Developing safety archetypes of construction industry at project level using system dynamics

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A B S T R A C T

Introduction: Safe behavior and work conditions are a major concern in construction projects. However, accidents occur due to system failures, not a single factor such as unsafe behavior or condition. Construction safety should be investigated by a systematic view capable of illustrating the complex nature of accidents. Method: The present research aims to detect and categorize behavior patterns recurring in construction safety management continuously. Content analysis and ground theory method (GTM) were adopted to achieve the study objectives. In total, 90 articles were reviewed to explore the factors influencing safety in construction projects all over the world. Furthermore, 20 interviews were conducted on participants with rich experience in construction health and safety. Four archetypes were identified from data collection process, including delay in design, number of subcontractors, cost and safety of project, and supervisors and safety. Each archetype is completely discussed at different steps of dynamic complexity, behavior over time, and the leverage point to show how to deal with the archetype.

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1. Introduction

Workplace accidents incur various losses to the injured workers, their families, employers, and society (Feng & Wu, 2015; Feng, Zhang, & Wu, 2015). The construction industry accounts for 29% of the total number of industrial workers, but is responsible for 40% of workplace accidents (Chua & Goh, 2004). Therefore, academic literature has emphasized the central role of occupational health and safety (OHS) management as a key long-range strategy, improving health at work and reducing the different costs of work accidents (Abad, Lafuente, & Vilajosana, 2013). However, despite the considerable efforts devoted to the reduction of accident rates, the construction industry accounts for a disproportionate injury rate when compared to the all-industry average (Ardeshir & Mohajeri, 2018; Cheng, Kelly, & Ryan, 2013; Shin, Lee, Park, Moon, & Han, 2014). Furthermore, delivery in a construction project should not emphasize merely time, cost, and quality as performance criteria, but clients must broaden their concern to advocate for site safety (Plebanskiwicz, 2010). Safety performance in a project is just as much a measure of the success of that project as are measures of time, quality, and cost (Hasan & Jha, 2013). The management of occupational safety and health in construction involves unique challenges and complexities such as dynamic work environments, the use of heavy equipment, and worker-hazard interactions (Hallowell & Gambatase, 2009). These complexities are unavoidable because of the causal interactions between its different elements including technical, human, and organizational factors (Bouloiz, Garbolino, Tkouat, & Guarnieri, 2013).

Many researchers have studied safety management systems using analytical methods dependent on statistics and empirical analysis (e.g., Nielsen, 2014; Oedewald & Gotcheva, 2015). However, the mechanism for how any factor affects individual behaviors still remains unclear (Asilian-Mahabadi et al., 2017, Khosravi et al., 2014). The more clearly the cause–effect chains of accident processes can be recorded, the more specific the measures, solutions, and interventions can be (Swuste, Frijters, & Guldenmund, 2012). Therefore, it is necessary to carry out a systematic view with the capacity of unraveling the complexity of the construction accidents.

2. Safety and systems thinking

Systems thinking is a set of synergistic and analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects (Arnold & Wade, 2015). Systems thinking is widely considered as an effective approach to understand and manage the complexity of systems such as construction safety (Guo, Yiu, & González, 2015).

Swiss cheese model (SCM) developed by Reason (1997) and the model of migration and the sociotechnical system view (STS) developed by Rasmussen (1997) are some of the accident models using systems...
thinking. One of the conclusions of these systems is that the accidents can be caused by system failures, not by a single causal factor such as unsafe behavior. As a result, studies have been designed for taking a system view of accidents in such systems (e.g., Bouloiz et al., 2013; Goh, Brown, & Spickett, 2010; Kontogiannis, 2012; Shin et al., 2014).

Senge, (2000) defines system dynamics (SD) as “a modeling method that mainly focuses on feedback structure and the resultant behavior to understand a complex system in a holistic manner.” SD has two interesting aspects: systemic study of the concept of feedback and dynamic study of system behavior, indicating how the structure of a feedback system and the loops that it contains are responsible for its dynamic behavior (Bouloiz et al., 2013). Archetypes and SD can help safety analysts clarify why undesired side effects arising from apparently good decisions, why organizations become complacent, and how independent decisions in different parts of the organization can combine to affect safety (Kontogiannis, 2012; Marais, Saleh, & Leveson, 2006). Systems archetypes aim to highlight the underlying structure of complex situations in a relatively simple fashion so as to facilitate identification of leverage in these situations (Goh et al., 2010). In this line of work, Senge (1990) proposed eight system archetypes that would occur on systems. Furthermore, other researchers such as Marais et al. (2006), Kontogiannis (2012), and Guo et al. (2015) employed system safety archetypes to shed a light on the interaction between factors affecting safety in the construction projects. In summary, SD provides a powerful perspective to understand the complexity and dynamics of safety management (Underwood & Waterson, 2013).

