A CONCEPTUAL ACCIDENT CAUSATION MODEL BASED ON THE INCIDENT ROOT CAUSES

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Abstract: The measurement and control of incident root causes allows for proactive actions to mitigate risk in advance. In practice, however, it is difficult to identify and collect data that represent the root causes due to the complexity of incident occurrence processes. Despite previous studies on incident causation modelling, the identification of root causes in practice still relies on the investigator’s subjective opinion. This research presents a conceptual model that explains the causal relationships between the root causes and the site unsafe level, and eventually assesses incident investigation processes. A case study was conducted to evaluate the 13 root causes in a company’s investigation practice. The causal relationship between the root causes was observed based on the company safety database, interviews, and literature review. Then, the detailed model, which explains the incident occurrence process, was explored. Additionally, a hypothetical simulation model that allows for evaluation of the influence of each root cause on the safety level was built and tested to discuss the potential use of the conceptual model. Based on the company database, this paper also suggests and discusses the types of data to measure the root causes in practice. The model demonstrates that not only do safety personal and safety strategies affect the site unsafe level, but other factors also do, such as procurement, engineering, human resources, etc. As a result, the proposed model can be used to help identify the root cause in incident investigation practice and to develop strategies to improve safety performance.

1 INTRODUCTION

Incidents in the construction industry can influence project cost, schedule and quality. According to the Association of Workers’ Compensation Boards of Canada (2012), the incident rate in the construction industry is 30% higher than in any other industry. Moreover, the fatality rate of the construction industry is approximately three times higher than the industry average. Incidents can affect the worker’s family, the community, and will also decrease the amount of worker resources available to the industry.

Incidents can generate accidents. According to Bird and Germain (1996), an accident is an event that results in unintended harm or damage, and when it is related to the worker, can result in injury. Any accident can be avoided; however, preventing accidents is difficult, mainly due to the difficulty of understanding accident causes, since several factors, such as worker and management commitment, schedule, and training, can affect it.
Construction companies usually perform an incident investigation to identify the root causes leading to an incident. Based on this investigation, the companies take actions (e.g. safety training, audits) that allow proactive management of safety performance by mitigating the risk in advance. Although several studies have developed accident causation models, the identification of the root causes in practice relies on investigator experience.

Besides identification of the root causes, the measure and control of the incident root causes can also contribute to improvement of the risk mitigation process. However, construction companies have difficulty identifying and collecting relevant data that represent the root causes due to the complexity of the incident occurrence process. Moreover, relevant data could be used to produce simulation models to better predict or estimate the site unsafe level.

The difficulties in identifying, measuring and controlling incident root causes could be due to the difficulty of understanding the causal relationship between them. Nevertheless, the relationship between the root causes should be determined, since projects usually have a limited safety budget, and better results can be achieved if the company can identify the best safety strategy to allocate the resources available (Wirth and Sigurdsson, 2008).

The objective of this research was to develop a conceptual accident causation model in order to explain the causal diagram between the root causes and the site unsafe level.

2 BACKGROUND

Accident causation models aim to “understand the factors and processes involved in accidents in order to develop strategies for accident prevention” (Arboleda and Abraham, 2004; Mitropoulos et al., 2005). According to Hovden et al. (2010), the main reasons for discussing the accident causation models are to: (1) create a common understanding of the accident phenomena; (2) help structure and communicate risk problems; (3) guide investigation on data collection and accident analyses; and (4) analyze the relationship between the factors.

Researchers have developed methodologies to identify incident root causes. Wagenaar and Schrier (1997) developed the TRIPOD model. This model classifies the causes for an incident into 11 General Failures Groups (e.g. design and training). Abdelhamid & Everett (2000) developed the Accident Root Causes Tracing Model (ARCTM). This model uses a decision tree to identify the main root cause of an incident. Suraji et al. (2001) developed a model that classifies the factors that cause an incident into distal and proximal factors. Leveson (2004) developed the Systems-Theoretic Accident Model and Process (STAMP). In this model, the accident occurs when external disturbances, component failures or dysfunctional interactions are not adequately controlled. However, these models are only able to pinpoint the main factors that cause the incident, not support the dynamic relationship between them.

