IDENTIFICATION OF FACTORS CAUSING FATAL CONSTRUCTION ACCIDENTS

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KEYWORD

Construction; accidents; investigation; causation; categorisation; database

Introduction

Safety had always been a persistent problem in the construction industry. In the United States, it was reported that construction industry accounted for 20% of all occupational fatalities, when they made up only 5% of the United States' work force (National Safety Council, 1997). In Kuwait, the industry accounts for 42% of all occupational fatalities (Kartam and Bouz, 1998) and in Hong Kong the industry accounts for more than a third of all industrial accidents over the last ten years (Tam and Fung, 1998). These studies are among many others that shows that the industry has a very poor safety performance record. In order for the industry to improve, it needs to learn from its mistakes.

The identification of the accident sequence and causal factors of accidents, in particular the underlying factors, forms the first step in the learning process. The acquired information like these can then serve as invaluable inputs for preventive measures. However, there had been very few comprehensive studies on how and why construction accidents happen. Whittington *et al* (1992) attempted to analyse the management and organisational factors of construction accidents, but it was realised that the accident data available within most companies were insufficiently detailed to permit a comprehensive analysis. Most other studies on construction accidents focuses on immediate causes, characteristics of accident victims or accident sequence (Kartam and Bouz, 1998; Cattledge *et al*, 1996; Jeong, 1998; Hinze *et al*, 1998). Information like these are important, but they will not be complete without compilations of the frequency of occurrence of underlying factors and Safety Management System failures.

Thus, this paper is part of a larger project that attempts to identify how (accident sequence) and why (immediate factors, underlying factors and safety management system failures) construction accidents occurs and to make appropriate recommendations to improve construction safety.

The Modified Loss Causation Model

In order to have a meaningful analysis of the accident data, there is a need for a fundamental accident causation model that highlights the main accident events and main types of causal factors. Based on the accident causation model, a comprehensive set of accident variables taxonomy can then be developed to code the accident data.

The choice of accident causation models is based on the intended usage. After reviewing existing literature on accident causation model, the Loss Causation Model (Bird and Germain, 1996) was modified to suit the objectives of the project. The Modified Loss Causation Model (MLCM) is presented in Figure 1.

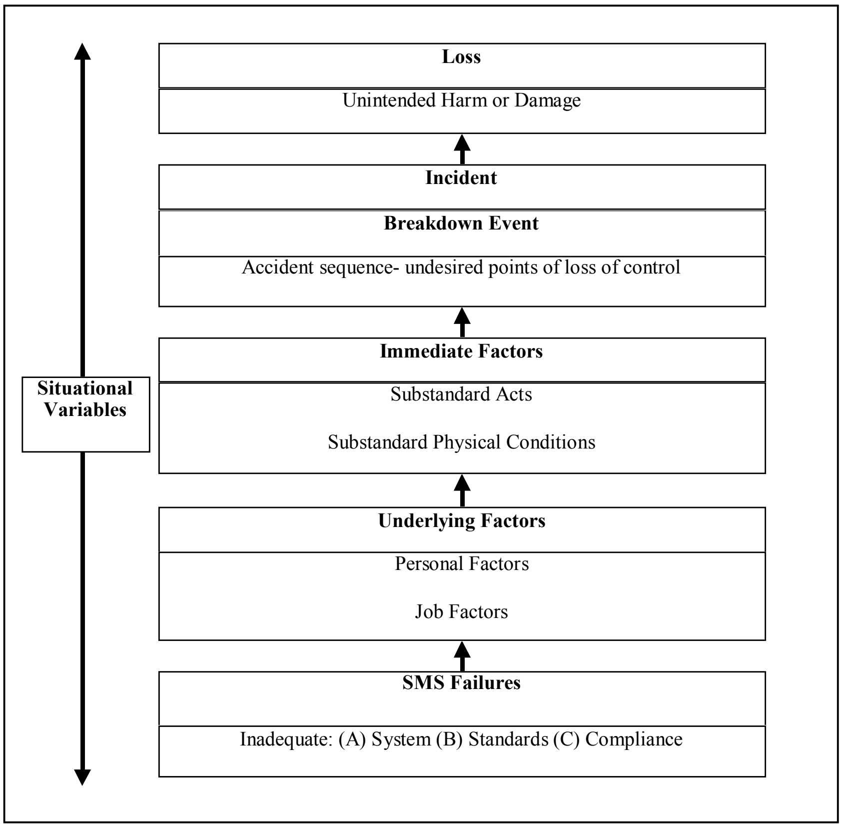

Figure 1: The Modified Loss Causation Model

The main modifications are highlighted as follows. Firstly, the component "situational variables" is included into the model. For each chain of accident causation there is a need to identify the critical characteristics of the context or situation in which the accident occurred. In this way, the information and learning points derived from the accident can be more easily applied to similar context or situations. Furthermore, the situational variables will act as stratifying variables during data analysis, so that the differences in stratifying variables will not affect the outcome of the analysis. In this paper, the main stratifying variable used is the type of work that the main participants of the accident were involved in just before the accident.

