PRODUCTION CONTROL AND SAFETY MANAGEMENT AS PROJECT SAFETY DETERMINANTS

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ABSTRACT

This paper proposes that the likelihood of accidents on a construction project is determined by two primary factors: (1) the safety management system; and (2) the production control system. The safety management system includes all the policies, programs and efforts to control the hazards and the workers' safety-related behaviors. The production control system includes all the processes, decisions and criteria that produce the work assignments for the workers. An effective production control system produces high quality work assignments for the crews. An ineffective production control creates high-risk situations, such as unexpected conditions, high workload and production pressures, frustration, rushing, fatigue, and conflicts between production and safety. These situations increase the likelihood of violations, errors and accidents. The paper proposes a 2 x 2 matrix for classifying projects based on the production control system and the safety management system. The framework provides a more comprehensive understanding of the factors that drive construction safety. Traditional safety strategies focus on strengthening the safety system. The paper argues that safety can be improved significantly by improving the quality of the production system.

KEYWORDS

Production control; Task demands; Safety management; Project safety; Safety performance.

INTRODUCTION

Rasmussen (1994) identifies three paradigms in safety research: (1) the normative paradigm, (2) the human error paradigm, and (3) the cognitive engineering paradigm. **The normative paradigm** focuses on prescriptive theories concerning the way people ought to act with regards to hazards. Efforts to prevent occupational accidents focus on control of hazards and safe rules of conduct. Normative practices attempt to control workers' behaviors through normative instruction of the 'one best way,' selection and development of competent personnel, and motivation and punishment. Typical responses to errors and accidents are increased training and selection practices to eliminate 'error-prone' individuals, and have the rest try harder through 'zero defects' programs (Rasmussen 1994).Safety practices in construction are based on this paradigm.

The human error paradigm focuses on the deviations from the normative, "best way" of working—that is errors and biases. This paradigm views errors and violations as a human "malfunction." .Efforts to control behavior focus on removing

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causes of errors.This paradigm includes studies of errors (Rigby 1970; Rasmussen *et al. 19*81), management errors and resident pathogens (Reason 1990).

The cognitive engineering paradigm is concerned with how groups of individuals interact with the work system, as well as each other, in the organizational and production context.With regards to risk management, cognitive engineering is concerned with the characteristics of the work system (the features of the task, tools and work context) that influence the decisions, behaviors and the possibility of errors and failures (Rasmussen *et al. 19*94).From a cognitive perspective, an error is not simply a human failure but a symptom of a problem in the work system (Dekker 2006).Thus, to understand human error, cognitive engineering attempts to capture the systematic connections between human assessments and actions and features of people's tools, tasks and operating environment.The cognitive approach to safety attempts to prevent accidents by designing work systems that are adapted to people and avoid operators' overload and errors.

Taking a cognitive perspective of construction safety, we need to better understand how the production system factors affect the likelihood of accidents (Saurin *et al. 20*08; Mitropoulos *et al. 20*09).

Building on previous discussions of production control and safety, this paper develops a framework that examines how the production control system and the safety management system shape the safety outcomes of a project. Using examples from literature and recent field case studies, the paper identifies four different project situations depending on the levels of production control and safety efforts: (1) projects with ineffective production control and low safety effort, (2) projects with ineffective production control and high safety effort, (3) projects with effective production control and low safety effort, and (4) projects with effective production control and high safety effort. This simultaneous consideration of the production design/control system and the safety system contributes to a more integrated consideration of both safety and production, although these two project "functions" have different primary goals.

BACKGROUND

In construction, traditional safety strategies focus on the reduction of hazards through engineering, and the control of hazards through barriers and procedures. Because in construction many hazards cannot be controlled through barriers, construction safety emphasizes safety procedures (that is, safety rules that prescribe how workers must interact with the various hazards), and means to control the behavior of individuals and organizations and increase compliance with safety procedures. Safety efforts such as training, inspections, motivation, enforcement, etc., aim at increasing compliance with safety rules. Efforts towards safety culture and behavior-based safety also aim at increasing the workers' voluntary compliance with prescribed behaviors.

This approach does not account for the production system elements that shape the work situations and work behaviors. Rasmussen (1994) explains how the workers' behaviors tend to migrate closer to the 'boundary of loss of control' due to two primary pressures: the production pressures for increased efficiency, and the tendency for least effort, which is a response to increased workload.