As the previous models are not able to deal with the dynamic relationship between the factors, researchers have developed system dynamic models to understand how factors cause an incident. Cooke & Rohleder (2006) focus on how worker risky behavior and the learning process can cause an incident. Han et al. (2014) verified how the production pressure is related to incidents. Jiang et al. (2015) and Shin et al. (2014) developed models to understand the influence of the worker’s unsafe behavior on the incidents. It is possible to verify that these models are not able to deal with different root causes specified in practice by construction companies. Moreover, these models are generally conceptual and it is difficult to apply them to company safety routines.

The models and techniques presented have difficulties measuring the root causes that influence incidents. In practice, the incident investigation is usually only able to classify the occurrence of a pre-established root cause as Yes/No. The incident investigations utilized by construction companies usually collect information to describe the incident, but do not collect data to measure the influence of each root cause on the incident. Therefore, the companies have difficulty finding preventive actions to avoid further incidents.
3 METHODOLOGY

A case study was conducted to evaluate the root cause in a company's incident investigation practice. The incident root causes were identified. Although the root causes were established based on Bird and Germain (1996), there was no definition about how to classify each root cause during the incident investigation procedure. Therefore, the root causes were defined based on literature review and the company incident investigation.

After identifying and describing the root cause used by the construction company, the causal diagrams were developed. These diagrams were built based on the company's incident investigation, safety database, interviews, HSE Manual and further literature review.

The last step was to define empirical equations and build a hypothetical simulation model to understand the model behavior and evaluate the influence of each root cause on the site unsafe level. Moreover, data types were suggested to measure each root cause based on the safety database and the incident investigation.

4 IDENTIFY AND DEFINE THE ROOT CAUSES

According to the company safety policies, for every incident that occurs on the construction site, an incident investigation should be conducted. The company established 13 root causes of incidents, and the investigator should choose at least one cause based on his/her experience. A short description for each root cause is shown in Table 1.

Besides the incident root causes, the incident investigation defined by the construction company also collects information about the date and time of the incident, weather and lighting conditions, worker information, worker schedule, injury details, activity type, tools and equipment utilized in the incident, substandard act, substandard conditions, witness statement, etc.

5 CONCEPTUAL MODEL

The conceptual model established two main categories as the cause of the site unsafe level: worker behavior and site conditions. These categories were defined based on the incident investigation and literature review (Lingard and Rowlinson 2005). The site unsafe level can cause an incident. An incident, in this research, is every occurrence likely to lead to grave consequences. Accidents are every occurrence that decreases worker availability in the project. Therefore, incidents and accidents are positively correlated.

Three main loops were identified in the conceptual model. Loop R1 is related to the site condition. The company and some researchers (Mitropoulos et al. (2005) and Han et al. (2014)) stated that the accident affects the schedule pressure causing congestion, and increasing the site unsafe condition. Moreover, factors such as temperature, project type, activity type (Lee et al. 2012), and site layout (Anumba & Bishop, 1997), can also affect the site unsafe condition.

The other two loops (B1 and B2) are related to the worker behavior. The schedule pressure can affect the worker intention to work safe (Mitropoulos et al. 2005), and consequently, the worker safe behavior. Moreover, incident investigations can increase worker knowledge and also the perception of risk (Construction Industry Institute, 2002), improving the worker safe behavior (Han et al. 2014). Figure 1 shows a conceptual model of the influence of the worker safe behavior and site conditions on the site unsafe level.
### Table 1: Incident root causes description

