Incident Causation Model for Improving Feedback of Safety Knowledge

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Abstract: In order for the construction industry to improve its poor safety performance it needs to learn from its mistakes and put the lessons learned to good use. This need calls for effective feedback mechanisms that can transmit information derived from incident investigation to be utilized in safety planning. The feedback should be at two levels; first, feedback to the Safety Management System that had failed, and second, feedback to the safety planning of future projects. The first level of feedback can be achieved by basing the investigation on an incident investigation model that explicitly identifies system failure. The second level of feedback can be achieved if both incident investigation and safety planning share the same incident causation model, such that the information from each process can be retrieved and utilized in the other process smoothly. One prerequisite to fulfill the two levels of feedback is the development of an incident causation model. In this paper, the modified loss causation model (MLCM), which is able to meet the above-mentioned purposes, will be presented. The MLCM is developed based on an extensive literature review and application on 140 actual accident cases obtained from Singapore's Ministry of Manpower, Occupational Safety Department. In this paper, the model's application will be demonstrated through a case study, which involves codification of investigation information based on an actual incident report, and a safety planning process based on a hypothetical case.

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Introduction

Safety has always been a persistent problem in the construction industry. In the United States, it was reported that the 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 one-third of all industrial accidents over the last 10 years (Tam and Fung 1998). In Singapore, the construction industry takes up 29% of the total number of industrial workers, but the industry accounted for an unproportionate 40% of the industrial accidents (MOM 2001). These studies are among many others that show that the industry has a very poor safety performance record.

To improve the industry's safety performance, one strategy would be to ensure continual improvement of safety management systems (SMS) of construction projects. Based on the definition given in British Standard (BS) 8800 (BSI 1996), SMS can be thought of as an interdependent set of preventive measures, which is targeted at maintaining and improving safety performance of an organization. SMS is essentially based on the risk management process (BSI 2000) as illustrated in Fig. 1, which consists of four interdependent components: hazard identification, risk analysis, risk control selection, risk control implementation, and maintenance. In this paper, the first two components, i.e., hazard identification and risk analysis are defined as risk assessment, and the first three components, i.e., risk assessment and risk control selection, are defined as safety planning.

As shown in Fig. 2, there are two improvement loops that could be employed to support continual improvement of a SMS. The two loops are facilitated by risk control maintenance and incident investigation, respectively. Risk control maintenance is proactive, providing feedback based on preplanned monitoring and inspection activities, whereas incident investigation is activated only when some kind of physical failure or injury occurs (an incident). Even though the incidents might not result in death or injuries, there would usually be some amount of losses in terms of lost time or property damage, which are also highly undesirable. Thus incident investigation should not be used as the primary continual improvement measure.

However, due to the "after-the-fact" nature of the information gathered during an investigation, incident investigation information tends to be evidence-based and practical. Thus the information gathered from incident investigations have tremendous value in facilitating improvement of the safety management of construction projects. In order to fully exploit incident investigation information, the incident investigation system should be carefully planned such that it can facilitate feedback at two levels. First, feedback to the SMS that had failed and hence caused the incident, and second, feedback to the safety planning of future projects (Fig. 2).

The first level of feedback is more straightforward. The key is to ensure a thorough investigation that identifies the relevant SMS failures so that appropriate improvement to the SMS can be made.

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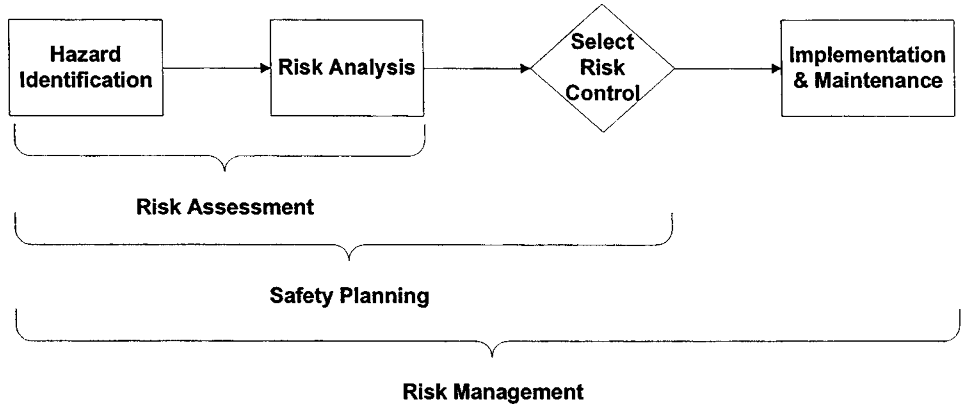

Fig. 1. Basic risk management model

The second level of feedback requires the retrieval of relevant safety knowledge from a safety knowledge base, and its adaptation for use in the safety planning of new projects. Safety planning relies heavily on the experience and competency of the safety planning team. The processes of identifying hazards, assigning appropriate level of risk, and selecting the most efficient control, requires extensive field knowledge and experience. One valuable source of such experience can be derived from the investigation of past incidents.

To ensure that the two levels of feedback are carried out effectively and efficiently, incident investigation and safety planning should be based on a common incident causation model (refer to Fig. 2), which can be utilized to guide both the processes individually, and also to allow sharing of information between the two processes. Thus the objective of this paper is to propose an incident causation model that provides a structure that facilitates the two levels of feedback as described above.

The proposed incident causation model, the modified loss causation model (MLCM), is developed based on a thorough literature review and also application on 140 actual incident investigation cases (Goh and Chua 2002) obtained from Singapore's Ministry of Manpower, Occupational Safety Department. Following a brief discussion of the existing incident causation models, the MLCM will be presented and subsequently applied in a case study.

Incident Causation Models: A Review

Following the seminal work by Heinrich (1939), numerous other incident causation models (also known as accident causation models) have been developed. These incident causation models differ in many fundamental ways and may be classified based on their area of application, general structure, and key characteristics. In this paper, the relevant incident causation models are categorized into three general categories: energy transfer models, individual specific models, and systemic models.