Therefore, to explore patterns of relationships between the elements of safety management systems, the objectives of this study are to: (a) explore the behavior patterns (archetypes) of construction safety occurring at project level, and (b) suggest solutions on how to manage the undesired effect of these archetypes. The rest of the paper is structured as follows. Section 3 presents the methodology of this study. The results are presented in Section 4. Discussion and limitations are argued in Section 5. Finally, Section 6 includes the conclusions of this study.

3. Methodology

The use of system archetypes is one of the cornerstones of qualitative system dynamics (QSD; Wolstenholme, 1999). The QSD focuses on system description, problem identification, and qualitative analysis (Boylan, Syntetos, & Sanders, 2008). There are two main steps for developing a QSD model, problem articulation, and formulation. The problem articulation involves theme identification, problem definition, and identification of key variables. Formulation includes exploring causal loop diagrams (CLD) and system archetypes (Senge, 2000).

The study flowchart is shown in Fig. 1. To obtain the study objectives, the first step aimed to identify the common themes or problems in the construction industry occurring at the project level. Next, the key variables related to each theme or problem are identified (Step 1 in Fig. 1: Open Coding).

The purpose of the second step was to generalize from the specific variables to the patterns of behaviors by considering the causal relationships between them. Delays, balancing, and reinforcing loops are the main components of CLD. A reinforcing loop occurs when an increase (decrease) in a variable will lead to a tendency for the variable to be increased (decreased) due to the feedback through other variables in the loop. On the other hand, in a balancing loop, when a variable increases (decreases), there will be a tendency for the same variable to decrease (increase) due to the feedback through other variables in the loop. In addition, delays represent the time that elapses between cause and effect (Senge, 2000). In this step, the trend of each variable was also collected and enough interviews were conducted to ensure data saturation according to the grounded theory method (Step 2 in Fig. 1: Selective Coding). Afterwards, based on existing system archetypes developed by Senge (1990), the identified feedback loops were analyzed to see if they fit and work within a safety archetype under the theme. The purpose of this step was to integrate the feedback loops into an archetype that can describe the complex behaviors within the identified theme (Step 3 in Fig. 1: Theoretical Coding). Data collection processes of these three steps are illustrated in the next section.

![Flowchart of the study](https://example.com/flowchart.png)
3.1. Data collection

In this paper, the grounded theory method developed by Glaser and Strauss (1967) and the content analysis was used for collecting and analyzing data, as well as developing the archetypes. Content analysis is defined as a systematic, replicable technique for compressing many words of a text into fewer content categories based on explicit rules of coding (Stemler, 2001). The grounded theory included a set of techniques to identify themes or concepts across texts. However, one of the main objectives of grounded theory resides in linking these concepts to generate meaningful theories (Luna-Reyes & Andersen, 2003). The grounded theory could be applied using two approaches, namely systematic procedure and constructive approach. In the systematic procedure used in this paper, the researcher conducts enough interviews to ensure data saturation. Also, the researcher collects data in a zigzag process and analyzes documents and data. The participants interviewed were theoretically chosen (called theoretical sampling) to help the researcher best form the theory (Creswell, 2007). In total, 20 interviews were conducted with participants, including 3 government safety inspectors, 5 health and safety researcher, 3 health and safety consultants, 3 safety officers, and 6 health and safety managers from construction companies. The participants have rich experience in the field of construction health and safety (experience history of 8 to 20 years, a mean experience of 13 years). The duration of each interview was between 60 and 100 min (mean interview length of 80 min). The interviews were conducted face-to-face at workplaces. According to Creswell (2007), the number of interviews is appropriate for grounded theory studies. All of the interviews were recorded and then written down carefully.

