THE DEVELOPMENT OF AN ACCIDENT CAUSAL MODEL FOR OFF-SITE PRODUCTION IN CONSTRUCTION

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The major objective of construction health and safety prevention systems is to eliminate the risk of adverse health and safety occurrence. The advent of off-site production (OSP) has introduced a new challenge for the management of health and safety. This paper is one of a series of papers on health and safety driven research. It will present the theoretical foundation of the development of an accident causation model based on an extension of an existing generic health and safety model created for traditional construction. The Model identifies the correlation between the three primary shaping factors and the type of issues that dominate accident causality in OSP. This paper explains what further measures OSP manufacturers still need to take.

Keywords: causation model, manufacturing, health and safety, off site production, standardization.

INTRODUCTION

The UK construction industry has a lower fatal accident rate than most other EU member states and the US (Eurostat 1996). A similar situation exists for non-fatal accidents. However, one third of all work fatalities in the UK happen in construction and it's employees are six times more likely to be killed at work than employees in manufacturing (HSC 2001a). A number of high profile initiatives have been carried out that address the industries poor health and safety record. These include, Rethinking Construction (DETR 1998) and Accelerating Change (Strategic Forum for Construction 2002). Despite these efforts, from the "league table" of industries, the construction industry still has one of the highest rates of fatal and major injury (HSC 2001a). The industry continues to survive with a poor record of health and safety performance, inadequate training, and irresponsible contractors who minimize their risk by transferring it back to the employees. Many contractors are embracing the drive toward OSP, which is the manufacture of construction elements, components, modules and complete buildings in a factory environment. OSP is changing the causal relationship between accidents and construction methods and while the actual health & safety risks reduce with OSP, the actual hazards change and these need to be considered carefully throughout the project process. The authors propose that the challenge for the management of health and safety in OSP will not succeed unless an environment and culture change toward that of manufacturing takes place.

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Accident causation process

In explaining accident causation Suraji *et al.* (2001) identify two fundamental questions that must be addressed in order to develop strategies necessary to reduce accidents and practices that will reduce ill-health. The two questions relate to how do accidents happen and why do accidents happen. The "how" is concerned with the direct causes of accidents termed the event area. The "why" relates to the set of circumstances that precede the event area these are the underlying or root causes of accidents (Groeneweg 1994). Groeneweg realized the complexity of the accident causation process and used the analogy of a marble resting on a rough plateau, with the underlying mechanism causing its movement to be unpredictable. Any attempt at modelling accident causation needs then to fully understand both the why and the how questions, only then can appropriate actions for accident and ill-health prevention be achieved. In connection with OSP, there is in the authors' knowledge very limited research that attempts to model the contributions and varying proportions of the direct and underlying causes of accidents.

ACCIDENT CAUSAL MODELS

Modelling of accident causation can be traced back to the early 1930s. Heinrich (1969) attempted to model accident causation across all industries and developed a number of domino theories. The social and environmental factors, which precede and influence an individual and which may cause human behaviour deficiencies in that individual, may lead to an unsafe act and ultimately an accident and injury. A number of modifications to Heinrich's basic theory have been developed, most notably Bird (1974) where the inclusion of management's lack of control and deficiencies in organizational aspects contribute to the underlying factors in accident causation.

Other attempts at modelling the accident causation process have included the development of a fishbone model after Nishishima (1989), where the related factors of human behaviour, equipment, work practice, and management contribute to generate unsafe conditions. The tripod model, after Reason (1990) models the interconnection of accidents, unsafe acts and resident pathogens. Resident pathogens are dormant or concealed failures in technical systems that when combined with a situation or triggering factor such as human error or an equipment fault may give rise to an accident. Reason's Tripod model is concerned with underlying or root mechanisms of accident causation, termed general failure types, rather than the event area where the accident happens.

A sociotechnical pyramid model of accident causation, presented by Bellamy and Geyer (1992) consists of five causal factors; engineering reliability, operator reliability, communication and feedback control, organization and management and psychological climate. These can contribute to induce unsafe acts and conditions on the production site.