The energy transfer models, as the name implies, focus on the transmission of uncontrolled energy from the source to the victim. The energy transfer model developed by Haddon (1980) has much relevance to this study. Haddon developed the model and proposed 10 basic prevention strategies based on the points of intervention, i.e., the energy source, the barriers (between victim and energy source), and the victim. The model is very useful in

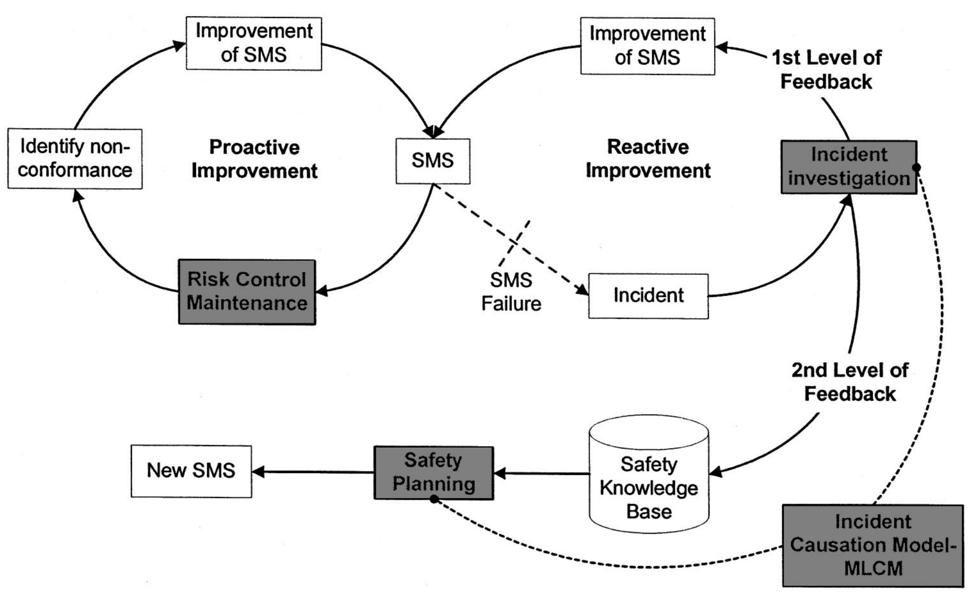

Fig. 2. Feedback mechanisms to facilitate continual improvement

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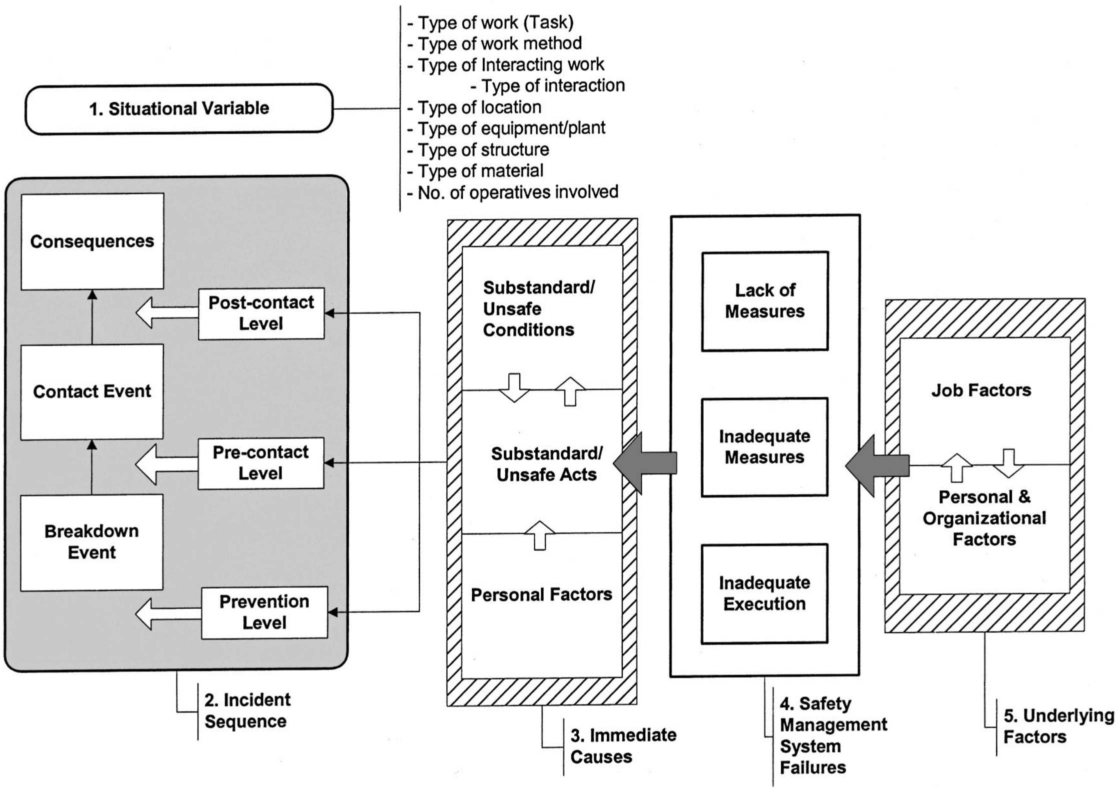

Fig. 3. Modified loss causation model

categorizing the types of preventive measures, but it does not provide a suitable feedback-oriented framework for incident investigation and safety planning.

Individual specific models are models that place emphasis on individuals that contributed to the incident in a direct way. These models identify the causes and effects of erroneous acts by individuals (usually front-line workers). They (for example, Kerr 1950, 1957; Hinze 1997) usually focus on psychological and behavioral aspects of humans. However, these models do not emphasize the role of the organization and the safety management system. Thus individual specific models do not facilitate continual improvement of SMS explicitly.

