed in this work that the central feature in accident causation is inappropriate human behavior (Ramussen 1990; Reason 1990). This can occur at many positions in an organization or industry and can be a fundamental factor in creating the circumstances in which the potential for accidents is increased (Suraji 1997b; Atkinson 1998). A model is needed to represent ways in which the behavior of all participants in construction projects, from client to site operative, could lead to accidents. A constraint-response model has been developed to map the potential contributions of all participants within the project organization to the accident causation process. The fundamental assumption is that all participants operate within a variety of constraints arising from features of the project environment or produced by the behavior of other project participants. Their responses to these constraints can generate inappropriate situations or conditions, which directly increase the risk of an accident (Fig. 1).

The model classifies causal factors into two general types,

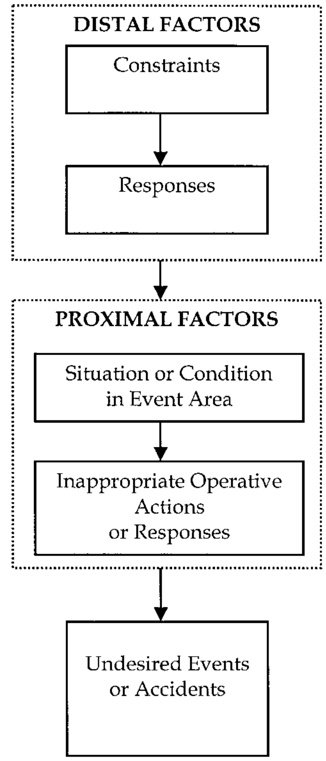

FIG. 1. General Model of Accident Causation

proximal and distal. Proximal factors are those that can be said to lead directly to accident causation (for example, a method of construction that uses a machine in a dangerous manner or disturbs asbestos-based materials). Distal factors are those that can, in the event of inappropriate responses by project participants, lead to the introduction of these proximal factors in the construction process and thus to the increased risk of accident.

These would, for example, include cost or time constraints, possibly prompting inadequate or inappropriate resourcing of the construction process (e.g., failure to provide personnel to conduct an asbestos survey).

All participants involved in a construction project may provoke, intentionally or unintentionally, inappropriate system states in the construction process. This model depicts the interactions between the participants and their potential opportunity to initiate what Reason (1990) described as pathogens that are likely to increase the risk of accident. Pathogens may originate from project conception, be transmitted through the project development and design phases, and subsequently result in inappropriate system states during construction operations. Everyone involved in the construction project will have the potential to initiate, influence, or control the pathogen through one or more of the following: strategic project decisions, project design, selection of technology, project or construction management, and supervisory or production activity. People in higher positions of authority have more potential to produce pathogens than people in lower positions because of their wider influence on the process (Levitt and Samelson 1993).

In theory, therefore, any accident or dangerous occurrence on a construction site should be capable of diagnostic analysis by examining all participants' contributions. Beginning with operatives, the causal chain can be traced back through supervisors, site managers, construction planners, and construction managers, and upstream to designers, clients' management and advisory team, and, ultimately, clients themselves. Any factor arising during or impinging on the development of a project brief is classified as a project conception constraint.

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Factors influencing architects or engineers during the design phase of the project are classified as project design constraints and factors confronting the client's other project team members, project managers, cost consultants, etc., during project implementation are classified as project management constraints.

Construction management constraints, construction management responses, subcontractor constraints, subcontractor responses, and operative constraints also all have the potential to influence accident occurrence in the construction process. Constraints are likely to divert the attention of construction personnel from removing or controlling pathogens and may provoke unsafe construction planning and control methods. For example, changing the sequence of work may result in insufficient storage space, limited or congested working space, or competition for the same equipment or plant. Such a pathogen may provoke inappropriate and unsafe operative behavior that may lead directly to the occurrence of accidents.

The model also considers that operatives may create situations that could present subsequent problems to other workers. Operatives themselves can be directly influenced by external factors such as pressures from the social, economic or political climate, or environmental conditions. These factors can distract them from their work, potentially leading to accidents (Hinze 1996).