Secondly, the accident sequence was elaborated with more details by including the breakdown event. This is defined as a point of loss of control of a source of energy that leads to the occurrence of an incident. In contrast, incident focuses on events that describe the contact of the victim with the source of energy. With the richer description of accident sequence, preventive measures can then be planned more precisely, hence improving safety performance.

Thirdly, the "lack of control" domino in the LCM is replaced by Safety Management System (SMS) failures. The SMS refers to an organised and inter-related group of preventive safety measures that have the common purpose of preventing accidents, improving and monitoring safety performance of an organisation. The advantage of using the term "SMS failures" is that it brings into focus the full set of measures and steps involved in improving safety performance. In contrast, the term "lack of control" tends to highlight control measures like supervision and enforcement of rules.

The use of the MLCM as the fundamental accident causation model has several other advantages. As in most other sequential model, the MLCM can be used to analyse accident sequence and causation chain clearly and logically. The model is also very well structured; hence it facilitates the development of the accident variables taxonomy. Another advantage of the model is that it leads to proactive thinking (Covey, 1989). By ending each accident investigation with an examination of the SMS, prompts organisations to accept the responsibility to respond to accidents and not blame it on the individuals or physical conditions. In this way, the SMS can be improved, thus improving safety performance.

<u>Accident Variables Taxonomy</u>

A thorough literature review on existing accident variables taxonomies and classifications was conducted. The aim is to identify suitable categorisations for each of the components in the MLCM. During the search for suitable categorisations, it was realised that most of the available taxonomies lack a strong underlying accident causation model (Hinze *et al*, 1998; Kartam and Bouz, 1998; Feyer and Williamson, 1991; Sawacha *et al*, 1999), this makes the logic structure of the taxonomies harder to grasp. Bird and Germain (1996), and Gordon (1998) developed taxonomies that were relatively comprehensive, but they were not tailored to the context of construction industry. Hence, causing difficulty in the classification of accident variables, in particular the job factors. Furthermore, some parts of the taxonomies were split into very fine factors without sub-categorisations, hence causing difficulty in statistical analysis (as the data would be too sparse). Whittington et. al. (1992) came up with a taxonomy based in the construction industry, but due to a difference in the underlying accident causation model and research objectives, the taxonomy developed by Whittington *et al* (1992) could not be fully adopted.

There were also several works in the human error areas (Reason, 1990; Rasmussen 1982) where the classification requires cognitive information that are often missing or inconclusive in construction accident investigation reports. These conceptual level classifications (Reason, 1990) often require expertise and resources that are not readily obtainable in the construction industry. Furthermore, the conceptual level classification does not fit into the MLCM, as the substandard act component refers to observable behaviours that are more objective and direct. Thus, conceptual level classifications were not suitable for the context of the research. However, human error classifications that focus on behavioural aspects, for example Swain and Guttman (1983), can be more easily adapted into the substandard act component of the MLCM.

Even though, there was no single taxonomy that can be fully adapted to be used in the research, a compilation of the taxonomies from the literature review and the coding that were already in use in OSD was developed to fit the framework of the MLCM. A draft taxonomy was first used to analyse forty accident cases. Following that, the taxonomy is evaluated and changes were made based on the evaluation. During the actual analysis, the taxonomy was constantly re-evaluated and minor changes were made as and when it was deemed necessary. The main categorisation of the taxonomy adopted in the study is summarised in Figure 2.

Method of Investigation

The source data for the study is based on the accident investigation reports that were produced by the OSD. As the reports are in free-text format, the accident variables identified in the reports has to be classified according to the MLCM taxonomy to allow statistical analysis. In order to minimise errors due to subjectivity during classification, the MLCM taxonomy was clearly defined. Furthermore, the causal factors are identified only if clear statements describing it were stated in the reports, in this way subjective inference by the researchers could be kept to a minimum.

In order to ensure that the data for analysis are of sufficient quantity and quality, the study focuses on accidents with at least one fatality. That is because the depth of investigation usually increases with severity; hence fatal cases usually reveal more objective description of the accident and causal factors. After reviewing the fatal accident investigation reports between 1993 and 1999, 140 accident investigation reports were chosen for analysis.

Discussion of Results

The results presented in this section represent the main findings at the time of writing. Figure 3 shows the summary of the preliminary results. It can be seen that about 60% of the fatal accidents occur during the execution of structural work and architectural/renovation/finishing work. The results might be affected by the greater occurrence of the two types of work. Still, the figures itself already warrants attention to both types of work.