Systemic models refer to models that highlight the role of the organization and its systems in the causation of the incident. Henderson et al. (2001) regarded a system-based approach as one of the requirements of a successful incident investigation, and this view is reflective of the current paradigm of incident causation. Numerous systemic models have been developed over the years, for example, Management Oversight Risk Tree (MORT) (Johnson 1980), contributing factors in accident causation (CFAC) model (Sanders and Shaw 1988), pathogen model (Reason 1990), Whittington et al.'s (1992) model, loss causation model (Bird and Germain 1996), accident root causes tracing model (ARCTM) (Abdelhamid and Everett 2000), and constraint-response model (Suraji et al. 2001). These models generally agree that the organization as a whole plays an important part in the causation of an incident. However, these causes are generally latent (Reason 1993), that is, these causes or failures reside in the organization and only when local triggers (or immediate causes) arise, incident may occur. These models also implicitly or explicitly reinforce the concept of multiple-causation, where the cause of an incident does not lie in one line of causation, but often branch out into various chains of factors. Due to the emphasis on contributions of organization, systemic models provide the basic paradigm for the development of the proposed incident causation model.

Modified Loss Causation Model

The proposed incident causation model, the modified loss causation model (MLCM) depicted in Fig. 3, is primarily based on the loss causation model (LCM) by Bird and Germain (1996). The LCM has several useful characteristics. One of the main merits of the model is that it promotes proactive thinking (Covey 1989) on the part of the management, which in turn facilitates feedback. In particular, the model identifies "Lack of control" as the fundamental source of incident occurrence, hence prompting investigators to end each incident investigation with an examination of the safety management system. Thus the model encourages organizations to accept the responsibility to respond to incidents and not blame it on individuals or physical conditions. In this way, each time an incident occurs the planned SMS will be reviewed and compared with the causation factors identified to determine whether there is a lack of measures to control the occurrence of the causation factor, an inadequacy in the planned risk control, or whether the planned measures were inadequately executed. In this way, systematic actions can then be implemented to remove flaws in the management system and organizational culture.

Another useful characteristic of the LCM is that it clearly identifies and distinguishes immediate causes and underlying factors (also known as basic causes). The immediate causes are the triggers that directly lead to the incident sequence, whereas the underlying factors are factors that contribute indirectly to the occurrence of the immediate causes. The underlying factors are usually hidden in the organization and are hard to be detected. They are also often contributory in nature and their determination may

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have to depend on investigators' subjective judgment, but their clear identification can usually lead to more significant improvements in safety performance. In the LCM, immediate causes are classified into substandard/unsafe conditions and substandard/unsafe acts, which refer to the respective physical conditions and human behaviors that do not meet safety requirements and can directly cause incident occurrences. Underlying factors are also categorized into 2 subcategories, personal factors and job (or system) factors. Personal factors are defined as factors related to individual's capability, knowledge, skills, attitude, and motivation. On the other hand, job factors refer to factors related to work or task definition and execution, for example, inadequate leadership and/or supervision, inadequate engineering, and inadequate work standards.

Modifications to the LCM have been made to achieve the objectives of the present study and the modified version of the LCM, the MLCM, is presented in Fig. 3. The MLCM is composed of five main components, situational variables, incident sequence, immediate causes, SMS failures, and underlying factors.

The component ''situational variables'' has been included in the model because for each chain of incident causation there is a need to identify the critical characteristics of the context or situation in which the incident occurred. In this way, the information and learning points derived from the incident investigations can be more easily identified and applied to similar contexts or situations across different construction projects. This is especially valuable to an industry which is project-based in nature so that the experience gleaned from one project can be transferred to other projects. Moreover, these situational variables serve as indices for maintaining the incident investigation information in the safety knowledge database and for retrieval of related incident experience for safety planning.

The situational variables can also act as stratifying or categorical variables during data analysis of incident statistics, so as to allow meaningful comparison of statistical results. For instance, the number of incidents can be stratified based on the type of work executed prior to the incident. Statistics based on the type of work will provide insights into the contribution of different work types to the occurrence of incidents. Some of the typical categories of situational variables are listed in Fig. 3.

One of the key situational variables that is characteristic of the construction industry is the type of interacting work. In a construction project, several different types of work usually occur at the same time, and these works can interact in several ways to cause different forms of hazard. The type of interaction can be categorized as one or more of the following types: (1) space (close proximity), (2) time (sharing the same time slot), (3) resource (conflicting characteristics of resources or scarcity of shared resource), (4) information (required information from another task), (5) product/component (sequential or simultaneous work on the same product/component, e.g., column, beam, scaffold), and (6) others.

If an investigation or safety planning does not identify the interacting works but just focuses on one type of work, actual or potential sources of harm can be easily overlooked. The importance of interacting work can be illustrated from the following example based on an actual incident investigation report. In the renovation project, two of the main tasks are the removal of air-conditioning ducts and hacking of sidewalls. The two tasks appeared to be independent, and posed no harm to each other. During the project, one of the air-conditioning ducts collapsed and killed one of the workers working on the ducts. Upon investigation it was realized that the air-conditioning duct was partially supported by the sidewalls. When the sidewalls were removed, the duct was insufficiently supported leading to the collapse. Thus in this incident the sidewall was the point of interaction between the two tasks, and the interaction can be classified as the product/component type. If this interaction between the two tasks was identified during safety planning the fatal incident could have been prevented.

The second component of the MLCM is the incident sequence, which is made up of the breakdown event, contact event, and consequences. The breakdown event is defined as an initiating point of loss of control of a source of energy or substance that, without an intervening event, will lead to the occurrence of a contact event. In contrast, a contact event is an event where the victim comes into contact with the source of energy or substance. The consequences refer to the undesirable effects of the incident, for example, number of man-days lost and type of injuries. It is beneficial to define incidents based on the incident sequence structure so that causal factors and safety measures can be classified systematically into three levels of intervention and causation, namely, postcontact, precontact, and prevention levels (refer to Fig. 3).

During incident investigation, the incident sequence structure of the MLCM will prompt investigators to broaden their scope of investigation, and not end an investigation prematurely. For example, when a worker loses balance and falls off the edge of a building, an investigator could easily state that the main cause of the accident is due to the fact that the worker was not wearing a safety belt. Even if the underlying factors and the SMS failures that had contributed to the contact event (falling from height, subsequently striking the ground) were identified, the knowledge will only prevent the recurrence of the contact event, but not the breakdown event (loss of balance, in this instance). To better improve the SMS, the factors that contributed to the occurrence of the breakdown event, contact event, and the consequences of the incident should be identified. Similarly, safety planning should also be based on the three levels of intervention to identify sufficient measures to prevent and mitigate the consequences of breakdown events and contact events.