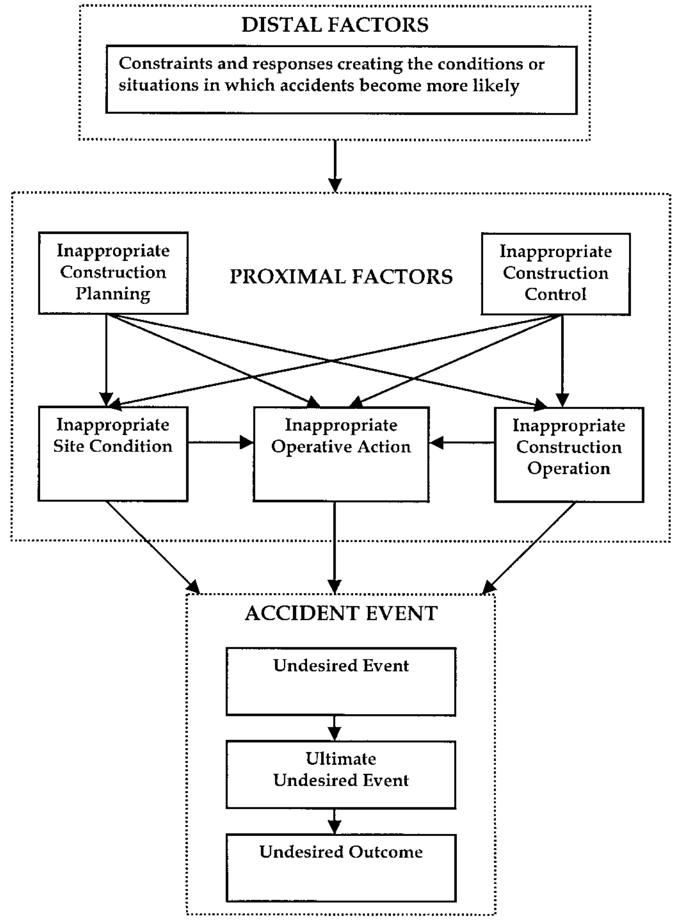

FIG. 2. Pattern of Construction Accident Causation

PATTERN OF ACCIDENT CAUSATION

The conceptual model described above may be structured as a pattern of accident causation that describes the sequential and parallel paths of constraints and responses that are experienced and initiated by all participants within the project organization. In Fig. 2 these relationships fall into three sections, which are drawn heavily from domino theory. Reading the diagram from bottom to top, the first area of interest must be the accident process (i.e., the sequence of undesired event, ultimate undesired event, and undesired outcome). This can be exemplified by a typical crane accident. Careless operative positioning and stabilizing of a mobile crane leads to failure of the crane outrigger support (undesired event) such as sinking into soft ground, overturning of the crane (ultimate undesired event), and thus, injury of a site operative and damage to the materials being lifted (undesired outcome). Note that the undesired outcomes of an accident sequence could be injury to any persons (construction personnel or members of the public) or damage to property or the environment. The investigation of the causal process then moves to the second area of the model, the immediate event area, to deal with proximal factors.

The model identifies five types of proximal factor: inappropriate construction planning, inappropriate construction control, inappropriate site condition, inappropriate construction operation, and inappropriate operative action. The failure to properly position and stabilize the crane is the inappropriate operative action. Lack of adequate supervision may well have been a contributing factor and would be classified as inappropriate construction control. In the event that the crane was not suitable for the operation being attempted because, for example, its outrigger could not have reached stable ground, then this factor would be classified as inappropriate construction operation. This may have arisen as a result of ground conditions surrounding the operation, which were unsuited to the use of a mobile crane, one of the factors classified as inappropriate site conditions. The failure to recognize this situation is often caused by inadequate site investigation by the contractor, a factor classified in the model as inappropriate construction planning.

The third, and often ignored, area of focus of the model represents the distal factors, the constraints and responses upstream of the immediate event area that create the situations in which the proximal factors are generated. In the complete model (Fig. 3), the distal factors and their relationships are developed to show the influence of the client, design team, and project management team, as well as recognizing the specific influence of subcontractors in the construction management process. The range of interactions in the model, necessary to take account of all the working relationships between construction project participants, leads to a complex model. However, any attempt to simplify it would inevitably ignore many of the real, but distal, influences of some participants on the safety and health of construction sites. The ultimate value of the model, as a guide to accident investigation and prevention, would be prejudiced. In the development of the constraint-response model, no account is taken of the procurement system being used. Although varying this does change both the operational and the contractual relationships, it is argued that all the functions (design, project management, construction management, etc.) and the people who carry them out are found in all procurement systems. The only thing that changes is the organizational location of the function. The relevant safety responsibilities remain, wherever the function is located.

