Accident Prevention through Production Control: Lessons from High Reliability Foremen

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ABSTRACT
An important challenge for construction practitioners and researchers is to develop production systems that are highly productive and safe. Towards this aim, this study investigated the work practices of field supervisors who consistently achieve very high levels of productivity and safety. In the context of this research, such supervisors are called “High Reliability” (HR) supervisors. In-depth field studies documented the work practices of HR supervisors in three trades: residential framing, masonry, and concrete. The HR foremen used several strategies that prevented errors and variability, while at the same time, increased the speed of production. An unexpected finding was that there were significant differences with regards to the control of hazards and exposures. The HR supervisors were able to prevent accidents even under conditions of significant exposures to hazards. The findings provide empirical evidence that the production practices that prevent errors and variability not only improve production, but they also prevent accidents.

INTRODUCTION
In 2011 the construction industry employed 5.2% of all industries and had 17.6% of the fatal work injuries (Bureau of Labor Statistics 2013). The 738 fatal work injuries among construction trade workers were a slight improvement from the 774 fatalities in 2010, however, in recent years, the fatality rate has remained stable (around 9 fatalities per 100,000 full time workers). While the rates of recordable injuries have declined in the last 20 years, the magnitude of injuries, illnesses and fatalities continues to present a significant social and economic problem.

In the evolution of safety research, Rasmussen and colleagues (1994) identify three paradigms: (1) normative paradigm, (2) 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. The human error paradigm focuses on deviations from the normative, “best way” of working, and views errors and violations as a human “malfunction.” This paradigm includes studies of errors (Rasmussen et al.1982), management errors and resident pathogens (Reason 1990). The cognitive engineering paradigm is concerned with the characteristics of the work system (the features of the task, tools and operating environment) that shape the decisions, behaviors and the possibility of errors and failures (Rasmussen et al. 1994). The cognitive approach to safety attempts to prevent accidents by designing work systems that are adapted to people and avoid operators’ overload and errors.
The current approach to accident prevention in construction is based on the normative paradigm. Safety programs focus on the control of hazards and aim primarily at increasing compliance with safety rules—they emphasize training, inspections and enforcement of safety requirements, and workers’ motivation. Efforts towards safety culture and behavior-based safety also aim at increasing the workers’ voluntary compliance with prescribed hazard controls. This approach has contributed to the reduction of accidents, but it also has theoretical and practical limitations as it neglects the important role of production processes in accident causation.

From a cognitive engineering perspective, the challenge for construction safety is to develop production systems that are at the same time highly productive and safe. Towards this goal, this research set out to identify production practices that systematically support high levels of production and high levels of safety. The approach taken was to investigate the work practices of field supervisors who consistently achieve high levels of production and safety—in the context of this research, such supervisors are called “High Reliability” (HR) foremen. The term High Reliability Organizations (HRO) has been used in organizational research to describe organizations such as aircraft carriers, who operate extremely reliably under very complex, dynamic and hazardous environments (Weick and Sutcliffe 2001).

BACKGROUND
A cognitive model of occupational safety
Rasmussen (1994) explains how the production system shapes the behaviors and performance of the individuals in the system. 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. Safety programs attempt to counter the above pressures and prescribe “safe behaviors” away from the boundary. However, the continuous pressures due to efficiency and workload result in a “systematic migration toward the boundary of acceptable performance (Rasmussen et al. 1994).

Production factors affecting safety
Construction research has identified several production factors that influence workers’ safety. Suraji et al. (2001) argued that ‘distal factors’ such as project conditions, design decisions or management decisions can cause responses that create inappropriate conditions or actions that lead to accidents. Scharf et al (2001) argued that a very dynamic environment and a constant change is a key feature of hazardous work environments. Hinze and Gordon (1979) found that crews with higher turnover also had higher accident rates. 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. Thomassen et al. (2003) found that crews using the Last Planner system (LPS) of production control (Ballard & Howell 1998) had 45% lower accident rate than crews in the same company performing similar work who did not use LPS. Studies of task demands in construction crews identify how project features and production practices influence the level of task demands (Memarian & Mitropoulos 2012, Mitropoulos & Memarian 2013, Saurin et al. 2008, Mitropoulos et al. 2009).
METHOD

This study investigated how HR supervisors design the production system and achieve high levels of production and safety. The research used a case study approach and conducted in-depth field studies of the production practices of HR foremen. The practices of each HR foreman were compared against the practices of an average performing foreman from the same contractor. This approach involved extensive observations, interviews and discussions with many project participants (supervisors, workers, managers, safety professionals, etc.) which resulted in deeper understanding of the production practices and their implications. The findings from each case provided hypotheses for testing on the next case, and each new case was used to validate the findings of previous cases. The case study method allows analytical generalizations rather than statistical ones.