<table>
<thead>
<tr>
<th>N</th>
<th>Root Cause</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hazard Identification and Control</td>
<td>Worker characteristics influence the identification and control of hazards.</td>
</tr>
<tr>
<td>2</td>
<td>Human Resource / Professional Development (HR/PD)</td>
<td>The hiring process was not able to verify the workers’ skills and knowledge.</td>
</tr>
<tr>
<td>3</td>
<td>Standard Operating Procedures Practices</td>
<td>The safety procedures to perform a task in a safe manner were not defined.</td>
</tr>
<tr>
<td>4</td>
<td>Leadership and Administration</td>
<td>Attitudes from the management do not demonstrate commitment to safety.</td>
</tr>
<tr>
<td>5</td>
<td>Inspection and Audits</td>
<td>The inspection and audits of equipment, processes, and workers were not defined/realized. In this research, the worker perspective of the inspection and audits will be considered.</td>
</tr>
<tr>
<td>6</td>
<td>Orientation and Training</td>
<td>The orientation/training was not able to transfer knowledge to the worker.</td>
</tr>
<tr>
<td>7</td>
<td>Site Specific Safety Plan</td>
<td>There is no recommendation about the safety procedures that should be followed in the construction site.</td>
</tr>
<tr>
<td>8</td>
<td>Communication Systems</td>
<td>The communication system was not able to inform the worker about the risks on the site.</td>
</tr>
<tr>
<td>9</td>
<td>Security/Emergency Response Engineering</td>
<td>There are no procedures to follow if an incident occurs.</td>
</tr>
<tr>
<td>10</td>
<td>Procurement</td>
<td>Verify problems related with the project design.</td>
</tr>
<tr>
<td>11</td>
<td>Sub / Trade - Contractor Management</td>
<td>Verify errors in the procurement process, such as lack of material specification and delay in delivery.</td>
</tr>
<tr>
<td>12</td>
<td>Sub / Trade - Contractor Management</td>
<td>Verify problems related with the sub/trade training and commitment to safety.</td>
</tr>
<tr>
<td>13</td>
<td>Environment</td>
<td>Verify the climate conditions that can influence an incident.</td>
</tr>
</tbody>
</table>

![Figure 1: Basic conceptual model](image)

The root causes defined by the construction company were categorized between the worker safe behavior and the site conditions categories. Each loop is explained in further detail below.

**Site Condition (R1):** Figure 3 shows the influence of the incident root causes on the site unsafe conditions. The site unsafe level increases the quantity of incidents and accidents. According to Han et al. (2014) and Mitropoulos et al. (2005), an accident can cause delays, increasing the schedule pressure. To compensate for the delay, the company can hire new workers. However, these workers increase the site congestion. The congestion increases the site unsafe condition because it increases workers’ exposure to struck-by or struck-against incidents (Fortunato et al. 2012). According to the company safety investigation, the site safety conditions can also be affected by the root causes Environment (e.g.
temperature, lighting, and wind), Standard Operating Procedures, Site Specific Safety Plan and Security Emergence Response.

Figure 3: Influence of the root causes on the site unsafe conditions

The site conditions are also affected by the root causes Engineering and Procurement. Both of these root causes can also contribute to the schedule pressure. Procurement can lead to material delay and poor design can increase rework.

*Hazard Identification (B1)*: Figure 4 shows the influence of worker knowledge on the site unsafe level. If the investigation is able to identify the root causes and the results are shared with the workers, they will increase their knowledge. Workers' previous experience can also affect worker knowledge. According to the company safety database, worker experience and incidents are negatively correlated. Therefore, during the hiring process, it is important to identify workers with more experience. Furthermore, according to the company safety database, the quantity of pre-task meetings is negatively correlated with the quantity of incidents because it increases worker hazard perception (Construction Industry Institute, 2002). In this model, the root cause Safety Communication represents the pre-task meeting.

Figure 4: Worker knowledge influence on the site unsafe level

The improvement of workers' knowledge facilitates worker perception of hazards (Jiang et al., 2015). However, worker perception can be affected by the root cause Hazard Identification and Control. This
root cause represents worker physical conditions such as work shift, worker’s age, health condition and other personal characteristics that can prevent the worker from recognizing a hazard.