The client will be under a number of economic, social, and political pressures in the conceptual development of the project, which are called project conception constraints, and these will provoke client responses in the development of the project brief to the project management and design teams. These responses will provide many of the constraints, project management constraints and project design constraints, within which the project management and design participants have to operate. Their responses will, in turn, provide construction management constraints within which the construction process will take place. These will provoke construction management responses, subcontractor constraints, and subcontractor re-

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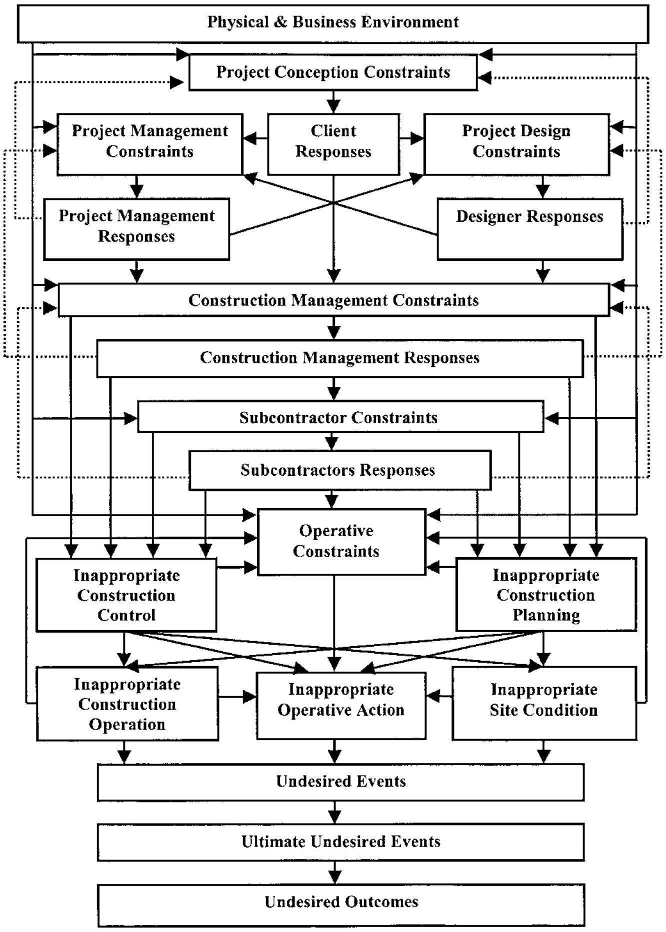

FIG. 3. Constraint-Response Model

sponses. This cause-and-effect process has the potential to increase operative constraints and directly, or indirectly through inappropriate construction planning or inappropriate construction control procedures, lead to inappropriate site conditions, inappropriate operative action, or inappropriate construction operation.

The complete model thus contains 19 classes of constraint, response, proximal factors and event characteristic in accident causation, each of which is defined and exemplified below.

Project conception constraints are constraints arising from the internal or external project environments that confront clients during the project conception phase. These might include, for example

- Difficulties in obtaining funding
- Environmental legislation
- New business strategy
- Change in business competitive environment
- Planning constraints
- Land-take constraints

Client responses are the actions (or inactions) by the client in response to constraints during development of a project brief. These include, for example

- Reduce project budget
- Add new project criteria
- Change project objectives
- Accelerate design or construction of project

Project design constraints are limitations or problems confronting designers during the design process. These may be stimulated by the client's responses, project management responses, or business environment of the design organization. For example

- Modified technical requirement of the constructed facility
- Accelerated design program
- Inadequate design budget
- Conflict of objectives or demands of other projects

Designer response is the action or inaction by designers to confront the constraints existing during the project design stage. These are, for instance

- Increase design complexity
- Sublet part of design process
- Reduce design resources
- Reduce quality of components
- Ignore legal duties [e.g., U.K. Construction (Design and Management) Regulations]

Project management constraints are the difficulties arising from the internal or external organization that confront the client or client's professional team during project planning and design or construction phases. These are, for instance

- Late delivery of design detail
- Limited availability of suitable contractors
- Lack of appropriate project experience

Project management response is the action or inaction by the client or client's professional team to confront an existing constraint during the project implementation stage. These are, for example