Furthermore, studies investigating safety domain in the construction industry were reviewed for collecting data of the literature. The titles, abstracts, and keywords were searched using a manual search in the databases of studies published between January 2000 and January 2016. These databases included American Society of Civil Engineers library (http://ascelibrary.org/), Scopus database (http://www.sciencedirect.com), and Taylor & Francis Online (http://www.tandfonline.com/). To identify relevant previous studies, the search keywords were selected to be (“safety” OR “safety performance”) AND (construction). Next, the titles and abstracts of the articles were reviewed and those identified as relevant to the study were selected to be retrieved and reviewed in full text. The articles were selected on the basis of the following inclusion criteria: (a) the study on the factors influencing safety on construction projects, (b) the study published between January 2000 and January 2016, (c) the study available online, (d) the study published in a refereed journal, and (e) the study in English. In total, 90 studies were reviewed to determine variables that influence safety on construction projects.

3.2. Data analysis

Data analysis included three steps: Open coding, selective coding, and theoretical coding

To find the main categories of information about safety problems or themes, the data collected from literature review and interviews were examined and encoded. The selective coding was started after the identification of safety problems or themes. The aim of this step was to identify behavior patterns of each safety problem/theme and to explore the factors involved in each problem/theme. Causal effects including reinforcing and balancing feedback loops were identified during this step using interviews and literature review. Then, the feedback loops were mapped using SD VENSIM modeling software. At the final step of data analysis, the feedback loops were examined to determine how they fit in presented archetypes developed by Senge (1990). This step explained how the problem is emerged using the dynamics of each archetype. Finally, the identified archetypes were mapped using VENSIM.

4. Results and discussion

Four archetypes are developed to address the identified safety problems or themes that emerged during the data collection process including: (a) delay in design, (b) number of subcontractors, (c) project cost and safety, and (d) supervisors and safety. Each archetype is completely discussed at different steps of dynamic complexity, behavior over time, and the leverage point to show how to deal with the archetype. It should be noted that the sources of the data of figures in the behavior over time sections are based on the collected trend of variables from interviews. These figures are not specific for a project, because archetypes feature storyline with a distinctive theme and are useful for gaining insight into the “nature” of the underlying problem and for offering a basic structure or foundation upon which a model can be further developed and constructed (Braun, 2002; Kim & Anderson, 1998). The archetypes are rarely sufficient models in and of themselves (Braun, 2002). Each archetype is presented and analyzed as follows:

4.1. Delay in design

As shown in Fig. 2, the archetype of delay in design is a combination of two balancing loops (B1Delay, B2Completing design), and two reinforcing loops (R1Rework, R2Accident). The archetype of “delay in design” can be considered as a special case of “fixes that fail,” described by Senge (1990).

4.1.1. Dynamic theory

Various authors underline the fact that many construction accidents are caused by deficiencies in the project design phase (Rubio-Romero et al., 2013); and various investigations have concluded that the primary causes of failure were design and construction errors within the building processes (Terwel & Jansen, 2014). Designers play an important role as the project evolves from conception to final design because many construction hazards are avoidable with proper design control (Hallowell, Hinze, Baud, & Wehle, 2013). In practice, many design and construction organizations pay limited attention to errors and the resulting rework or failures that may occur (Love, Edwards, Irani, & Walker, 2009; Love, Lopez, Edwards, & Goh, 2012).

As shown in B1Delay, the pressure on designer increases as the project faces delay, especially in EPC (Engineering, Procurement, Construction) projects. The design pressure will increase the completeness of the design, and as a result, the design pressure and delay caused by design is reduced, as it is described in B2Completing design and B1Delay. However, the design pressure has side effects that appear in a long-term period (e.g., design errors). Han, Love, and Peña-Mora (2013) concluded that the design errors can significantly delay project schedule in spite of continuous schedule recovery actions taken by construction managers. Additionally, phenomenological approach of Love et al. (2012) proves that the uncertainty and inevitability of error are not perceptions, but are a reality for design consultants, resulting from the exogenous factors influencing their ability to perform tasks effectively. These factors include schedule pressure, design fees, client procurement strategy, and skilled labor supply. Also, schedule pressure can propagate the negative impact of design errors to numerous construction activities (Han et al., 2013). Errors are often not identified immediately but tend to transpire after a period of incubation in the system (Busby & Hughes, 2004).