Construction researchers have also emphasized the influence of production factors on safety.Hinze and Parker (1978) found that job pressures and crew competition are related to more injuries, and suggested that job practices are more important than safety policies in preventing accidents. Hinze (1979) found that crews with higher turnover also had higher accident rates. Suraji *et al.* (2001) argued that project conditions, design decisions or management decisions can cause responses that create inappropriate conditions or actions that lead to accidents. Scarf *et al.* (2001) argued that a very dynamic environment and a constant change is a key feature of hazardous work environments. Mitropoulos *et al.* (2009 2011) argued that construction work involves significant physical, mental, and temporal task demands. The combination of the various demands that influence performance and responses from a human operator is called “workload.” . Task demands significantly affect task performance. In general, when task demands exceed an individual’s capacity, the likelihood of errors increases and performance decreases (Wood 1986).

The above discussion briefly highlights the importance of production factors for safety.If production factors are so important for safety, then the organizational system that shapes these conditions is critical for safety. On project-based organizations, this system is the production control system. The paper discusses how the safety outcomes of a construction project are a function of two primary organizational systems: (1) the safety management system, and (2) the production control system.

PROJECT SYSTEMS CRITICAL FOR SAFETY

Safety Management System

The safety management system includes all the safety policies, programs and efforts that aim at controlling the hazards and the workers’ safety-related behaviors. This includes management efforts towards safety, safety policies, training programs, safety resources (in personnel and equipment), site audits, safety enforcement, efforts to increase safety-related workers’ motivation, safety culture, and all the efforts and programs that increase the likelihood of “safe behaviors.”

A strong safety system is expected to result in fewer unsafe conditions and behaviors that a weaker safety system (under similar organizational and project conditions), and to result in better safety performance. However, safety efforts do not control or influence the production goals and pressures of the construction operations, or the way the work is organized—they plan for and check for potential hazards, and the use of required controls. Factors related to production (production pressures, work organization, etc.) are considered outside of the scope of the safety management system.

Production Control System

Production control has been described as the link between the work plan and the work execution (Ballard 1997).The production control system includes all the processes, actions, decisions and criteria that produce the work assignments for the workers. In order to increase process speed and productivity, it is critical that the production control system produces high quality work assignments (Ballard and Howell 1998).The Last Planner System (LPS) of production control provides a set of principles for developing and releasing work assignment of high quality/reliability.

To develop work assignments of high quality, the work assignments must meet the following criteria:

- The scope of the work assignments is well defined and understood by the crew.
- The work method is clear and well understood.
- The production goals are realistic and there is high confidence that can be achieved with the available manpower. The work schedule must allow enough time for all tasks needed (primary and secondary, such as clean up, etc.)
- The crew members are trained in their activities and have the capacity required.
- All required resources are available.
- The work area is available and in good condition.
- The work assignment does not conflict with the work of other crews.

Finally, another important element of the work assignment is the complexity and demands of the task. Thus, tasks that involve more physical demands, greater complexity and are more dynamic, have higher likelihood of errors.

With regards to safety, the production control system is important because it generates the task demands on the workers. An ineffective production control system will generate work assignments with high task demands that do not meet the above criteria. Such assignments create work situations with more opportunities for errors and violations.

- Unexpected work situation, such as unexpected scope or work conditions may lead to not having all the required equipment, tools, and material. This can create trade-off situations—where the workers face a dilemma between safety and production. For example, if the appropriate equipment is not available, the workers will have to choose between spending the time to find the equipment or "make-do" using the means available.
- High workload and production pressures can lead to rushing, frustration and distractions, and increase the task difficulty, and the likelihood of violations and errors.
- Poor task allocation may result in crew members performing tasks that are not skilled enough to do correctly. Fatigue, distractions and interruptions can also reduce the workers' applied capabilities.
- Tasks with high physical, high complexity or high mental demands have high likelihood of errors or reduced performance.

These situations increase the likelihood of violations and errors behaviors.