The study focused on trades and contractors with significant safety risk, as reflected in the high rates of traumatic injuries and fatalities, based on injury data from the Bureau of Labor Statistics and NIOSH (2004). This paper reports the findings from framing, concrete and masonry contractors, as they have high rates of recordable incidents. The research activities involved the following:

Identify High Reliability foremen. To identify HR foremen, each participating contractor evaluated their foremen based on their (1) safety incident rate and severity, and (2) production performance during the previous three years. The foremen’s incident rate and severity were calculated based on the labor hours supervised, the number of incidents that occurred under their supervision (including first aid, recordable injuries and lost time), and the direct cost of incidents. Where available, the foreman’s production performance was evaluated using actual vs. estimated cost of work supervised. When such data were not available, the operations manager evaluated the foreman using a 10-point scale (where 1 was the lowest and 10 was the highest). The assessment was based on (1) the foremen’s productivity and schedule performance, and (2) the difficulty of the projects the foreman managed, which reflected both production and safety difficulty. Foremen with exceptional performance in both production and safety were selected as HR foremen.

Review organizational context and safety incidents. Interviews with the operations manager and safety manager were conducted to understand the organizational context, including the safety management policies, hiring policies, foremen and crew training, compensation and bonuses, work method selection, and foremen’s level of decision-making regarding the work process. Safety incidents over the previous three years were reviewed to identify hazards and high-risk activities.

Document and compare production practices. After securing the necessary permissions from owners and contractors, and after the safety orientations, the researchers performed extensive field observations and interviews with the HR foremen, their crew members and other project personnel. About 20 site visits were conducted for each trade, including observations of average performing foremen. Operations were observed, and often videotaped. The foremen were interviewed multiple times regarding all aspects of the work organization.

The researchers collected field data on: (1) production practices; including foremen priorities, production planning, production organization, work method selection, work sequencing, task assignments, setting production goals, production
controls, etc.; (2) Safety practices, including safety training, enforcement, safety activities, toolbox talks, etc.; and (3) Crew management strategies, including crew members selection, orientation, task assignment, training, etc.

CASEx

Residential framing. The participating company was a large framing contractor, who employed about 85 framing crews. All crews performed very similar work in terms of complexity, size and schedule. The HR foreman was the one with the highest production score and zero incidents. The average foreman had productivity slightly above average, and incident rate just above the company average, and average workers’ compensation cost. Both crews had 7 crew members, and both foremen were working foremen.

Masonry. The participating company was a large masonry contractor who performs residential, commercial and industrial construction in several states. The company employed more than 700 workers including 50-60 foremen. The identified HR foreman was observed on a project that involved several buildings: four 7-floor residential buildings, one building with 4 floors, and 2 buildings with one floor. Another foreman was also on this project. Each foreman was assigned different buildings and each had a crew of 45-55 workers (a ratio of 2 masons to 1 laborer). The project has a complex design and was on an accelerated schedule. The foreman was primarily planning, monitoring instructing and performing/checking layout.

Concrete. The participating company was a large concrete contractor who performs primarily commercial and industrial work in several states. The contractor had about 20 foremen. The identified HR supervisor was observed on a project that involved the construction of a 10-story office building, with a cast-in-place concrete frame and post-tensioned concrete slab. Each floor was about 27,000 Square Feet (SF). The design complexity of the project was low. The main challenges were the tight schedule of 13 weeks and the high temperature. The supervisor was in charge of the entire concrete operation that included a deck crew (19 members), a wall crew (9 members) and a night crew (8 members). He was also managing the deck crew.

FINDINGS

The findings indicate that the HR foremen are characterized by the following:

- The primary focus of HR supervisors was to prevent errors, rework and incomplete work. All their practices supported this focus.
- The HR foremen were actively looking for production difficulties and risks on each project, while the average foremen operated largely based on repetition.
- The HR foremen organized and simplified the activities to reduce complexity and physical demands on the workers.
- HR foremen prepared the activities thoroughly to avoid interruptions.
- They mitigated the production pressures on their crews to prevent rushing.
- They organized the process for speed by completing smaller batches of work—as a result, they had less work in process at any time.
- They used practices that kept their crew informed and focused.
- They continuously monitored for errors, threats and difficulties, and responded fast to excessive workload and problems.
• Surprisingly, the safety practices of HR foremen did not involve extensive control of hazards in all cases. The HR foremen achieved high safety performance, even with limited control of hazards.