Whittington *et al.* (1992) state that in the construction industry the predominant factors that contribute to accident causation are poor management decisions and poor management control. Their simplified accident causation process involved a four step sequence of failure initiation cited as, individual failure, site management failure, project management failure and policy failure. In comparison to the previous models, Hinze (1996) presents a model based on worker distraction caused by surrounding physical hazards and the diversion of the individual's mental attention. These models are theoretical in nature as opposed to dealing with practical investigation.

A constraint-response model based on practical investigation, developed by Suraji *et al.* (2001) attempts to represent the potential contributions of all participants within a construction project to the accident causation process. The model designates two general types of causal factors namely proximal and distal. The proximal factors are those that lead directly to accident causation, for example the use of tools in a manner that is dangerous or causes the production of dust and air pollutants. Distal factors, on the other hand, are those which if no appropriate action is taken by project decision makers may lead to the creation of proximal factors in construction activity and hence to the increased risk of an accident. An example of a distal factor may be the inadequate training and supervision in the use of power tools. The basic premise on which the model is developed stems from the assumption that all participants in the construction activity operate with a number of constraints placed on them. These constraints arise from the project itself or are produced by the behaviour of other project participants. The response to these constraints can generate inappropriate conditions which may give rise to the increased risk of an accident. The model is 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 construction project (Suraji *et al.* 2001).

The pattern of accident causation is described as three interrelated sections, the first of these is the accident process: the undesired event, the ultimate undesired event and undesired outcome. The second section of the model deals with the immediate accident event area, the proximal factors. The third section of the model focuses on the distal factors, these are the constraints and responses upstream of the immediate event area that create the situations in which proximal factors are generated. The distal factors and their relationships are developed to show the effect of the client, design team, and the project management team, as well as acknowledging the influence of subcontractors in the construction management process. The complexity of the model results from the fact that it attempts to take account of all the working relationships between construction participants. The model indicates that by classifying causes of accidents into proximal and distal factors, accident causation can be provoked by actions of clients, designers, and contractors as well as operatives.

Haslam *et al.* (2003) used a combination of focus groups and a detailed study of 100 construction accidents in the development of an accident causation model for traditional construction using an ergonomics system approach. This approach relates to examining the ergonomics of the operatives task, workplace and use of materials and equipment. The work developed a hierarchy of influences to aid understanding and learning opportunities from construction accidents. The hierarchy is: 1) immediate accident circumstances; 2) shaping factors; and 3) originating influences. The immediate accident circumstances are affected by the shaping factors that are in turn affected by originating influences. Immediate accident circumstances include workplace, work team, materials and equipment aspects. Examples of shaping factors include for workplace: site constraints, for work team: supervision and for materials and equipment: specification. An example of an originating influence is economic climate. The model shown in Figure 1 summarizes the influences identified by the research that operate to cause construction accidents.