As shown in R1Rework, a contributor to the rework is design errors. When an error is identified, it often requires rework to be undertaken, which involves additional time and resource expenditure (Han et al., 2013; Han, Lee, & Peña-Mora, 2011). It has been found that 5–20% of the contract value can be attributed to rework in construction and engineering projects (Love & Edwards, 2004). In construction, rework results from quality deviations caused by changes, errors, and omissions during design and construction (Sommerville, 2007). Furthermore, rework has been identified as an endemic problem in construction and engineering projects, and a major contributor to schedule delays and...
cost overruns. Rework, on average, contributes to 52% of total cost overrun, and can increase schedule overrun by 22% (Love & Edwards, 2004).

Furthermore, the design errors increase the exposure to hazards, which is one of the causes of the accidents (R2Accident). Regarding this issue, researchers found that 42% of the construction fatalities and 22% of the injuries are linked to decisions made during design (Hallowell et al., 2013).

4.1.2. Behavior over time

Fig. 3 depicts how delay rate, design completeness, and design pressure changes over time. Delay rate shows the amount of the delay changes in a particular period. Initially, design completeness and design pressure experience increase until the design completeness reaches 100% (fully completed). After completion of the design, the design pressure has a sharp decrease. In initial stages, the balancing loop, B1Delay, is successfully reducing the delay rate. However, as the negative effects of reinforcing loops (R1Rework, R2Accident) manifest themselves, the delay rate increases and the problem (schedule delay) reappears again. (See Fig. 4.)

4.1.3. Leverage points

The leverage point of this archetype lies in the reinforcing loops (R1Rework, R2Accident). As Busby (2001) pointed out, designers omit to involve others in design decisions, inform others of assumptions made, elicit other’s needs and schedules, or understand the history of problem-solving in a replicated design. Therefore, minimizing the effects of reinforcing loops require designers to challenge their designs and involve others in design decisions. Moreover, checking the designs by construction managers, with proper construction and design knowledge, is very useful to increase the constructability of the designs.

4.2. Number of subcontractors

The archetype of number of subcontractors consists of a reinforcing loop (RSubcontractors’ Coordination) and one balancing loop (BSafety Control). Feedback loops R and B can be considered as a special case of “fixes that fail” developed by Senge (1990).

4.2.1. Dynamic theory

Subcontractors are a critical part of the modern construction process (Lingard & Rowlinson, 2005). There is a considerable evidence linking
Subcontracting to hazardous work practices in the construction industry (Mayhew & Quinlan, 1997). In safety critical industries many activities are currently carried out by subcontractor (Oedewald & Gotcheva, 2015), and many of the problems concerning site safety on construction sites are attributable to subcontractor performance (Lingard & Rowlinson, 2005). In fact, the subcontracting has been noted by several authors as one of the causes of accidents in Spain (Guadalupe, 2003). Furthermore, the involvement of more subcontractors in the project tends to increase the levels and complexity of management (Feng et al., 2015). In such circumstances, cooperation and coordination between all parties is crucial for improving health and safety, and integrated teams are an effective way of achieving this (Rowlinson, 2004). Moreover, Cheng, Leu, Lin, and Fan (2010) pointed out that the number of subcontractors is one of the factors influencing occupational accident developments for small construction enterprises. By means of illustration, López-Alonso et al. (2013) concluded that the average number of accidents is directly related to the average number of subcontractors, total number of workers, and the health and safety budget.

As shown in $B_{\text{Safety Control}}$, when the number of accidents rises in a project, top managers tends to increase the safety control pressure; as a consequence, the accident rate will be reduced in the short-term period. However, as Lingard and Rowlinson (2005) pointed out, no safety improvement scheme can be successful unless it includes subcontractors (Lingard & Rowlinson, 2005). Increasing work pressure on safety supervisors has long-term consequences, which is described in $R_{\text{Subcontractors' Coordination}}$.

When subcontractors are increasingly involved in safety critical industries, it is critical that they have proper knowledge and understanding of what is safe and what is not, and what are the safety consequences (Oedewald & Gotcheva, 2015). According to Rowlinson (2004), one of the main roles of the contractor in making projects safer is to manage health and safety on site by coordinating activities (Rowlinson, 2004). All contractors and subcontractors are required to cooperate in order to assure that a safe operation occurs (Reese & Eidson, 2006). Safety risks experienced by one subcontractor may also be caused by the activities of another subcontractor, and coordination is essential, with special attention being paid to manage the interfaces between different work crews and activities (Lingard & Rowlinson, 2005).