- Increased time pressure on design team
- Inadequate contractor prequalification
- Inadequate budget for supervision of construction procedures
- Inadequate attention to risk management

Construction management constraint is defined as difficulties arising from client, project management and designer responses, or project environment that confront contractors during the project construction stage. For example

- Short program timescale
- Design variations
- Designs difficult to construct safely
- Labor skill shortage
- Excessively inclement weather
- Penalty clauses

Construction management response is the action or inaction by construction managers, usually of the main contractor, to confront construction management constraints or problems created by the project environment. These responses deal with managerial, organizational, technical, and operational aspects of the production process during the project construction stage. For instance

- Adjust level of supervision
- Fail to supply safety equipment
- Revise or accelerate construction program
- Fail to investigate subcontractor methods
- Change construction method

Subcontractor constraint is similar to constraints that confront main contractors. For example

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- Cash flow problems
- Pressure from other contracts for resources
- Lack of relevant experience

Subcontractor response is the action or inaction by the subcontractors to confront the constraints. For instance

- Slow down work
- Reallocate resources to another site
- Recruit untrained operatives

Operative constraint is any factor, from whatever source, that may distract operatives from carrying out construction activity. For example

- Social or domestic pressure
- Physical disability
- Lack of skill or familiarity with process
- Peer pressure (to conform to potentially dangerous practice)

Inappropriate construction planning is the inadequate analysis or formulation of the construction plan, method statement, or schedule, in relation to the risk of undesired events, that may lead to injury to construction personnel or the general public and damage to either property or environment. This represents such failures as

- Inadequate method statement
- Inadequate structural design for temporary support structures
- Inadequate site layout plan
- Inadequate site investigation

Inappropriate construction control is the inadequate, in either quantity or quality, effort to direct or supervise the factors of construction so as to cause deviation of the construction operations from the plan and to increase the risk of undesired events. This represents, for example

- Inadequate control of plant or equipment operation
- Inadequate supervision of operative work
- Inadequate control or protection of weather effects
- Inadequate control of the stability of temporary structures

Inappropriate site condition is the unsuitable physical environment in which a construction operation takes place that may impinge on the performance of the operation and directly increase the risk of undesired events. For example

- Unsuitable existing topography
- Unsuitable weather or climatic conditions
- Inappropriate ground conditions
- Unacceptably noisy or crowded surrounding site

Inappropriate construction operation is the unsuitable process of production of permanent or temporary work that increases the risk of undesired events. This represents, for instance

- Improper construction procedure
- Improper plant or equipment operation
- Inadequate illumination or poor lighting
- Untrained or inexperienced workforce

Inappropriate operative action is the improper action or inaction, either intentionally or unintentionally, by an operative that may result in increasing the risk of undesired events. This is often referred to as ''worker error,'' but it is preferable to encourage objective reporting of an accident so that the term ''error,'' which has an inference of blame, be avoided. Such as

- Carelessness
- Failure to adopt standard procedures
- Improper or inadequate use of personal protective equipment
- Failure to follow instructions

Undesired event is an unwanted incident immediately preceding and leading to an accident that did, or could, have caused injury to construction personnel or the general public, or damage to property or the environment. Undesired events can occur to any of the following:

- Structure
- Equipment or plant
- Ground
- Service
- Material or component
- Facility
- Operatives or other personnel

Ultimate undesired events are accidents to people or accidents to property. For example

- Fall
- Struck
- Scaffolding collapse
- Excavator overturn

Undesired outcome is the extent of consequences of an accident. Injury to people is classified as

- Minor injury
- Major injury
- Fatality

Damage to property is classified as

- Minor damage
- Major damage
- Destruction

A complete classification of these proximal factors involved in accident causation and possible undesired events and outcomes is given in Tables 1–8.