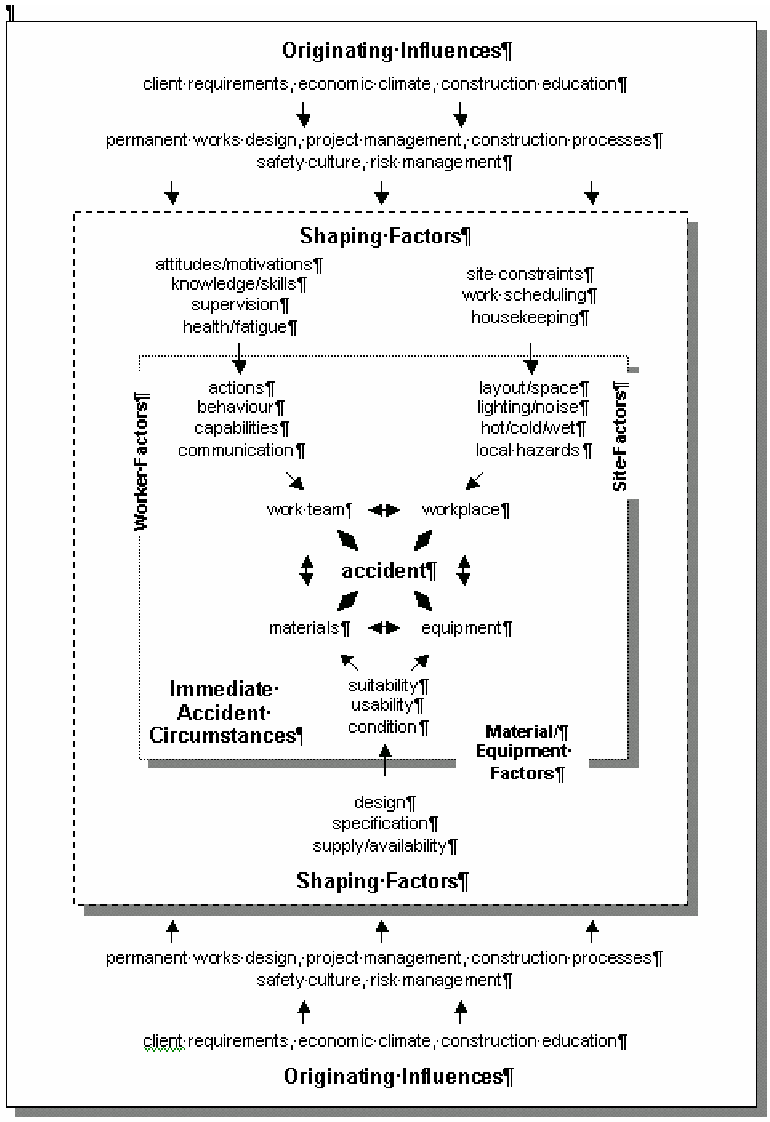

Figure 1: Generic Health and Safety Causation Model (Haslam *et al.* 2003)

ACCIDENT CAUSATION MODEL FOR OSP

Introduction

There is a scarcity of literature about OSP that attempts to model the contribution of proximal or distal factors in accident causation. The research reported here is the first stage of an attempt to gain detailed knowledge to provide effective reduction in those causal factors that are most influential in terms of health, safety and accident causation. A model is required to show the ways in which the behaviour of all participants and their environment could lead to accidents and factors that may lead to ill-health. The first stage in the development of the model was to identify those traditional insitu construction process environments that have an OSP alternative.

Process comparison between insitu and OSP

The typical working breakdown of a construction project called the process environment, ranging for example from site investigation, excavation to structural works was used as the basis to compare insitu activities and hazards to the equivalent OSP alternative. Table 1 presents an excerpt from the complete classification across engineering construction, civil engineering and building sectors. The table indicates that in some instances no OSP option exists or there may be several alternative OSP options for one process environment, for example insitu rotary piles verses pre-cast driven or Vibrated piles.

Table 1: Insitu Process Environment and OSP alternative (Excerpt)

Process Environment		insitu	Osp	Osp	OSP	Co	In	Ci	En	Re	o
SUBSTRUCTURE Ground remediation			No OSP Option			X	X	X	X	X	
Excavation	Drainage/Utilities	Timbering	Shoring systems			X	X	X	X	X	
Foundations	Piles	Rotary Bored Piles	Precast Driven	Precast Vibrated		X	X	X			

Key: Co = Commercial In = Industrial Ci = Civil Engineering En = Engineering Re = Residential o = Other.

The second stage was to prepare activity lists and associated hazards for all process environments and compare and contrast the hazards with the insitu option to the OSP alternative. An example of an excerpt from the process environment substructure under the category foundations compares rotary bored insitu augured piles to pre-cast driven piles is shown in table 2.