The third and fifth components of the MLCM are the immediate causes and underlying factors, respectively. Unlike the LCM, both immediate causes and underlying factors of the MLCM include personal factors. This is to prevent difficulties in the classification of personal factors, particularly in cases where the identified personal factors do not fit the definition of underlying factors. For instance, when a worker committed a substandard act by climbing up the bracings of an access scaffold, and it was identified that the personal factor that led to this substandard act is improper motivation to save time and effort. Under the LCM the personal factor will have to be classified as an underlying factor. However, this classification will not fit the definition of underlying factors, which are organizational and/or contributory in nature. In the MLCM, personal factors that lead to substandard acts of front line operatives are separated from personal factors that influence SMS failures and job factors. In this example, an underlying personal factor could be the lack of experience of the safety planning team to develop adequate measures (SMS failure) to deal with the improper motivation (immediate personal factor) that led to the substandard act. Furthermore, organizational factors are also included in underlying factors to take into account their effects on SMS. Organizational factors include factors like poor safety culture and unsuitable organizational structure.

The fourth component of the MLCM is SMS failures, which can be further classified into: lack of measures, inadequate execu-

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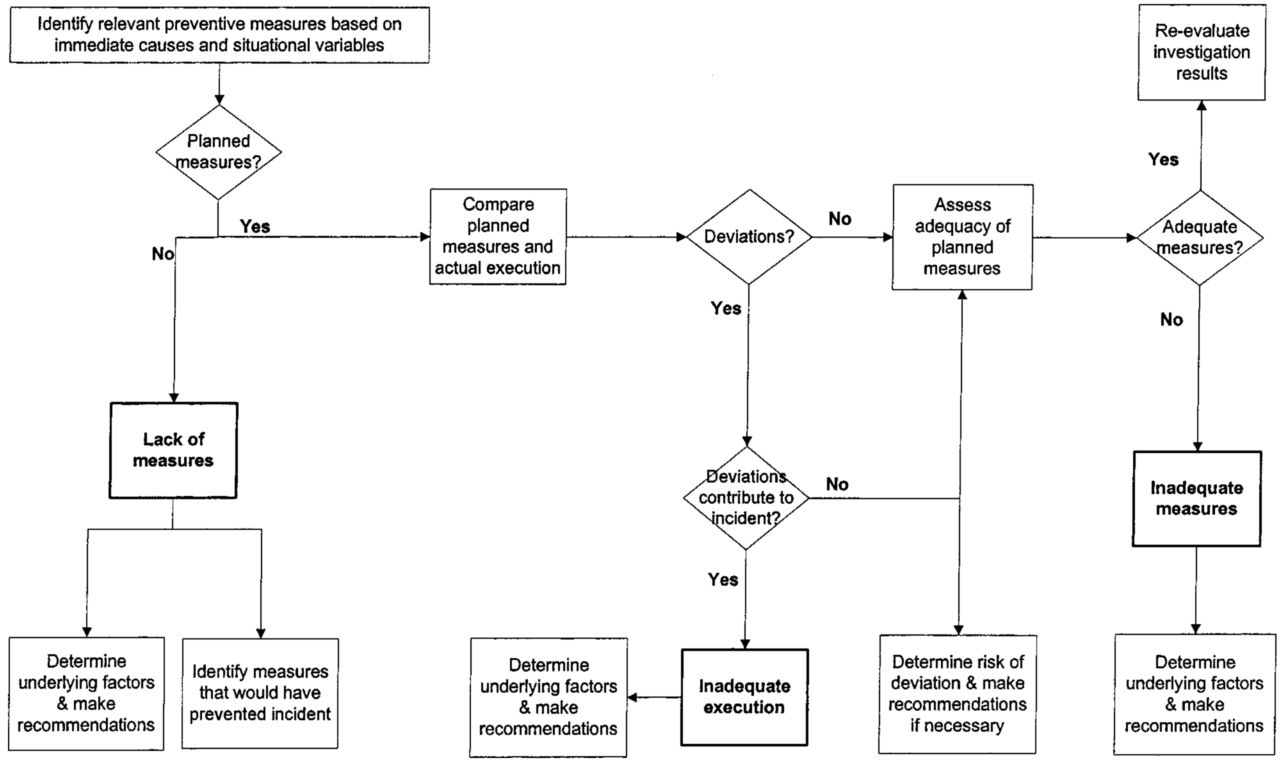

Fig. 4. Modified loss causation model investigation approach

tion, and inadequate measure. This component is similar to the ''lack of control'' component in the LCM, but in the MLCM the SMS failure is identified prior to the underlying factors, which is the reverse of the LCM approach. After attempts to apply the LCM approach in this study, it was realized that the classification of SMS failures is often a prerequisite to the identification of job factors, thus leading to the order proposed in the MLCM. This investigation approach will be elaborated subsequently.

Another feature of the MLCM is the explicit identification of directions of influence and causation between the various types of factors. In the MLCM (Fig. 3), substandard acts can be influenced by substandard conditions and vice versa; substandard acts can also be caused by personal factors. In the model, SMS failures can lead to the occurrence of immediate causes of an incident, and underlying factors are deemed to contribute to the failure of the SMS. Within underlying factors, job factors influence personal and organizational factors, and vice versa. These possible directions of influence and causation form part of the MLCM framework for incident investigation and safety planning.

Modified Loss Causation Model Investigation Approach

In order to facilitate the first level of feedback (i.e., feedback to the SMS that failed), the MLCM is designed to guide incident investigation to uncover SMS failures and underlying factors. Based on the MLCM, the flow chart depicted in Fig. 4 is developed to illustrate the MLCM approach to identification of SMS failures and underlying factors.