TABLE 1. Inappropriate Construction Planning

Code	Inappropriate construction planning
ICP-01	Inadequate design of access structure
ICP-02	Inadequate identification and assessment of risk
ICP-03	Inadequate planning of construction work
ICP-04	Inadequate site layout plan
ICP-05	Inadequate method statement
ICP-06	Inadequate planning and design of plant or equipment operation
ICP-07	Inadequate planning and design of site services
ICP-08	Inadequate safety plan
ICP-09	Inadequate site investigation
ICP-10	Inadequate structural design for temporary support structures
ICP-11	Inadequate structural design for mechanical and electrical installation work
ICP-12	Inadequate preparatory training
ICP-13	Other

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TABLE 2. Inappropriate Construction Control

Code	Inappropriate construction control
ICC-01	Inadequate control of dangerous chemicals or substances
ICC-02	Inadequate control of plant or equipment operation
ICC-03	Inadequate control of ground conditions
ICC-04	Inadequate control of material or component storage and handling
ICC-05	Inadequate control of the stability of temporary structures
ICC-06	Inadequate control of safety facilities and protective equipment
ICC-07	Inadequate control of systems of work
ICC-08	Inadequate control or protection of weather effects
ICC-09	Inadequate control of worksite condition (housekeeping)
ICC-10	Inadequate supervision of operative work
ICC-11	Other

TABLE 3. Inappropriate Construction Operation

Code	Inappropriate construction operation
ICO-01	Access/egress defective or unsuitable
ICO-02	Breach of regulation or code of practice
ICO-03	Confined working space
ICO-04	Defective services
ICO-05	Defective equipment or vehicle
ICO-06	Improper construction procedure
ICO-07	Improper instruction to operatives
ICO-08	Improper maintenance of temporary structure
ICO-09	Improper plant or equipment operation
ICO-10	Improper stacking and routing of materials or components
ICO-11	Inadequate communication or coordination
ICO-12	Inadequate illumination or poor lighting
ICO-13	Inadequate maintenance of equipment or plant
ICO-14	Inadequate provision of personal protective equipment
ICO-15	Inadequate provision of safety warnings or other precautions
ICO-16	Inadequate safety facilities
ICO-17	Inadequate setting out
ICO-18	Inadequate working drawings
ICO-19	Inadequate site layout
ICO-20	Inadequate temporary structure
ICO-21	Inadequate traffic control system
ICO-22	Inadequate ventilation
ICO-23	Inadequate working tools or instruments
ICO-24	Inadequate working platform, including no guardrails
ICO-25	Unsuitable plant or equipment
ICO-26	Unsuitable material or component
ICO-27	Untidy workplace or poor housekeeping
ICO-28	Untrained or inexperienced workforce
ICO-29	Other

TABLE 4. Inappropriate Site Condition

Code	Inappropriate site condition
ISC-01	Unsuitable weather or climatic conditions
ISC-02	Unsuitable existing topography
ISC-03	Unacceptably noisy or crowded surrounding site
ISC-04	Inappropriate ground condition
ISC-05	Restricted working area
ISC-06	Other

MODEL VALIDATION

The constraint-response accident model represents the structure of both proximal factors and distal factors in accident causation. Having produced the model, the next stage of the research was to validate the classification of proximal factors by analysis of accident reports and other data reported by inspectors of the U.K. HSE, during investigations of construction accidents. The model has, so far, been partially validated by analysis of the U.K. HSE inspectors' reports. Because of the limitations of the accident data available, the validation currently only deals with the proximal factors. The validation of the part of the model relating to the distal factors is being undertaken in a 3-year project for HSE, in collaboration with a research team at Loughborough University, through detailed study of 100 recent accidents. For the purpose of the validation of proximal factors, the research team was given access to the HSE database, FOCUS. FOCUS contains a wide range of data about HSE inspector visits to sites, including a free format text description of the visit. This visit may be proactive, to inspect the safety of site activity, or reactive in response to a reported accident, in which case the record will detail the result of the accident investigation. FOCUS accident records also contain a maximum of two proximal causes, called deficiencies by the HSE, in each investigation summary. In many cases, it has been possible to determine, from the text of the

TABLE 5. Inappropriate Operative Action

Code	Inappropriate operative action
IOA-01	Annoyance, horseplay
IOA-02	Arson, burglary, vandalism
IOA-03	Carelessness
IOA-04	Commission: adding or including something they should not
IOA-05	Confusion: incorrect choice from range of options
IOA-06	Exceeding prescribed limits: load, strength, speed, etc.
IOA-07	Improper or inadequate use of personal protective equipment
IOA-08	Improper use of tools or instruments
IOA-09	Improper working position
IOA-10	Judgment error, underestimate, overconfidence
IOA-11	Failure to adopt standard procedures
IOA-12	Failure to follow instructions
IOA-13	Omission: missing something from sequence of steps
IOA-14	Physical or mental assault on or violence to persons
IOA-15	Working under the effects of alcohol or drugs
IOA-16	Other

