Accident Analysis and Prevention 68 (2014) 106–116

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Toward an understanding of the impact of production pressure on safety performance in construction operations

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ARTICLE INFO

Article history:
Received 4 April 2013
Received in revised form 8 October 2013
Accepted 10 October 2013
Available online 19 October 2013

Keywords:
Safety
Systems thinking
Accident prevention
Simulation
Causal loop analysis

ABSTRACT

It is not unusual to observe that actual schedule and quality performances are different from planned performances (e.g., schedule delay and rework) during a construction project. Such differences often result in production pressure (e.g., being pressed to work faster). Previous studies demonstrated that such production pressure negatively affects safety performance. However, the process by which production pressure influences safety performance, and to what extent, has not been fully investigated. As a result, the impact of production pressure has not been incorporated much into safety management in practice. In an effort to address this issue, this paper examines how production pressure relates to safety performance over time by identifying their feedback processes. A conceptual causal loop diagram is created to identify the relationship between schedule and quality performances (e.g., schedule delays and rework) and the components related to a safety program (e.g., workers' perceptions of safety, safety training, safety supervision, and crew size). A case study is then experimentally undertaken to investigate this relationship with accident occurrence with the use of data collected from a construction site; the case study is used to build a System Dynamics (SD) model. The SD model, then, is validated through inequality statistics analysis. Sensitivity analysis and statistical screening techniques further permit an evaluation of the impact of the managerial components on accident occurrence. The results of the case study indicate that schedule delays and rework are the critical factors affecting accident occurrence for the monitored project.

1. Introduction

The development of new technologies has been led to rapid changes in our society and working environments, also resulting in increasing complexities and changes in the causes of accidents (Leveson, 2012). To reflect the complexity and coupling of system components into safety management, the concept of systems thinking—understanding the behavior of an entire system as a result of interactions among individual system components—has been applied to accident analysis and investigation (Goh et al., 2010, 2012; Leveson, 2011, 2012). In construction, safety is also an integral component of a construction project that cannot be isolated from other project elements (e.g., schedule, cost, and quality) (Hinze, 1997). As progress deviation increases, workers are encouraged by management to complete their work within the contract time. The resulting production pressure (e.g., being pressed to work faster) adversely affects safety performance (Hinze and Parker, 1978; Hinze, 1997; Goldenhar et al., 2003; Mitropoulos and Cupido, 2009). Rework that results from quality deviations is also a major contributor to production pressure (i.e., schedule pressure), which consequently degrades safety management (Rodrigues and Williams, 1998; Love et al., 1999; Park and Peña-Mora, 2003). A systems thinking approach explains that this variation can lead to accidents by mentally influencing operators (i.e., construction workers) (Leveson, 2012). In this respect, production pressure is an essential factor in understanding scheduling and quality

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http://dx.doi.org/10.1016/j.aap.2013.10.007

performances (Nepal et al., 2006) as well as in safety performance in construction operations. Under production pressure, the managerial priority may not be given to safety, and hence the goal conflicts with other project elements, such as schedule and quality, need to be understood to prevent accidents and to improve productivity.

To understand such relationships between production pressure and safety performance, research efforts have been made in construction during the last decade. For example, Nepal et al. (2006) investigated the impact of production pressure on productivity and rework through cause-and-effect analysis. Lee et al. (2005) proposed a framework for project planning and control in design and construction processes that allows assessing the effects of changes and rework on schedule and quality performances. The complex relationship between rework and schedule and cost performances was also studied to identify effective strategies for the prevention of rework (Love et al., 1995, 2002). As to safety, Mitropoulos et al. (2005) presented an accident causation model illustrating how at-risk situations are generated in a production system. Specifically, the impact of production pressure on safety has been studied. A review of the relevant literature reveals that perceived production pressure affects worker productivity and can result in a degradation of safety, which eventually has an impact upon both safety management and accident rates (Hinze, 1997; Rundmo et al., 1998; Brown et al., 2000; Mohamed, 2002; Seo, 2005; Mitropoulos et al., 2005). However, such findings and knowledge still have not been applied to actual practices during a construction project. To reflect the concept of systems thinking in practice, further research efforts—beyond such findings from the prior work—are required to address the following issues: (1) a lack of understanding regarding process mechanisms such as how production pressure affects safety (Mohamed, 2002; Mitropoulos et al., 2005), (2) a limited quantification of the effect of production pressure on safety, and (3) difficulties in identifying the critical factors that the managerial priority needs to be given to improve safety during construction operations (Shaw, 1994). Underwood and Waterson (2013) pointed out that this gap between research and practice is due to investigator bias, resource constraints, and the qualitative nature of a systems approach affecting its reliability.