The first step in the investigation would be to identify the situational variables, incident sequence, and immediate causes. Subsequently, the relevant safety measures that could have prevented the immediate causes are identified. If no relevant measures exist, then there is a failure in the SMS of the ''lack of measures'' type and the investigation will focus on identifying the underlying factors that lead to this failure, and subsequently propose appropriate safety measures to prevent a recurrence. If relevant safety measures exist, the execution of the measures will be evaluated based on the planned procedures.

When there are no deviations from the planned procedures, the adequacy of the planned measures is next evaluated. For any measures that are inadequate, the investigators will determine the underlying factors that lead to the SMS failure and recommend appropriate ramifications. Otherwise, the investigators will reevaluate their assessment of the incident, since from a proactive paradigm few or no incidents are unpreventable.

If the deviations from the planned procedures had contributed or caused the incident, then there is an inadequate execution of the planned measures so that the underlying factors causing the SMS failure have to be detected, and the rectifications made. On the other hand, when the deviations do not contribute to the incident directly, there is a need to assess the adequacy of the planned measures and the risk posed by the deviation.

Application in Incident Investigation

In this section, the purpose of the case study is to illustrate the usefulness of the MLCM in providing a structure for the investigation.

The case is based on an actual fatal incident investigated by the Singapore's Ministry of Manpower, Occupational Safety Department. The incident shown schematically in Fig. 5 occurred during a lifting operation, which involved the use of a crawler crane. The crawler crane driver was requested to lift a bundle of rebars to the fourth level of a building under construction. During the lifting operation the victim was doing some general work on

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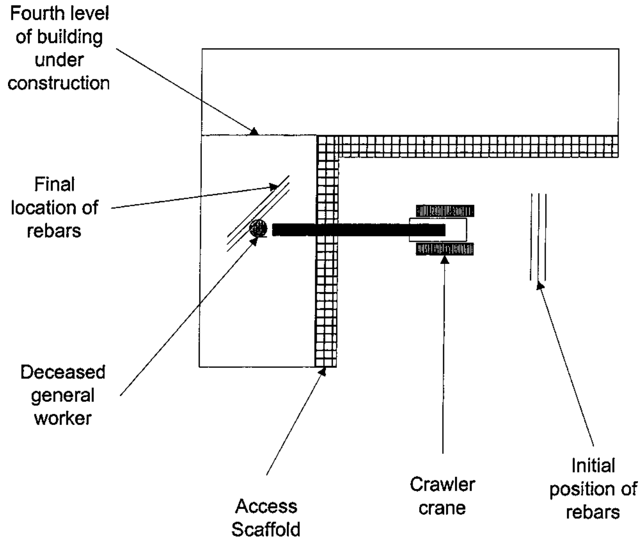

Fig. 5. Schematics of incident case study

the fourth level of the building under construction (near the location where the rebars were to be placed). When the boom angle of the crane reached approximately 60°, the overload alarm sounded and the crane operator lowered the load quickly. In the process of releasing the hoist rope, the crawler crane tilted and the boom hit the access scaffold. As a result, the bundle of rebars fell onto the victim, who was killed on the spot.

The information from the incident investigation can be structured based on the MLCM as depicted in Fig. 6. The key situational variables of the incident are the type of work (lifting operation), type of interacting work (general work), type of interaction (space and time), type of equipment/plant (crawler crane), type of structure [access scaffold (nearby)], and type of materials (rebars). The death of the general worker (consequence) is due to him being struck by the falling rebars (contact event), which had fallen due to the crawler crane losing its stability (breakdown event). The crawler crane and the nearby access scaffold were also damaged due to the breakdown event (consequence).

The investigation report revealed no information at the precontact and postcontact levels. There had been no investigation on what could have prevented the contact event to occur (i.e., precontact level measures) even after the breakdown event had occurred, and what was done to deal with the emergency (i.e., postcontact level measures) after the contact event had taken place. However, the investigator did identify causal factors at the prevention level. The substandard act was the overloading of the crawler crane, and the personal factor leading to the substandard act was the crane operator's underestimation of the load. The investigation revealed a lack of explicit measures in the SMS to prevent the occurrence of the immediate causes. If there had been lifting supervisors appointed and proper measures to ensure that the weight of the load was clearly communicated and determined prior to the lift, the incident could have been prevented. However, the investigation did not attempt to determine the reasons for the lack of measures, which would constitute the underlying factors for the SMS failures.

From the case study, it can be seen that if the MLCM had been adopted and applied during the investigation, the level one feedback (feedback to improve the SMS that failed) would be achieved. Even though the investigator did identify the type of SMS failure (lack of measures) at the prevention level, the investigator did not identify the underlying factors that contributed to