**Worker Intention (B2):** Figure 5 shows the influence of the worker intention on the site unsafe condition. Because of the particularity of the worker intention, it was divided in two sub-loops: Fatigue (B2.1) and Safety Climate (B2.2).

**Figure 5: Worker intention influence on the site unsafe level**

**Fatigue (B2.1):** The schedule performance can make the company increase the workers’ shifts. According to Alvanchi et al. (2012), prolonged working hours can produce fatigue due to decrease in the muscular strength and mental stress. Fatigue can make the worker take shortcuts, not follow the safety recommendations, and consequently, decrease the worker’s intention to work safely (Jiang et al., 2015). Moreover, mental stress can cause distraction and decrease the worker’s capacity for hazard recognition (Hinze, 1997).

**Safety Climate (B2.2):** In this sub-loop, accidents increase the safety pressure and consequently increase management’s commitment to safety. However, Mitropoulos et al. (2005) stated that the schedule pressure may prevent management from providing and maintaining required safety measures, decreasing efforts to control the worker behavior. Moreover, management commitment is affected by the Leadership and Administration. According to the company HSE manual, the Leadership and Administration considers factors such as lack of discipline, lack of enforcement, lack of safety resources and lack of safety planning. The Management Commitment consequently affects the safety climate (Chinda & Mohamed, 2008). Although not specified as a root cause, safety climate is also affected by the Foreman Behavior (Choudhry and Fang, 2008). The root cause Sub-Contractor Management also affects Safety Climate.

The worker perception of safety (Han et al. 2014) is influenced by the safety climate and inspection and audits. One example of inspection is the Behavior-Based Observation (BBO) Card. The BBO improves worker safe behavior because the worker feels that he/she is being watched by the safety personnel (Vaughen et al., 2010).

Figure 6 shows the complete conceptual model.
6 MODEL EXPERIMENTS AND DISCUSSION

A hypothetical simulation model was built and four scenarios were tested to evaluate the influence of each root cause on the site unsafe level. In the first three scenarios, three different root causes were tested individually: 1) Environment, 2) Orientation and Training, and 3) Inspection and Audits. To better understand the influence of the root cause in each scenario, its value was set to 0 (worst condition), 0.5 and 1 (best condition). The other root causes had their values set at 0.5. The last graph compares the site unsafe level when all root causes are equal to 0 and 1. The time defined to visualize the root causes' influence on the site unsafe level is 90 days. Figure 7 shows the site unsafe level obtained in each scenario.

Figure 7: Effect of different root causes on the site unsafe level
It is possible to verify that the root causes defined by the construction company can affect the site unsafe level. The root causes defined in the model are inversely proportional with the site unsafe level. Moreover, it is possible to verify that after day 40, the site unsafe level is almost constant. This behavior is due to the schedule pressure, since the work hour overload and the crew size can compensate for the delay caused by incidents and rework. The similarity between the results of the three first graphs demonstrates that different root causes should be improved concurrently to decrease the site unsafe level (graph 4).

To improve the root causes, it is necessary to measure them. Furthermore, Table 2 suggests types of data to measure each root cause.