However, by increasing the pressure work of supervisors, the supervisor effectiveness will be lowered, and the coordination between subcontractors reduces in the long run.

### 4.2.2. Behavior over time

The typical behavior of the archetype of number of subcontractors is shown in Fig. 5. In initial stages, the balancing loop ($B_{\text{Safety Control}}$) reduces the accident rate. However, the positive effects of safety control are then undermined by decreased coordination between subcontractors. As a result, accident rate begins to incline due to the effect of $R_{\text{Subcontractors' Coordination}}$ loop. (See Fig. 6.)

![Figure 4. Number of subcontractors.](image)

### 4.2.3. Leverage points

For the archetype of “number of subcontractors,” leverage lies in creating balancing loops that minimize the side effects that are produces by $R_{\text{Subcontractors' Coordination}}$ loop. It is critical for project managers to be conscious that an accident has many causes. The project managers should be aware that increasing work pressure of supervisors is just a temporary solution for the problem, and it has side effects in the long-term period. Thus, focus of planning to reduce accidents should be top priority, instead of working on practices that just eliminate the signs of the problem. Conducting proper accident investigations to identify root causes of the accident is the appropriate way to deal with an increasing accident rate.

### 4.3. Project cost and safety

The archetype of project cost and safety consists of two reinforcing loops ($R_1$Cost of accidents, $R_2$Lost time) and two balancing loops ($B_1$Cutting safety budget, $B_2$Corrective actions). This archetype can be considered as a special case of “shifting the burden” developed by Senge (1990).
Investment of 46.08%, while, on the contrary, lack of safety has an adverse impact on the economic performance of a construction project (Zou & Sunindijo, 2015). Besides, such a symptomatic solution carries long-term side effects. In general, the safety efforts are reduced as safety budgets are cut; hence, the higher risk of exposure to occupational damages and injuries in the long-term will eventually prove more costly than the preliminary cost-determinations (Guo et al., 2015). This case especially happens in competitive contracts. Zou and Sunindijo (2015) discussed that most construction contracts are awarded through competitive tenders, with the lowest bidder taking the contract. This system has been identified as the cause of a vicious circle of cost cutting, and the first item that suffers in the competitive bidding system is often the safety budget (Zou & Sunindijo, 2015). The negative effects of cutting safety budget are shown in R1 \( \text{Cost of accident} \) and R2 \( \text{Lost time} \). The reinforcing loops imply that decreasing the safety effort will finally increase the project cost through incrementing cost of the accidents and project time.

### 4.3.1. Dynamic theory

Safety performance in a project is just as much a measure of the success of that project as are measures of time, quality, and cost (Hasan & Jha, 2013). According to Sgourou, Katsakiori, Goutsos, and Manatakis (2010), there are two types of evaluation for measuring safety performance, namely, retrospective (lagging), and prospective (leading) indicators. The retrospective approach is through measurement and statistical analysis of incident-related data (i.e., number of injuries). The prospective or leading safety performance evaluation methods provide the information lacking from incident-based measurement and keeps up-to-date with current organizational and safety management trends. Delivery in a construction project does not emphasize merely time, cost, and quality as performance criteria, but clients should also broaden their concern to advocate site safety with regard to the importance of human being (Jitwasinkul & Hadikusumo, 2011). On the other hand, inadequate safety measures go beyond health concerns, since the costs of construction injuries can have a substantial impact on the financial success of construction organizations and increase the overall costs of construction up to 15% (Hallowell, 2011). The accident costs to contractors are the sum of direct and indirect accident costs (Feng, 2015; Feng et al., 2015); and the severity of the construction injury affects the components of the direct and indirect cost of the accidents. Moreover, Zou and Sunindijo (2015) stated that the project budget must include necessary proportions on safety investments, such as personal protective equipment, safety training, and other safety measures to support the implementation of safety management.

Over the past decade, many projects have experienced large variations in cost and schedule, which contribute to their failure (Chen, Hsu, Luo, & Skibniewski, 2012; Liu, Low, & Hec, 2011). The real solution to handle cost overruns in the projects is using cost analysis techniques to identify the root causes of the problems, as it is described in B2 \( \text{Corrective actions} \). The corrective actions may include value engineering, rescheduling the project, changing the project team, and so forth.