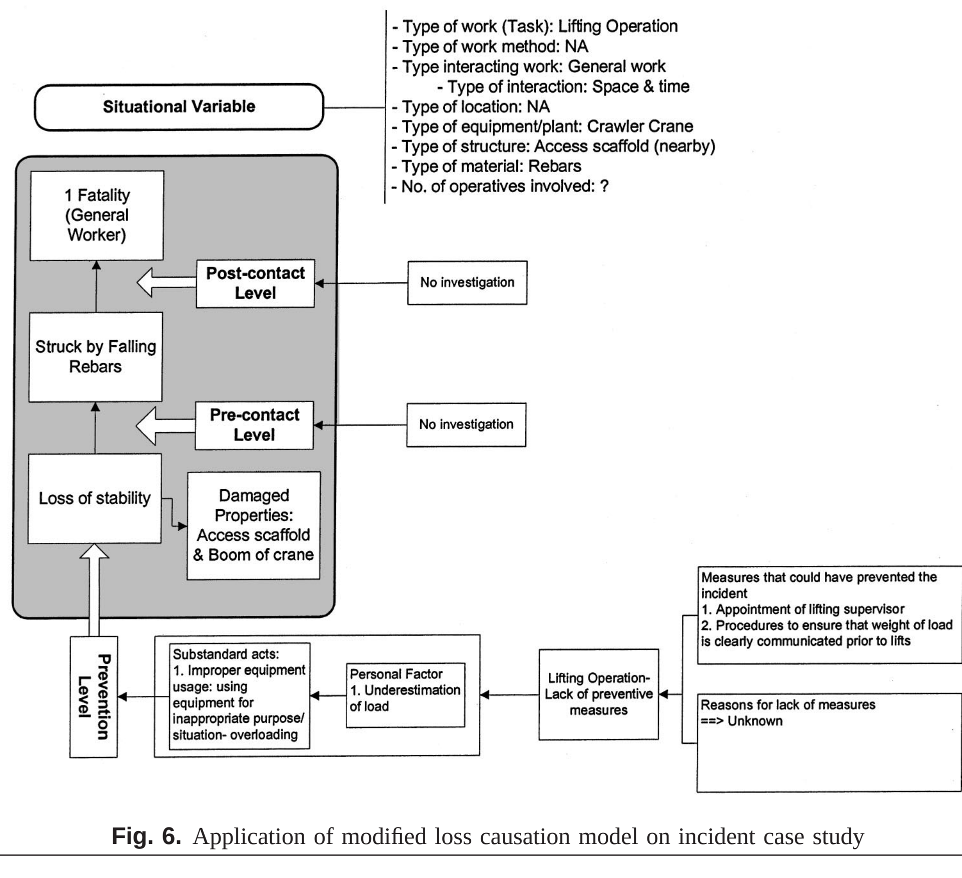

Fig. 6. Application of modified loss causation model on incident case study

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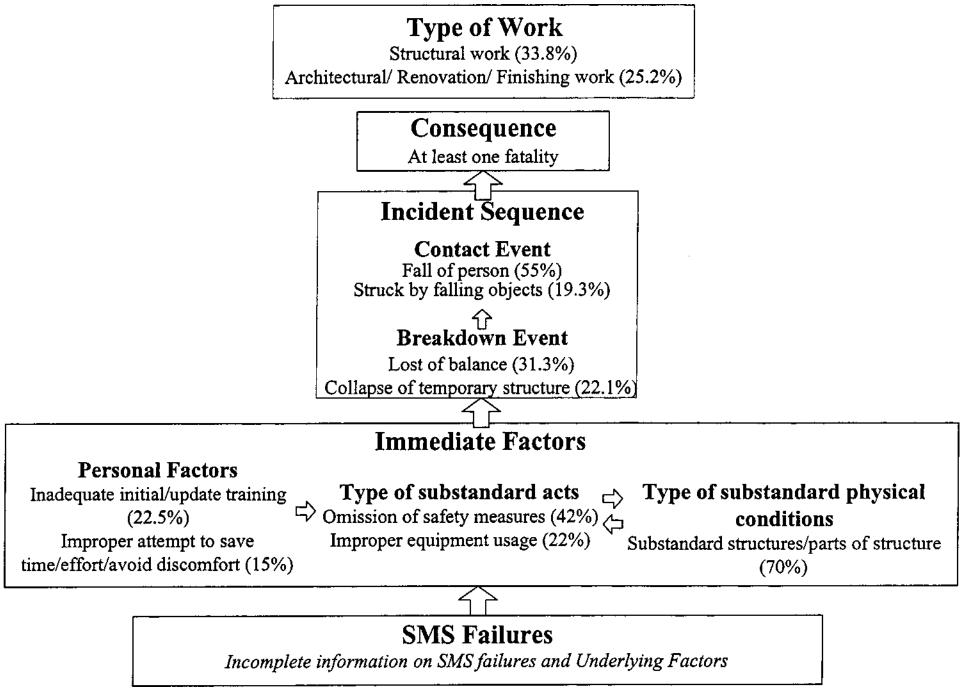

Fig. 7. Summary of 140 investigation cases

the failure of the SMS, which is essential to ensure improvement of the SMS. Identifying deep-rooted job, personal, and organizational factors is difficult, but it is only through their identification that effective strategies can be implemented to ensure improvement of the SMS.

Furthermore, if the investigation had been carried out based on the MLCM approach, precontact and postcontact measures could have then been identified or improved. Based on the preceding case, if there had been a lack of measures at the precontact level, the investigator could have recommended danger areas to be clearly identified or even barricaded during lifting operations. In this way, the contact event of worker being struck by falling loads could have then been prevented.

The case also illustrated that the MLCM can be applied to code (i.e., classification and simplification of information into short phrases and words) and structure the investigation information systematically. The logical flow of codified information and its clear structure, as shown in Fig. 6, facilitates storage of investigation information in a computer database, which could be retrieved in subsequent safety planning. To ensure consistency in the choice of codes when representing investigation information a set of taxonomy has been developed (Goh and Chua 2002) from the study of 140 investigation cases. For the convenience of readers, a summary of the codified incident investigation information of the 140 cases leading to at least one fatality is shown in Fig. 7, but readers should refer to Goh and Chua (2002) for a detailed discussion of the statistical results. As indicated in Fig. 7 most of the investigations did not explicitly identify SMS failures and their underlying factors. This deficiency can be reduced if the proposed MLCM investigation approach is used as the structure for the investigation.

Application in Safety Planning

In order to demonstrate how the second level of feedback (transfer of incident investigation information to safety planning) can be attained, a safety planning process (risk assessment and risk control selection) for a hypothetical case is illustrated in the following.

Risk Assessment

Fig. 8 shows a risk assessment of a lifting operation based on the MLCM framework. The situational variables are deliberately made to be similar to the incident case study presented earlier, which is highly probable as the situation is relatively common. Based on the situational variables, a risk assessment tree, structured similarly to the event tree analysis methodology, can be developed. The risk assessment tree is composed of the possible incident sequences and their possible consequences.

The assignment of probabilities of occurrence for each event [for example, $P(B_1)$, $P(C_{12})$, and $P(CSQ_{123})$] can be based on subjective sources such as expert judgment or objective observations of actual incidents. The use of objective observations will require a large amount of data and an effective retrieval and adaptation system, which are rarely available currently. On the other hand, a purely subjective assignment of probability will reduce the credibility of risk assessment. The objective in the proposed MLCM-based approach is to integrate the observed incidents into the subjective probabilities assigned. The shaded boxes in Fig. 8 show the incident sequence and consequences of the previously discussed incident being transferred into the risk assessment tree. The Bayesian approach (Ang and Tang 1975) can be used to provide this integration so that the prior subjective probabilities can be revised with observed occurrence of the events from incident investigations. A detailed discussion of the Bayesian statistics in this application is beyond the scope of this paper.