In an effort to address these issues, this paper examines the interactive relationship between production pressure and safety performance over time, and explores a simulation approach to applying the findings (i.e., the identified interaction) for management practices. In particular, System Dynamics (SD) is applied in this paper to gain an in-depth understanding of the complexity and coupling of project elements (e.g., schedule delays, rework, and safety) from the perspective of systems thinking (Leveson, 2012). SD represents and analyzes feedback processes among components in dynamic and complex systems using causal mapping and simulation modeling, which helps investigate the behavior of entire systems (Sterman, 2001). SD can thus facilitate an understanding of how production pressure is related to safety performance, and can explain and identify their feedback processes. Further, with project data, the proposed simulation approach evaluates and quantifies the impact on safety performances of other managerial decisions triggered by low schedule and quality performances. It also tests and finds adequate safety management strategies as a project's progress changes.

The rest of this paper is organized as follows: first, we investigate the complexity of project management (i.e., interactions among scheduling, quality, and safety), and we propose a conceptual SD model illustrating their interactive relations. As a case study, the relationship of those variables with accident occurrence is then simulated with the use of data collected from a construction site. The resulting SD model is validated; and the results are analyzed and discussed to understand the dynamics of managerial components. In conclusion, the findings of this paper are summarized.

2. The impact of schedule and quality performances on safety

A successful construction project must meet performance and delivery requirements for time, cost, quality, and safety. Achieving these diverse goals usually creates the complexity and coupling of management elements in a project's execution. Especially for a large-scale project, a project team consists of various task forces, as illustrated in Fig. 1. In general, each task force (e.g., accounting, scheduling, and quality) is in charge of its own work, and these separated duties and responsibilities may lead to the task force's ignorance of their influence on others in practice; Leveson (2012) explained this phenomenon with the term 'interactive complexity' (i.e., interaction among system components). For example, the safety director we interviewed in the preliminary study indicated the difficulty in reflecting safety into scheduling, as a team member in charge of scheduling commonly pays little attention to the impact of the schedule on safety performances. To gain an understanding of the interactions among different goals, this paper thus focuses on production pressure resulting from scheduling and quality management, which can negatively affect safety.

Production pressure is closely related to scheduling. Hinze (1997) demonstrated that the schedule status of projects is correlated to the frequency of injuries; for instance, subcontractors who were ahead of schedule had a smaller number of injuries, while subcontractors who were behind schedule obviously had more injuries in their projects. This result implies that managerial actions for the recovery of schedule delays adversely influence workers as being under pressure to increase their production rates. When perceiving production pressure (e.g., excessive workload, required work pace, and time pressure), workers perceive increasing risk and barriers, leading to a higher chance that they will work with unsafe behavior (Seo, 2005). Statistically, the behavior measurement and recordable injury rates are significantly correlated (Krause, 1990). Also, about 80–90% of accidents are strongly related to the unsafe behavior of workers, which is affected by safety-related factors (e.g., management, safety programs, and environments) (Heinrich et al., 1980; Salminen and Tallberg, 1996; Helen and Rowlinson, 2005). Consequently, previous studies show that production pressure is a key linkage between scheduling and safety in construction operations.

On the other hand, quality management is also associated with safety. In construction, rework results from quality deviations caused by changes, errors, and omissions during design and construction (Sommerville, 2007, referring to Farrington, 1987). Rework, which means to work again, is a major contributor to schedule delays and cost overruns, which are negative factors in safety management (Rodrigues and Williams, 1998; Love et al., 1999; Park and Peña-Mora, 2003; Lee et al., 2005). Love and Edwards (2004) stated that rework—that often requires diverting resources (e.g., overtime work, new hires, pushing workers to work fast) for the recovery—undermines the effective supervision of other work and results in demoralization, fatigue, and absenteeism, all of which have a negative effect on project safety. Nguyen and Ogunlana (2005) also studied how rework causes schedule delays that require overtime to rectify; this results in a high rate of worker turnover. Safety is then affected by the turnover when the cumulative experience of on-site workers deteriorates. Mitropoulos and Cupido (2009) additionally showed that accident rates can be reduced through the prevention of errors during dangerous activities. These studies imply that rework is relevant to production pressure eventually affecting safety (e.g., safety supervision, schedule delays, frequent errors).