PROJECT CLASSIFICATION FRAMEWORK

Based on the two major systems that influence safety—that is, the production control system (PCS) and the safety management system (SMS), projects can be classified into four general categories, as shown in Figure 1: (1) Projects with ineffective PCS and weak SMS. (2) Projects with ineffective PCS and strong SMS. (3) Projects with effective PCS and poor SMS. (4) Projects with effective PCS and strong SMS.

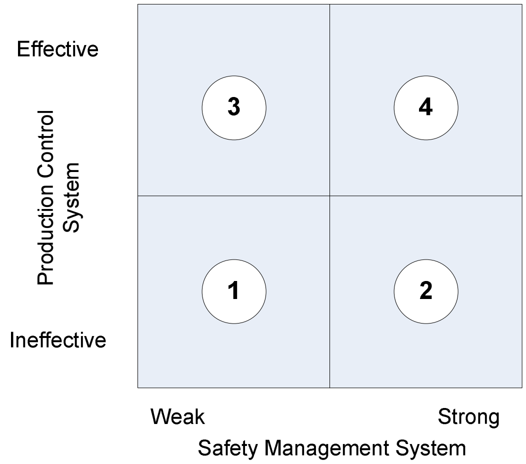

Figure 1: Project situations depending on the safety management system and the production control system.

Type 1: .Projects With Ineffective Production Control And Weak Safety Management

On such projects, the ineffective production control system generates many high risk situations. The crew may not be well prepared for the work (possibly another activity was disrupted and the workers were sent to another task), the work conditions or requirements may be different than what the crew expected, high production pressures create rushing and frustration, the required resources (for production or safety) may not be available, the manpower is not adequate for the schedule requirements, workers may be assigned work they are not well trained to do, etc. extensive rework creates work of high difficulty, etc. Overall, the production control system puts the workers in situations that they may not be prepared for, and creates may trade-offs between production and safety (work-safety conflict).It also increases interruptions, frustration, and rushing.

At the same time, a weak safety system provides inadequate training and controls, it may not identify or remove hazards, and may not provide the safety equipment required. Thus, the combination of ineffective production control and weak safety system is expected to result in more high-risk situations, and high levels of accidents, as illustrated in Figure 2.

Type 2: .Projects With Ineffective Production Control & .Strong Safety Management

These projects have strong safety system—the management emphasizes the importance of safety, provides training, there are regular safety audits, etc. However, the production management system is ineffective. As a result, many of the high-risk situations described previously are generated, such as operations with inadequate resources, inadequate manpower, or unanticipated conditions, out-of-sequence or conflicting operations, interruptions, and/or operations under high production pressures. The workers may be rushed, stressed or frustrated and face many situations where there is a trade-off between productively and safety. On these projects, the safety system can be overworked (and overwhelmed), fighting back the problems generated by the poor production control system. As violations, near misses and incidents start to occur, the typical management response is to increase the safety effort. This creates even more conflict between safety and production.

Based on the author's experience and discussions with safety professionals, it appears that these projects are common, even for companies who have strong commitment to safety. Many of these projects do not start this way—such situations can develop over time, often due to some early delays that accelerate the schedule, and create these pressures. Schedule pressures often lead to safety problems and safety-production conflict. It should be pointed out however, that it is not the schedule pressure per se that creates the problems, but the poor production control system that produces low quality assignments. Previous studies on exceptionally fast projects (Songer & Dikmann 2000) found that such projects can be completed with exceptional safety performance.

A solution to this situation would be to improve the quality of the production control system. The following study from Denmark illustrates the effect of production control on safety (Thomassen et a.2003). The study found that crews using Last Planner System had about 45% lower accident rate than crews in the same company performing similar work, who did not use the Last Planner system. Further use of Last Planner has confirmed these findings.