TABLE 6. Undesired Event

Code	Undesired event
UE-01	Equipment or plant disturbance
UE-02	Facility disturbance
UE-03	Ground disturbance
UE-04	Material disturbance
UE-05	Operative disturbance
UE-06	Services disturbance
UE-07	Structure disturbance
UE-08	Other

TABLE 7. Ultimate Undesired Event

Code	Ultimate undesired event	Remark
UUE-01	Asphyxiation	Accident to operative
UUE-02	Drowning	Accident to operative
UUE-03	Electrocution	Accident to operative
UUE-04	Exposure or burning	Accident to operative
UUE-05	Fall	Accident to operative
UUE-06	Struck	Accident to operative
UUE-07	Trapped	Accident to operative
UUE-08	Equipment or plant overturn	Accident to property
UUE-09	Facilities damage	Accident to property
UUE-10	Fall of material	Accident to property
UUE-11	Services explosion	Accident to property
UUE-12	Structure collapse	Accident to property
UUE-13	Ground or trench collapse	Accident to property
UUE-14	Other	Accident to property

TABLE 8. Undesired Outcome

Code	Undesired outcome	Remark
UO-01	Fatality	Damage to operative
UO-02	Major injury	Damage to operative
UO-03	Minor injury	Damage to operative
UO-04	Destruction	Damage to property
UO-05	Major damage	Damage to property
UO-06	Minor damage	Damage to property

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free format section of the accident report, further causal factors.

Analysis of the free format text records was undertaken to validate the hypothetical causal factors previously described. This analysis involved systematic recording of all the facts present in the text. Only those causal factors specifically alluded to in the text were recorded. It was sometimes possible to infer from the text that an additional factor (for example, inadequate supervision) may also have been present, but unless it was explicitly recorded, it was not included in the analysis. This fact alone suggests that even the proximal factors are underrecorded; hence, a more structured approach to processing and recording the results of accident investigations could yield more comprehensive results. The quantity of data in accident records is insufficient to uncover all the less important (as perceived by the inspectors) factors. The inspectors tend to identify only the dominant factors they perceive. The lack of comprehensiveness of accident records may, therefore, reduce the recorded incidence of many of the proximal factors in the model. Although this suspected underreporting of causal factors has lead, almost certainly, to smaller recorded frequencies of individual factors, it can be assumed that the inspectors report the most influential factors in the accidents they investigate. The relative frequencies of the recorded factors are, therefore, highly indicative of their relative importance in accident causation. Application of the model would help to structure future accident investigations to improve the comprehensiveness of accident causation data.

Study of approximately 500 construction accident records was undertaken, during which evidence was found of all the proximal factors listed in Tables 1–5. The HSE classification of these construction accident records is not based upon types

TABLE 9. Proportion of Construction Accident Records in Each Process Environment

Number	Process environment	Proportion (%)
1	Groundwork	7.96
2	Foundation/excavation groundwork	2.76
3	Landscaping/earthmoving	0.86
4	Structural erection	4.02
5	Falsework	0.42
6	Tunneling	1.50
7	Piling	0.70
8	Scaffolding: construction	4.31
9	Stone cutting: bricklaying	1.18
10	Mixing mortar or concrete	0.86
11	Bricklaying	4.72
12	Finishing	9.13
13	Plumbing	5.42
14	Electrical	7.79
15	Joinery/carpentry	14.35
16	Plastering	2.76
17	Floor covering	1.09
18	Roofing	6.80
19	Roof glazing	0.16
20	Side cladding	0.28
21	Roof sheeting	0.68
22	Tiling	0.74
23	Jobbing roofer	0.68
24	Surface treatment	3.60
25	Surfacing	3.26
26	Road making	0.42
27	Road repair	3.27
28	Site plant hire	0.97
29	Crane with operator	1.21
30	Crane with no operator	0.14
31	Mobile with operator	1.30
32	Mobile with no operator	0.19
33	Portable	0.64
34	Scaffolding	5.02
35	Commercial building	0.83

TABLE 10. Types of Proximal Factors Involved in Accident Causation

Proximal factor	Accidents caused by proximal factors (%)
Inappropriate construction planning	28.80
Inappropriate construction control	16.60
Inappropriate construction operation	88.00
Inappropriate site condition	6.00
Inappropriate operative action	29.80