Within the scope of accident sequence, the findings with respect to type of incident agree with the findings of several other works on construction accidents (Hinze, *et al*, 1998; Jeong, 1998; Kartam and Bouz, 1998), where fall of person is the main type of incident in construction industry (55%). In the study, struck by falling object is the next highest occurring type of incident, although at a much lower frequency (19.3%). With respect to breakdown event, lost of balance (31.3%) is the main type of breakdown event and the next highest occurrence is the collapse of temporary structures (22.1%). The findings regarding accident sequence tallies as the high occurrence of lost of balance and collapse of temporary structure naturally leads to a high occurrence of fall of persons and struck by falling objects.

Situational Variables- Type of Work

1. Architectural/Renovation/Finishing work
2. Building services work
3. Geotechnical work
4. Material/equipment handling/transportation
5. Plant/machinery/equipment maintenance/dismantling/installation
6. Structural work
7. Other types of work

Types of Incident/ Breakdown Event

1. Fall of person
2. Struck by falling objects
3. Caught in or between objects
4. Over-exertion or strenuous movements
5. Fire/explosion
6. Exposure/contact with extreme temperature/pressure
7. Exposure/contact with electric current
8. Exposed to harmful substances/radiations
9. Other types of incidents

Other Types of Breakdown Event

1. Collapse of object
2. Lost of balance
3. Object fall off surface
4. Loss control of plant/transport
5. Other types of breakdown event

Types of Substandard Physical Conditions

1. Substandard plant/machinery/equipment/tools
2. Substandard construction material
3. Substandard structures/parts of structure
4. Substandard work environment
5. Other substandard physical condition

Types of Substandard Acts

1. Extraneous Acts
2. Improper equipment usage
3. Inappropriate response to emergency
4. Omission of basic safety measures
5. Spatial error
6. Improper work procedure
7. Other substandard acts

Types of Job Factors

1. Factors related to designers
2. Factors related to operatives
3. Factors related to project management/corporate
4. Factors related to site management
5. Other job factors

Types of Personal Factors

1. Lack of knowledge/skill
2. Mental/psychological factors
3. Improper motivation
4. Physical/physiological factors
5. Other personal factors

Types of SMS Failures

Inadequate: (A) System, (B) Standards or (C) Compliance in one of the following elements

1. Safety policy
2. Safe work practices
3. Safety training
4. Group meetings
5. Incident investigation and analysis
6. In-house safety rules and regulations
7. Safety promotion
8. Evaluation, selection and control of sub-contractors
9. Safety inspections
10. Maintenance regime for all machinery and equipment
11. Hazard analysis
12. The control of movements and use of hazardous substances and chemicals
13. Emergency preparedness
14. Occupational health program