As shown in B1 \( \text{Cutting safety budget} \), the project cost is reduced by cutting the safety budget. As a result, the project cost will be decreased in the short-term. However, budgeting has a direct influence on the safety performance. Higher level of safety investment has yielded a return on investment of 46.08%, while, on the contrary, lack of safety has an adverse impact on the economic performance of a construction project (Zou & Sunindijo, 2015). Besides, such a symptomatic solution carries long-term side effects. In general, the safety efforts are reduced as safety budgets are cut; hence, the higher risk of exposure to occupational damages and injuries in the long-term will eventually prove more costly than the preliminary cost-determinations (Guo et al., 2015). This case especially happens in competitive contracts. Zou and Sunindijo (2015) discussed that most construction contracts are awarded through competitive tenders, with the lowest bidder taking the contract. This system has been identified as the cause of a vicious circle of cost cutting, and the first item that suffers in the competitive bidding system is often the safety budget (Zou & Sunindijo, 2015). The negative effects of cutting safety budget are shown in R1 \( \text{Cost of accident} \) and R2 \( \text{Lost time} \). The reinforcing loops imply that decreasing the safety effort will finally increase the project cost through incrementing cost of the accidents and project time.

### 4.3.2. Behavior over time

Fig. 7 shows a typical behavior of the archetype of "project cost and safety." At initial stages, the project cost is gradually increased and at the 50th month has logarithmic behavior, even though the safety budget is reduced to zero.

Fig. 8 depicts the accident rate, lost time, and safety effort. By cutting the safety budget, the safety effort is gradually reducing, and the lost time and accident rate are inclined during this process.

### 4.3.3. Leverage points

The leverage point of this archetype lies in using proper cost analysis techniques, and considering safety budget as part of the project budget. When project management personnel include safety in the project schedule and budget, as well as incorporating safety requirements in contract agreements or as part of tender requirements, the other stakeholders will realize that safety is being regarded as important in the project, thus positive attitudes and perceptions towards safety will be developed (Zou & Sunindijo, 2015).

### 4.4. Supervisors and safety

Construction supervisors are crucial to eventual site safety performance (Hardison, Behm, Hallowell, & Fonooni, 2014). The archetype
of supervisors and safety is shown in Fig. 9. This archetype consists of two balancing loops (B1 Safety control, B2 Accident investigation), and one reinforcing loop (R Side effects of increasing supervisors’ work pressure). This archetype can be considered as a special case of “shifting the burden,” developed by Senge (1990).

4.4.1. Dynamic theory

Supervisors are the employees of the contractor and may include general forepersons, job superintendents, and forepersons (Reese & Eidson, 2006). The supervisors play a key role in providing a safe and healthy work environment (Lingard & Rowlinson, 2005). Research during the London 2012 Olympics construction projects revealed that the supervisor competence enhanced effective site safety practices and is a key to broad construction industry impact (Finneran, Hartley, Gibb, Cheyne, & Bust, 2012). However, the supervisors have the least authority but are responsible for guaranteeing the implementation of almost all safety-related policies, standards, and regulations (Fang, Wu, & Wu, 2015).

As shown in B1 Safety control, while the frequency of accident increases in a project, the safety control pressure will increase to prevent further accidents. This would happen since the supervisors play the most crucial role in accident prevention and are the directly responsible persons to guarantee good safety performance onsite (Fang et al., 2015). The accident rate in the project will be reduced by increasing the safety control.

However, the real solution for preventing accidents lies in the B2 Accident investigation loop. The investigations on the accident are conducted by a team of individuals consisting of employee representative(s), a safety representative, and the injured employee’s immediate supervisor (Wachter & Yorio, 2014). Supervisors should conduct an investigation of any accident/incident that results in death, injury, illness, or equipment damage (Reese & Eidson, 2006). The objective of any accident investigation should be finding and addressing root causes of the accidents. Although, since root cause analysis takes time to be effective in reducing accident rate, the project managers seek to apply practices that are effective in a shorter period.