Table 2: Activity and hazards comparison between augured piles and pre-cast driven piles (Excerpt)

		Augured Piles	**Pre-cast driven/vibrated piles**		
cf OSP	**Main Hazards**	**Main Off-Site Activities**	**Main Off-Site Activities**	**Main Hazards**	**cf insitu**
S	Various but same as OSP factory	Delivery of base materials to ready-mix and rebar suppliers	Delivery of base materials to factory	Various but same as for insitu	S
A	Road traffic, site access, site conditions	Transport & deliver ready-mix concrete and rebar to site	Mix concrete	Various but same as ready mix	S
cf OSP	**Main Hazards**	**Main On-Site Activities**	**Main On-Site Activities**	**Main Hazards**	**cf insitu**
S	Various but same as OSP	Prepare site for piling	Prepare site for piling	Various but same as insitu	S
A	Contaminated spoil, plant, vibration	Auger hole	Drive or vibrate pile to required depth	Plant, Vibration, hand injuries	

Risk change code (insitu>>pre-assembled): S = same (no change) R = Risk removed A = Additional (new) risk LL = Less likely ML = More likely LC = less serious consequence MC = more serious consequence C = more controllable

Data analysis

Analysis of the activities and associated hazards have identified the major risk change from insitu to OSP. It is worth noting that in OSP the risk change is not always toward that of mitigation, very often new hazards arise or the same hazard exists but with a more serious consequence. For example the movement of precast piles to the driving location involves the craneage of large loads with a subsequent more serious hazard. The activities, hazards and risk change code in table 2 have so far been partially validated by focus group discussion with industry.

Given the highly complex and challenging environment, within which this research project seeks solutions, the generic health and safety model developed by Haslam *et al.* (2003) as previously presented in figure 1 was used to establish a focus and direction for the development of the OSP model. To assist in the management and processing of the data a coding sequence was devised figure 2. This enabled the identification of the pattern of accident and ill-health causation. Thus a hazard identified as occurring within the work team section of the model associated with inadequate operative actions would be coded as 2.4. This process was continued and the results plotted in matrix form as shown in Table 3.

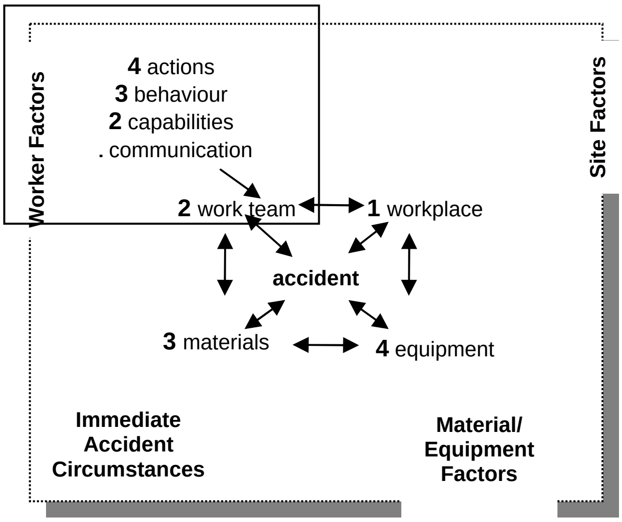

Figure 2: Extract of Generic Health and Safety Model

The numbering sequence chosen was purely arbitrary and assisted in the identification of areas of influence within the research and any additional influences not covered.

Table 3 Excerpt from data matrix

	Process Element	**Levels**	**hazards**	*2*	*2.4*	*2.4.1*	*2.4.2*	*2.4.3*	*2.4.4*	
	Substructure piling	Traditional: Rotary bored insitu piles and insitu pile caps	Place rebar		X	X	X	X	X	
		S&P Low;								
		S&P Med:								
		S&P High Pre-cast driven piles and pre-cast pile caps or capping beams.	Reinforce fix inserts		X		X		X	

Key: Standardization & Pre-assembly (S&P) S&P Low = non-volumetric, S&P Med = Volumetric, S&P High = Modular