This feedback of incident investigation information is facilitated by the common structure in both incident investigation and safety planning, through the consistent use of the MLCM. As a result, an augmenting tree can be developed based on past investigation cases to supplement the risk assessment tree. Fig. 9 shows an example of such an augmenting tree developed for

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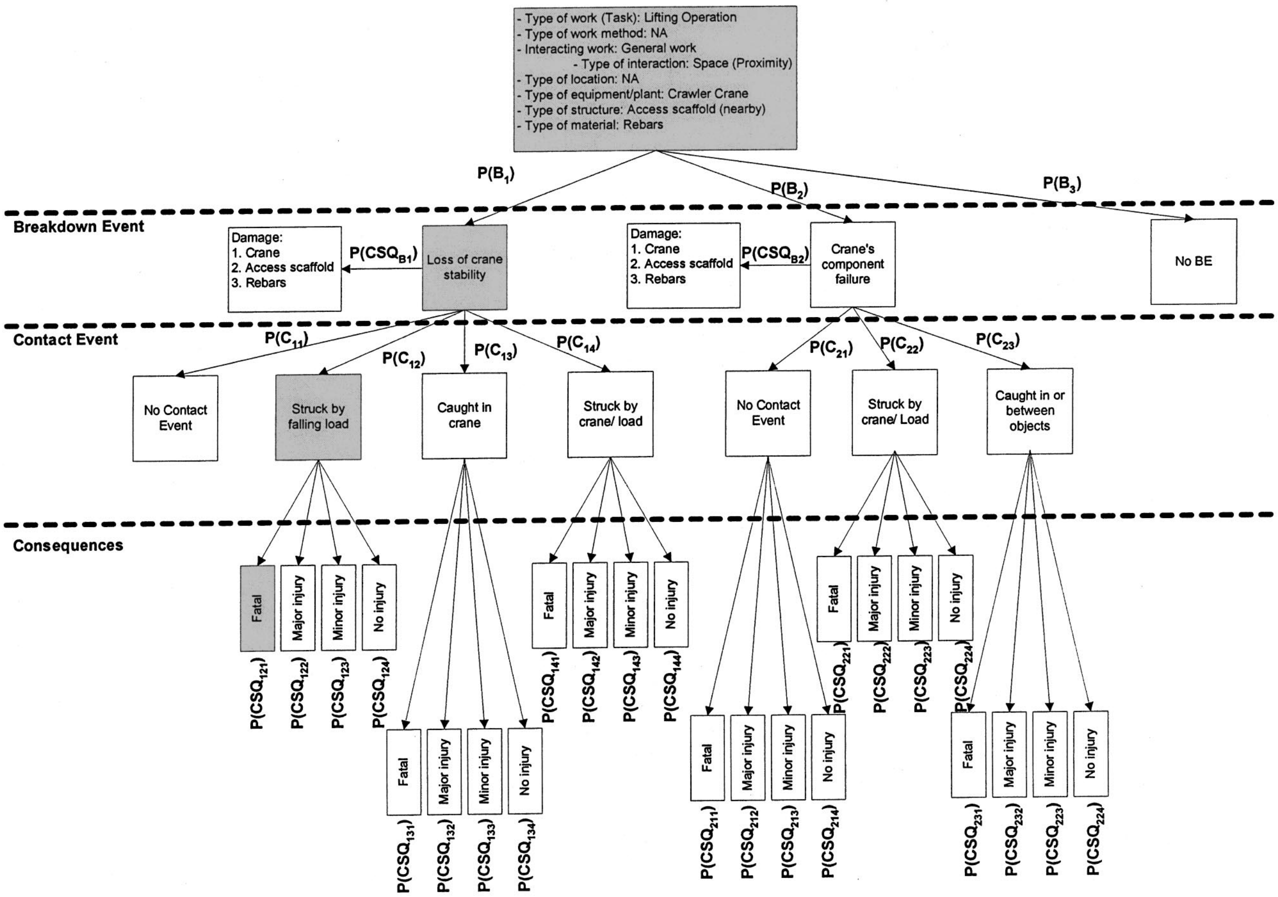

Fig. 8. Risk assessment based on modified loss causation model

painting work based on the 140 investigation cases. The figure summarizes the incident sequences of past painting work incidents and their corresponding number of occurrence. For instance, out of the 10 accident cases related to painting work, five cases have a breakdown event of the ''Lost balance'' category, two cases of the ''Loss control of transport/plant'' category, and the remaining three of the ''Collapse of temporary structure'' category. Further classification could also be made to provide more details on the category of the breakdown event. For example, out of the three cases with a breakdown event of the ''Collapse of temporary structure'' category, two involved a lifting platform and one involved a mobile access scaffold. Similarly, a contact event

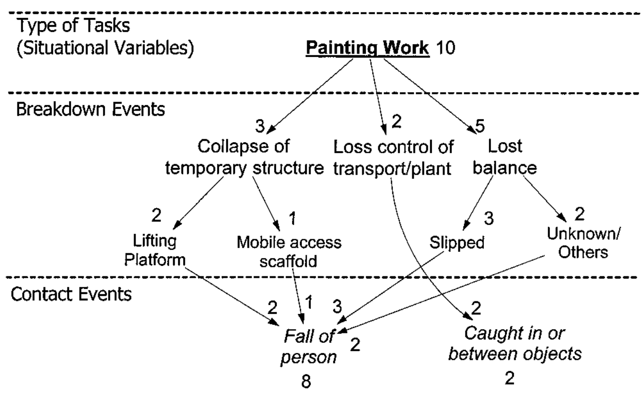

Fig. 9. Augmenting tree developed based on 140 investigation cases

and consequences for each of the incidents can also be classified based on a set of taxonomy, and the number of occurrences in each category can be determined as depicted in Fig. 9. All incidents in this study were fatal. During risk assessment, the augmenting tree serves to facilitate identification of the possible incident sequence (breakdown event, contact event, and consequences), and ensures that past incident occurrence will not be overlooked. Furthermore, the assignment of probability of occurrence can also be guided by relative frequencies derived from the numbers denoted in the augmenting tree, thus providing a more objective basis for probability figures.