However, this approach has some side effects described in R Side effects of increasing supervisors’ work pressure. Supervisors should be held accountable for production, safety, and health, but they must be provided with adequate resources to accomplish what is expected of them (Reese & Eidson, 2006). Work overload of managers and supervisors decreases their time on safety (Guo & Yiu, 2015). Increasing work pressure of the supervisors will reduce the effectiveness of the accident investigation, and root causes of the accident will not be identified. The work pressure refers to the degree in which employees feel under pressure to complete the work, and the time period to plan and carry out the work. There are numbers of methods to measure qualitative factors such as work pressure including questionnaires (using Likert scale), interview, and observation.

4.4.2. Behavior over time

Fig. 10 illustrates a typical behavior of the “supervisors and safety” archetype. Initially, the approach of increasing work pressure on the
supervisor’s works properly reduces accident rate. However, as project managers place their attention only on supervisors, the effectiveness of root cause analysis is decreased. Consequently, the root cause of accidents will be untouched and left without correction. Thus, any time in the project, the accident could happen without any warning. Since the approach of increasing work pressure on the supervisors worked before, project managers would insist on using it again. Hence, safety control pressure will incline during the project, but this symptomatic solution no longer works.

4.4.3. Leverage points

According to Senge (1990) on “shifting the burden” archetypes, solutions that address only the symptoms of a problem, not fundamental causes, tend to have short-term benefits at the best. Dealing effectively with shifting the burden structures requires a combination of strengthening the fundamental response and weakening the symptomatic response. Therefore, the side effects of the “supervisors and safety” archetype should be significantly minimized using proper accident investigation techniques. Moreover, the project managers should be aware that if a solution works for the short-term, it does not mean that it is the right solution or works for the long-term. The fundamental solution to reduce accident rate is conducting accident investigation, which has been noted by many researchers.

5. Overall discussion and limitations

5.1. Contribution to the construction industry

The current research is different from other studies that used SD to model construction safety issues (e.g., Jiang, Fang, & Zhang, 2014; Shin et al., 2014) because the previous papers focused on a specific area such as safe behavior, while this study identified safety problems that happen at projects repeatedly. The identified archetypes of this study are not specific for a project or company. Furthermore, these archetypes are pattern of behavior without any complicated mathematical formulation with the aim of focusing on interaction between factors that creates complexity in a system, rather than studying single factors.

Managing a construction project has many challenges due to the dynamic environments and the complex interaction between factors that influence safety. These challenges create uncertainty in the construction projects that need to be properly handled. Another problem in managing construction projects is that they are constantly changing. Therefore, a dynamic perspective that could integrate safety with other goals of the
project is necessary for project managers to have a better understanding of the problems that would happen on the construction sites.

Moreover, the safety management systems cannot plan for control and defend against all potential error-prone situations (Wachter & Yorio, 2014). Additionally, safety management systems tend to be institutionalized through policies and processes; thus, these are not easily and readily adaptable. For example, the safety management systems may not be flexible enough to deal with problems with project cost and safety (the archetype project cost and safety). Therefore, it is an inevitable fact that the project managers use safety management systems with a systematic perspective. The identified archetypes could be useful in developing effective safety management systems.

5.2. Limitations and future research

This study has several limitations. First, this study identified archetypes at the project level and did not make any effort to develop archetypes at other levels of safety management such as company and government. The second limitation concerns the generalization of the archetypes. The developed archetypes are extracted through interviews and literature review. Therefore, since the grounded theory method does not use probability sampling, it is impossible to generalize the findings. Third, the identified archetypes are based on the study by Senge (1990) that has some critics from other researchers. Hence, the archetypes should be used with caution. However, future research should be focused on developing other archetypes of the construction industry.

6. Conclusion

The grounded theory and content analysis are used to extract data and develop the archetypes in this work. Four archetypes of construction safety at the project level were developed using SD. The archetypes represent the side effects of the project managers and other stakeholders in the projects (i.e., subcontractors) decisions on the safety of the construction sites. Furthermore, they help to understand how putting pressure on supervisors and designers can affect safety on sites. Additionally, the identified archetypes occur at project level continuously and knowing how to deal with them would help project managers to make the best decisions for the project. They alert project managers to future unforeseen consequences of their decisions and encourage them to take a systemic view. In addition, archetypes can be used as a planning tool and could be useful in developing effective safety management systems.

Declaration of interest

The authors declare no conflict of interest.

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