OSP model development

The observations and the results of the data analysis influenced the development of the OSP model. The basic generic model needs to be adapted to take account of one of the predominant causes of accidents being that of inappropriate off-site operation. Thus the model will require additional shaping factor categories. An example of some of the additions to the work team section is shown in Figure 3. The category “operative stewardship” covers the commitment to employee protection during manufacturing processes. This includes manufacturing concepts such as the use of safety team leaders and health monitoring systems (Fawcett and Wood, 1982). Human anthropometry is the scientific study of the measurements of the human body, which assists in the design and layout of the operatives' workstation in the production process. The site factor section in the OSP sphere is much reduced, but still needs inclusion in that during installation of OSP components the site conditions can influence accident and health causation. The layout and space categories are much better controlled in OSP, as are lighting and noise. In installation, local hazards and weather conditions remain important factors. The shaping factors of site constraints and work scheduling have a greater influence on causation due to the fact that they are often out with the control of the installation team. The need for OSP representatives to be on-site during installation is key to reducing adverse affects during the installation of OSP components. The inclusion of ergonomic design both in the installation and materials and equipment factors reflects the need for a manufacturing approach to production process design (Fawcett and Wood, 1982).

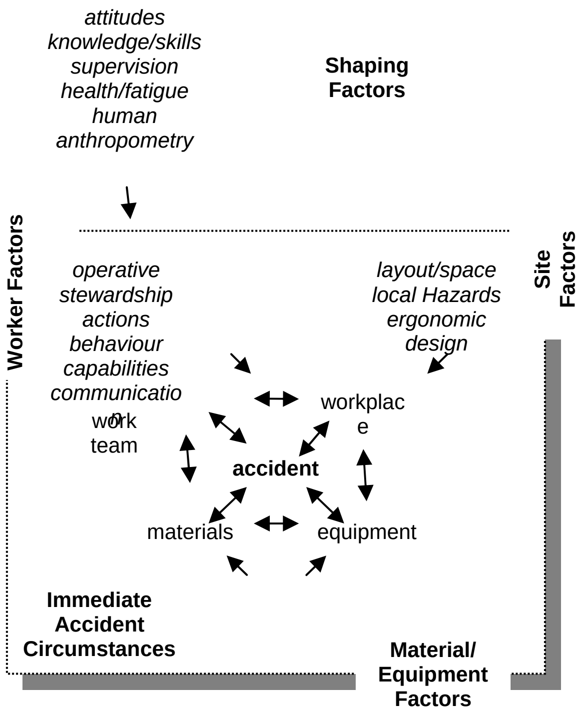

Figure 3: Extract of OSP Health and Safety Model

OSP Model

A full description of the model is out with the scope of this paper. Figure 4, illustrates an extract from the full model and summarizes some of the influences identified by this research. The originating influences, which include client requirements and project design consultants have greater potential to influence people in lower positions due to their wider influence on the process. These distal factors show the relative influence of the OSP design and manufacturing processes, in particular the importance of production risk management. Production risk management relates to the effort at all levels to actively identify and control risks as documented in the method statement. This will in turn influence the manufacturing processes concerning the manner in which the OSP component should proceed in the factory. These contribute to the safety culture in the firm and the ability of management to foresee and prevent the opportunity for proximal factors to develop. This is enabled in part by the education and training in the safety and health implications of OSP among factory based personnel and construction professionals.