TABLE 11. Major Contributors to Accident Causation

Type of factor	Major proximal factors; involved in >2% of all accidents	Percent
Inappropriate construction planning	Inadequate method statement	11.40
	Inadequate preparatory training	8.80
	Inadequate identification and assessment of risk	8.00
	Inadequate planning of construction work	3.40
	Inadequate safety plan	3.00
	Inadequate structural design for temporary support structures	2.80
Inappropriate construction control	Inadequate supervision of operative work	6.20
	Inadequate control of systems of work	4.20
	Inadequate control of the stability of temporary structures	2.40
	Inadequate control of plant or equipment operation	2.20
Inappropriate site condition	Unsuitable weather or climatic conditions	3.00
	Inappropriate ground condition	2.60
Inappropriate construction operation	Breach of regulation or code of practice	54.60
	Access/egress defective or unsuitable	18.80
	Inadequate safety facilities	15.40
	Improper construction procedure	15.00
	Defective equipment or vehicle	9.80
	Inadequate provision or safety warnings or other precautions	6.80
	Inadequate working platform, including no guardrails	6.60
	Untrained or inexperienced workforce	6.00
	Improper plant or equipment operation	4.20
	Improper instruction to operatives	3.60
	Inadequate working tools or instruments	3.60
	Inadequate temporary structure	3.40
	Defective services	3.20
	Unsuitable plant or equipment	2.60
	Inadequate communication or coordination	2.20
Inappropriate operative action	Improper or inadequate use of PPE	6.00
	Failure to follow instructions	5.20
	Carelessness	5.00
	Failure to adopt standard procedures	4.40
	Improper working position	4.20
	Judgment error, underestimate, overconfidence	4.00
	Others (undefined)	2.20

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of construction projects but on a process environment. The HSE defines the process environment as a typical working breakdown structure of a construction project, such as structural works, roofing, scaffolding, and excavation. Of the 500 construction accident records, the proportion of accidents in each process environment is shown in Table 9.

Analysis at the level of type of proximal factors—inappropriate construction planning, inappropriate construction control, inappropriate construction operations, inappropriate site conditions, and inappropriate operative actions—is shown in Table 10. The total of the percentages is >100, as many accidents have multiple proximal causes.

Analyzing each of these types of proximal factors has identified the major contributors to accident causation, as shown in Table 11.

CONCLUSIONS

In this paper a new, alternative model of accident causation is introduced. This constraint-response model highlights the complex and multicausal natural of accidents on construction sites. It classifies the causes of accidents as proximal factors and distal factors, many of which may be provoked by actions of clients, designers, and contractors, as well as operatives. The distal factors include project conception constraints, project design constraints, project management constraints, construction management constraints, subcontractor constraints, and operative constraints precipitating potentially unsafe responses by clients, designers, client's project team, contractors, subcontractors, and operatives. These constraints and responses include the influence of management and organizational factors; environmental factors such as economic, legislative, political and social; and individual participant factors. Proximal factors include inappropriate construction planning, inappropriate construction control, inappropriate construction operation, inappropriate site condition, and inappropriate operative action that can be identified as the immediate causes of construction accidents. The model forms as a potentially useful conceptual basis from which to develop accident investigation methods, safety audit systems, or total loss control systems.

The analysis of 500 accident records provided by the HSE validated the hypothetical proximal factors. It is clear from the analysis of the HSE data that the most frequent category of proximal cause is inappropriate construction operation, occurring in 88% of all construction accidents. Inappropriate construction planning and inappropriate operative action are also frequently encountered. Inappropriate construction control does not feature as frequently as might be expected when compared with the frequency of inappropriate operative action. This might be explained, at least in part, by the HSE inspector's focus on legal requirements rather than on uncovering all the contributory factors. A more structured and detailed investigation process would promote a clearer understanding of the relative importance of all proximal and distal factors. This is essential if the full accident causal process is to be properly understood and evaluated. Current associated research, funded by the HSE and in collaboration with the Departments of Civil and Building Engineering and Human Sciences at Loughborough University should make considerable progress toward this objective.

ACKNOWLEDGMENTS

This research is supported by the U.K. HSE. Thanks are owed to Blair Hilton at the HSE in Bootle for assistance in the use of the FOCUS database and to the third writer for his extensive advice during the process of the research and preparation of this paper.

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