<table>
<thead>
<tr>
<th>N</th>
<th>Root cause</th>
<th>Suggested types of data to measure the root causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hazard Identification and Control</td>
<td>Work shift; worker’s experience on the project; worker’s age</td>
</tr>
<tr>
<td>2</td>
<td>Human Resource / Professional Development (HR/PD)</td>
<td>Average of workers’ experience on project; worker’s previous ability</td>
</tr>
<tr>
<td>3</td>
<td>Standard Operating Procedures Practices</td>
<td>Activity risk level</td>
</tr>
<tr>
<td>4</td>
<td>Leadership and Administration</td>
<td>Management site inspection; participation in safety meetings</td>
</tr>
<tr>
<td>5</td>
<td>Inspection and Audits</td>
<td>Quantity of BBO filled per month; quantity of workers per foreman</td>
</tr>
<tr>
<td>6</td>
<td>Orientation and Training</td>
<td>Worker training hours; evaluate of workers’ learning of the course content</td>
</tr>
<tr>
<td>7</td>
<td>Site Specific Safety Plan</td>
<td>Equipment and tool maintenance per month; safety program level of maturity</td>
</tr>
<tr>
<td>8</td>
<td>Communication Systems</td>
<td>Quantity of pre-job inspections completed per month</td>
</tr>
<tr>
<td>9</td>
<td>Security/Emergency Response</td>
<td>Escape route facilities (clear, indicated and shorter path)</td>
</tr>
<tr>
<td>10</td>
<td>Engineering</td>
<td>Engineering quality by discipline</td>
</tr>
<tr>
<td>11</td>
<td>Procurement</td>
<td>Procurement quality by discipline</td>
</tr>
<tr>
<td>12</td>
<td>Sub / Trade - Contractor Management</td>
<td>Evaluate observation of safety practices in the project</td>
</tr>
<tr>
<td>13</td>
<td>Environment</td>
<td>Temperature; wind speed; noise</td>
</tr>
<tr>
<td></td>
<td>Foreman</td>
<td>Foreman skill level; foreman age; safety supervisor experience</td>
</tr>
</tbody>
</table>

Besides the data types presented in Table 2, the company can also collect information about other factors used in the model, such as congestion (worker ramp up and ramp down), schedule pressure (delays), rework (project quality) and safety pressure (total recordable incident rate – TRIR).

The incident investigation can be improved to collect the data type suggested. Moreover, as some of the company’s incident investigations were not fully completed, the model could reinforce the importance of collecting all data requested by the investigation. In this case, the investigation will not be utilized just to describe an incident, but also to measure and control the incident root causes. The definition of the root cause can also help to better identify the incident causes, especially for those investigators who have to conduct the investigation.

The conceptual model was developed to identify the relationships between the root causes, but it is not recommended to be used to predict the site safety level. For this purpose, other simulation techniques, such as hybrid models combining discrete event simulation with system dynamics, or agent-based models, can achieve better results. According to Sawhney et al. (2003), an agent-based model “can be used to mimic the construction environment in which the worker [is] performing [his/her] work, along with
heterogeneous set of agents representing these workers to study various aspects of safety." Furthermore, 
root causes such as Environment, Procurement and Engineering can change values during the simulation 
and improvements are necessary to better predict the site unsafe level. However, the relationship 
between the root causes identified in this research can be used on other simulation models to improve 
the results.

Based on the model and the data type suggested to measure the incident root causes, construction 
companies can adopt strategies to improve the site safety level, such as improve the selection of 
engineering, suppliers, and sub-contractors in aspects related to safety; implement inspection procedures 
such as the BBO card and measure the supervisor’s commitment to safety.

7 CONCLUSION

The accident conceptual model developed in this research was able to demonstrate the relationship 
between the incident root causes defined by the construction company and the site unsafe level. It is also 
possible to conclude that not only are safety procedures, safety personnel, and field workers responsible 
to improve safety performance, but other company departments are as well. In this way, it was possible to 
conclude that, root causes such as project design, procurement, and HR/PD can affect the site unsafe 
level. Moreover, all departments that can cause project delays or influence the quality can influence the 
site unsafe level.

The company can improve the incident investigation procedures based on the conceptual model. Factors 
to measure each root cause were suggested and it is recommended to collect them during the incident 
investigation. Although this conceptual model cannot be used to predict the safety level, it is believed that 
the relationship defined in this research can be used in the future to develop a simulation model to 
measure and forecast how different safety strategies can affect the incident root cause and consequently 
the site unsafe level.

Ongoing research on the company safety database has been developed to validate the relationship 
between the root causes. Further steps are to define to which degree the different root causes affect the 
site unsafe level and validate the data type to measure the root causes with the safety managers.

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Leadership.