Risk Control Selection

Fig. 10 shows the risk control selection at the preventive level for a possible breakdown event, ''loss of crane stability,'' during the crane-lifting operation presented in the risk assessment section (see Fig. 8). In order to select the relevant risk controls, the immediate causes of the breakdown event are first identified based on an approach similar to the preceding risk assessment. Due to the similarity of the situational variables and breakdown event between the past case of Fig. 6 and the new case described in Figs. 8 and 10, the findings from the investigation of the past case may be utilized. In particular, the immediate causes identified, i.e., the substandard act ''Overloading'' due to the personal factor ''Underestimation of load'' is included as a possible immediate cause of the breakdown event ''loss of crane stability'' in the new case. Furthermore, the preventive measures recommended by investigators are also retrieved. In this example, the retrieved pre-

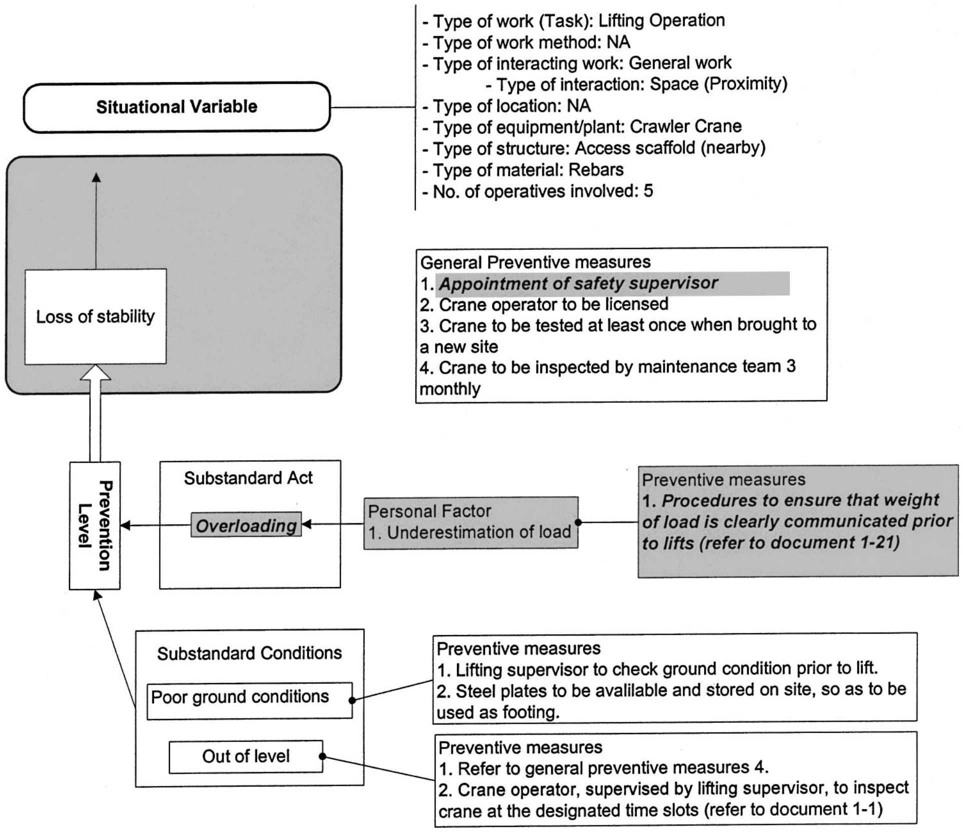

Fig. 10. Risk control selection based on modified loss causation model

ventive measures include procedures to ensure that weight of load is communicated prior to lifting, and also the appointment of a lifting supervisor (general preventive measure). In this way, preventive measures need not be developed from scratch; instead if possible, they could be retrieved from past incident investigations when the situational variables for the new case resemble those of past cases. These measures would usually be practical and effective since they have been implemented before. Moreover, the retrieved measures can be adapted to better accommodate any unique situation of the present case, and also improved on if necessary. It should be noted that the safety planning team need not be constrained by past cases and they can also identify immediate causes, and corresponding measures based on their knowledge and experience. For instance, the substandard conditions, "Poor ground conditions" and "Out of level," and their corresponding control measures in Fig. 10 (in nonshaded boxes) could have been based on preemptive evaluation of the situation.

It should be noted that the risk control measures shown in Fig. 10 will also be very useful during incident investigation, as they provide a structured framework to evaluate the SMS (refer to Fig. 4). Furthermore, a similar approach can be adopted for the other levels of intervention, i.e., precontact and postcontact levels, in this way a thorough and systematic SMS can then be developed.

Even though it is not possible to base the safety planning process purely on incident investigation information, the use of the MLCM in incident investigation and safety planning will ensure that relevant and valuable incident-based experiences are incorporated whenever possible. This feedback of incident investigation information to the safety planning process achieves the second level of feedback and hence facilitates continual improvement of the SMS.

Conclusion

This paper presents an incident causation model, the modified loss causation model (MLCM), which is meant to facilitate feedback at two levels, first, to the SMS that had failed, and second, to the safety planning process for future construction projects. Through the two levels of feedback, construction SMS, and hence safety performance of the industry, can be continually improved.

In order to achieve the two levels of feedback, the MLCM is designed to provide a systematic and logical structure for both incident investigation and safety planning, such that if the MLCM is applied consistently, the depth and breadth of both the processes will be ensured. Furthermore, through the use of the MLCM as a common model for incident investigation and safety planning, incident investigation information can be retrieved and utilized in safety planning.

However, in order to fully exploit the ideas and concepts illustrated in this paper, a computer-based system meant to assist incident investigators and safety planning teams will be necessary. Hence an intelligent database system is currently being developed to implement the MLCM approach for incident investigation and safety planning. With the computer-based system, the efficiency of incident investigation and safety planning can also be improved, allowing the time-constrained construction industry to deal with safety issues more effectively and efficiently.

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