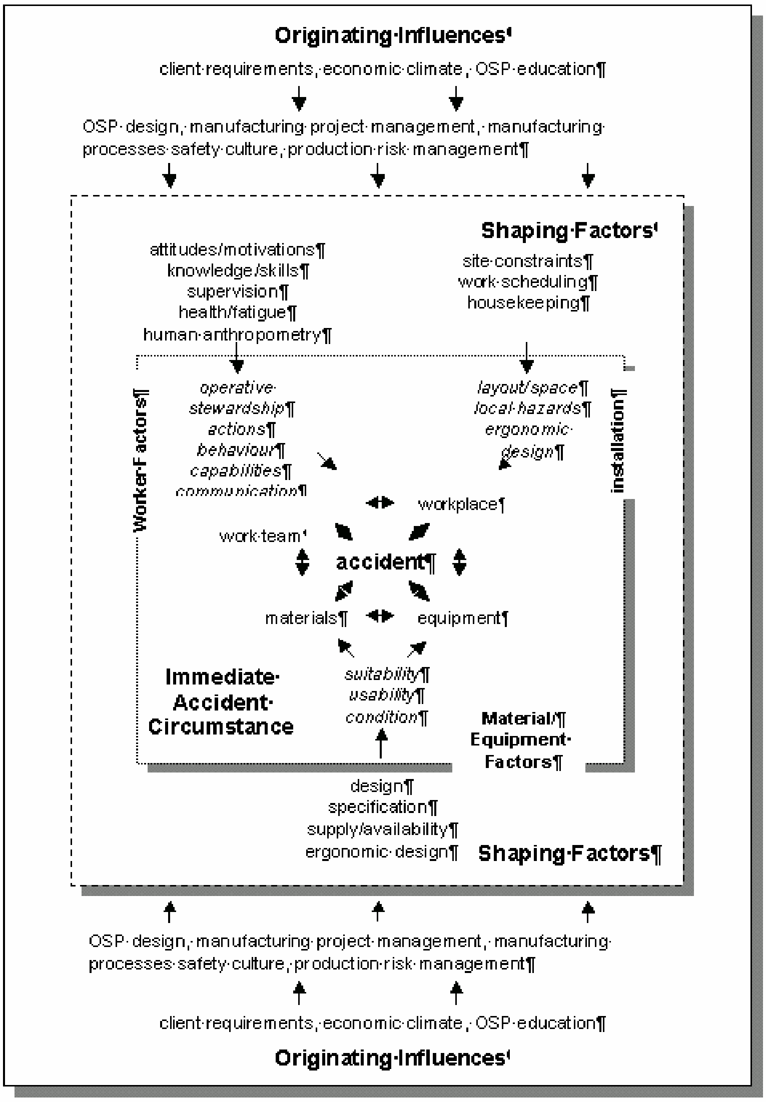

Figure 4: OSP model

Challenges OSP manufacturers must embrace

A selection of some of the challenges that OSP manufacturers must embrace include:

- the use of continuous flow manufacturing including group work cross training on the different tasks in a group and job rotation linked with the redesign of selected machines and workstations for the elimination of awkward postures (HSE 2000);
- the adoption of a systems approach to safety in manufacturing the initiation of safety awareness programmes, specialized training on ergonomics for machine operators (HSE 2000);
- the layout of the OSP facility to utilize the techniques of an in-line arrangement where the production lines are long straight and "in-line" and provides access to both sides of a considerable portion of the production runs (Fawcett and Wood, 1982);

- The use of medical surveillance in the form of a pre-employment examination is one of the cornerstones of an effective comprehensive program of health for manufacturing employees (Fawcett and Wood, 1982).

A critical in-depth analysis of all factors that will enable OSP manufacturers to embrace the challenges and benefits of OSP will follow this preliminary evaluation. When complete the advice will be used to support recommendations to industry.

CONCLUSIONS

The extract from the model indicates the complex nature of OSP and the interactions that may give rise to an accident. The causes of accidents can be classed as both proximal and distal, similar to the type of classification used for traditional construction. The distal factors tend to be more important in the OSP sphere, this is due to the fact that greater control can be exercised in the OSP environment but requires manufacturing project management and OSP design control in order to minimize precipitating operative unsafe actions. The final model may be used as a potentially useful basis to construct accident investigation methods and safety audit tools. Currently the model will be implemented as a management tool through the development of a CD, which will be disseminated to the OSP industry.

The successful parties in the current OSP industry for construction require to change in order to become successful in the manufacturing environment. The successful parties may attempt to maintain the current OSP practices which are incompatible with those used in the manufacturing sector for years. The authors recommend that other researchers perform research with OSP in construction to verify the validity of manufacturing concepts.

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