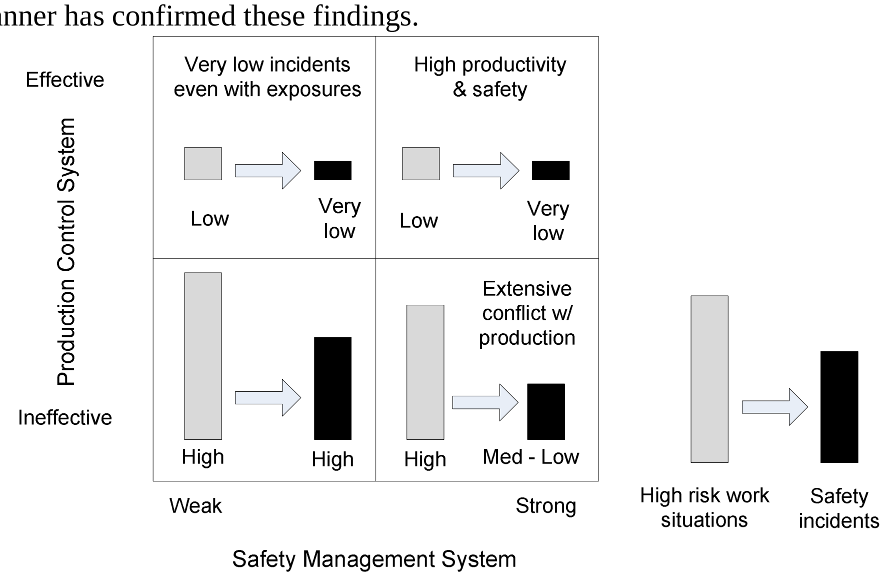

Figure 2: .Project situations and safety outcomes.

Type 3: .Projects with effective production control and weak safety management

This category includes projects where there is little emphasis on safety and minimal safety programs. As a result, workers are often exposed to hazards. On the other hand, these projects have an effective production control system that produces high quality work assignments. Work activities are well prepared, with all the resources to perform the work correctly—the appropriate material, tools, equipment and manpower. Production pressures are managed, to avoid rushing, fatigue, or the wrong person performing a dangerous task. The result is that although workers may be exposed to hazards, the production system effectively manages the task demands, and minimizes the likelihood of errors.

An example of this type of operation is found in a recent study of an exceptional residential framing crew (Mitropoulos and Cupido 2009).The study found that a very well managed production system resulted in exceptional productivity and safety, despite the extremely limited safety measures (absence of fall protection measures, no special safety training, no tool box talks, etc.) .This performance was due to a very effective production control system that focused on preventing errors. Some key elements of the production control were the following:

- Preparing all aspects of the operation before it starts (check material, tools, etc.).
- Shielding the crew from production pressures to avoid rushing.
- Identifying areas of high task complexity /difficulty to be performed by (or under the supervision of) the foreman.
- Assigning high-risk tasks only to the most experienced crew members.
- Performing additional checks before finalizing operations (e.g. erecting walls and trusses).

Another example of a project in this category is the construction of the dome of the Santa Maria del Fiore cathedral at Florence, by Filippo Brunelleschi. This was the first cathedral with unsupported octagonal dome. The dome construction lasted from 1420-1436 and required 37,000 tons of marble. During the 16 years of the dome construction, there was only one fatality involving a mason falling of the dome (Ross 2000).This was achieved despite the lack of serious safety measures in the 1400's, and the fact that the workers were having wine at lunch (it was believed that light intoxication helps workers work better at heights).Such low fatality count can be attributed to the design of the production processes, production equipment and the production system that the dome's architect Brunelleschi developed and implemented.

In summary, the effective production control system on these projects allows the crew to avoid situations of excessive task demands, production pressures, etc. This makes it possible to cope more effectively with the exposures to hazards that are not controlled by the weak safety system.

Type 4: .Effective Production Control & Strong Safety Management

The fourth category includes projects where the production control and strong safety management. Recent studies of exceptional foremen in masonry and concrete also show that their effective production systems focus on reliability and error prevention, in addition to their strong safety awareness and compliance. The key characteristic of these projects was that production and safety are achieved without friction, and without the excessive safety efforts that occur in category 2 projects.

CONCLUSIONS

Using the existing concepts of production control and safety, the paper proposed a new framework that described how the production control system and the safety management system shape the safety outcomes of a project. This framework creates a more integrated perspective of the interaction of the two systems. The framework accounts for the influences of both the production control system and the safety efforts, and provides a more comprehensive understanding of the factors that drive construction safety.

The implication of this perspective is that improving the effectiveness of the production control system should be a key strategy for safety improvement. However, in construction organizations, the functions of safety management and production control are not integrated. The framework provides another set of questions and criteria that project safety needs to address—such as the task design and complexity, the schedule pressures, the workload etc. Thus, a closer and more integrated effort between production and safety efforts is needed, with a focus on the production control system.

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