Figure 2: Main headings of MLCM taxonomy

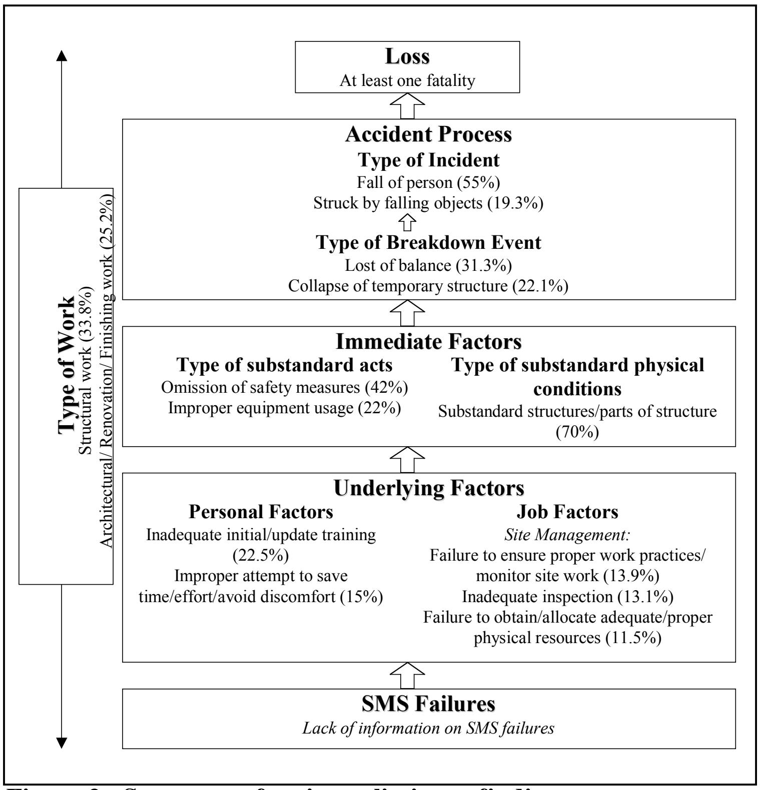

Figure 3: Summary of main preliminary findings

As indicated in MLCM (refer to Figure 1), immediate factors are spilt into substandard acts and substandard physical conditions. Findings on substandard acts reveals a high occurrence of omission of basic safety measures (42% of all substandard acts) like wearing of personal protective equipment (PPE) and checking of the vehicle's rear before reversing. The other main substandard act is improper equipment usage (22%), some common examples are workers using defective mobile scaffolds for work, and using employee lifts to transport construction materials. With respect to substandard physical conditions there is a high concentration of factors in the substandard structure/parts of structure (70% of all the identified substandard physical conditions). This usually refers to lack of safety structure like guardrails or barriers for open sides of buildings and shoring for trenches.

Within the scope of underlying factors (job and personal factors), most of the job factors belong to the category of site management. This shows that site management plays an important role in construction safety. The three most frequently cited factors concern failure to ensure proper work practices/monitor site work (13.9%), inadequate inspection (13.1%) and failure to obtain/allocate adequate/proper physical resources (11.5%). When there is a lack of supervision on site and inadequate provision of physical resources to operatives (e.g. workers, technicians and plant operators) causes the operatives to commit substandard acts and be exposed to substandard physical conditions.

As for personal factors, the main factors are inadequate initial/update training (22.5%) and improper attempt to save time/effort/avoid discomfort (15%). Furthermore, the personal factors usually refer to operatives instead of site management and other job categories. The findings show that training and education of operatives can be a vital link in reducing substandard acts and physical conditions. However, deeper analysis of the factors would be needed to identify the specific strategies in reducing the factors. For example, a training needs analysis will be needed in order to reassess current training courses and develop new courses.

One specific example on how the results of study can be used is the construction of event tree diagrams. Figure 4 shows an example of an event tree diagram that is constructed based on the results of the study. The number next to each event on the diagram indicates the number of occurrences of the event. An event tree like this can then facilitate risk assessment by practitioners. The event tree diagram identifies the possible routes of accident and the number of occurrences of each event can assist the practitioners in assigning the probability of each event recurring. With more data, more detailed event trees can be drawn and the diagrams will be invaluable to the industry.

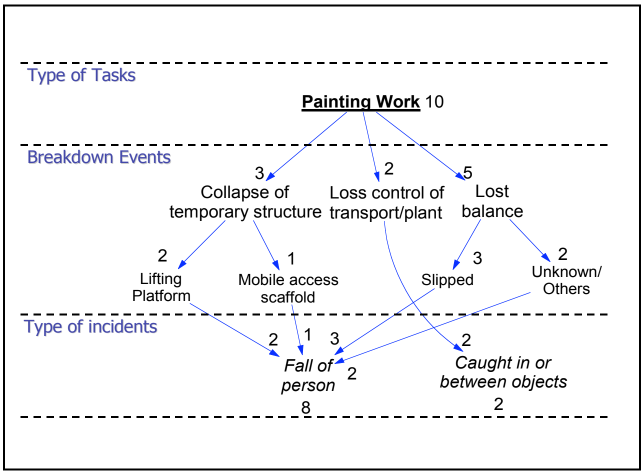

Figure 4: An example of Event Tree Diagram

Furthermore, the statistical results on immediate and underlying factors can also be used as training material, in training needs analysis, and to guide inspection, enforcement and promotional efforts. The continuous monitoring of the accident variables over time can also serve to provide critical information to practitioners and government safety department with regards to the actual effectiveness of safety efforts. For example, after the implementation of a national campaign to emphasise the importance of safety inspection on sites, it would be expected that if the campaign was successful the number of accident causal factors related to inadequate inspection would be reduced, if not a reassessment of the campaign may be necessary.

The MLCM taxonomy can also be used to develop accident database at national and organisational levels. Where consistent and careful application of the taxonomy to classify factors will allow the industry to learn from its mistakes and improve its safety performance.

Conclusions

In this paper the MLCM, its accompanying taxonomy and the statistical analysis of 140 construction accidents were presented. The MLCM traces the accident causation from the losses due to the accident to deep-rooted SMS failures. Based on the MLCM taxonomy, the 140 fatal accidents analysed reveals several main characteristics and causal factors of construction accidents. Examples on how the results can be used were also presented.

The MLCM and its taxonomy seek to ensure that critical learning points can be obtained from each accident. As with each accident, precious resources are lost and if the industry does not learn from the accident, the cost of each accident actually multiplies. However, the safety performance of the construction industry cannot be improved overnight. It is only through consistent and proper feedback, such as the implementation of the MLCM taxonomy, then can the industry's safety performance be improved permanently.

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