Focus on preventing errors, rework & incomplete work
All HR foremen had a strong focus on preventing errors, rework and incomplete work. For the framing foreman, the largest productivity losses happen when he has to perform rework. The masonry foreman emphasized that it is critical to have everything correct when he is finishing each area. Problems and mistakes are identified and corrected immediately and he rarely had any punchlist items. For the concrete supervisor, it was critical to avoid mistakes, and to complete all the planned activities every day, in order to meet the aggressive schedule. This emphasis on avoiding mistakes and rework guided their work practices.

Actively look for production and safety threats and difficulties
The HR foremen were constantly looking for potential problems—difficult work areas, missing resources, coordination difficulties, mistakes and omissions. The framing foreman was always looking for details or options that his crew was not familiar with. He discussed them with the crew and asked them to wait for him before they start working on those areas, to prevent errors. The masonry foreman was checking for complex block patterns, penetrations, changes in the block and connections to roof that the crew needed to be aware of. The concrete supervisor was considering the potential difficulties of every activity.

Thorough activity preparations to reduce unpredictability
All three HR foremen put significant effort to make sure that the crew had all the material and resources needed to perform the work as planned. This was critical in order to avoid interruptions and incomplete work. The framing foreman checked if the lumber, hardware and trusses packages were complete. The concrete supervisor assigned crew members dedicated to preparing the material, equipment, tools, for the activities. The masonry foreman was checking all the material deliveries for missing items. He was also checking if the crew had on the scaffold everything they needed—the right block (type and color) and mortar, inserts, wire, ties, projection pieces, lintels or steel beam with all stirrups, etc. According to the masonry foreman, the ability to prepare the activities determined the number of work areas where he could work efficiently.

Design the activities to reduce complexity and physical demands
The HR foremen were looking for opportunities to simplify the work methods. The concrete supervisor selected methods and components that required less onsite assembly, and less measuring and cutting (“Z metal” for the beam forms). He had the crew pre-mark the table legs to reduce measuring and prevent errors. If a wall involved complex block patterns, the masonry foreman had the block laid out in the correct order, to reduced complexity for the masons and prevent errors. To reduce physical demands and block cutting, the masonry foreman raised the scaffold more frequently. The concrete crew used rubber mallets that deliver a softer blow and
reduce the workers’ discomfort. The framing foreman had little discretion regarding the material, or method—even then, he was using longer than usual temporary braces for truss erection that made the installation easier. These strategies reduced the physical demands, the task complexity and the potential for errors.

**Manage production goals and time pressures**

To prevent excessive pressures and workload the HR foremen: (1) Set realistic production goals and tried to establish a pace that was not rushed. Having adequate manpower was an important consideration. The framing and concrete foremen had the authority to determine their crew size, and emphasized low absenteeism. Absenteeism was high in the masonry operation—the crew was “over-manned” by the management which was very tolerant to absenteeism. (2) Prepared tasks ahead of time (organized material in the order needed, pre-measured and pre-marked) to reduce pressures during installation. (3) “Shielded” the crew from being rushed by the following activities. The framing foreman was ordering the crane with a small time buffer to prevent it from arriving early and rushing his crew. The goal of these practices was to reduce excessive workload, rushing and fatigue, and reduce mistakes. However, when high pressures could not be avoided, the close monitoring enabled fast adaptations.

**Extensive monitoring and cross-monitoring**

The HR foremen established multiple checks especially for critical operations where errors would be very costly to correct. The framing foreman double checked the walls before they were lifted in place, and personally released the trusses during truss erection to ensure they were installed correctly. For the masonry foreman, layout, block patterns and openings, and raising the scaffold were the activities with the high consequences of errors. He was continuously checking to identify and correct any mistakes before the crew left the work area. The concrete supervisor had established multiple checks for the elevation of the tables, and embeds, as well as several daily milestones to check progress. Cross monitoring by the crew members was another strategy for identifying threats and difficulties. The concrete supervisor trained the crew to recognize the symptoms of dehydration and asked them to cross monitor each other for symptoms. Early recognition of mistakes and difficulties combined with a clear plan to address the problems made it possible for the crew to correct errors quickly or redistribute the workload. To prevent problems in one task affecting other tasks, the concrete crew was instructed to not stop their activity and help with production problems, but to notify the deck foreman immediately. The foreman knew the status of all tasks and redistributed the workload so that other tasks were not delayed.

**Crew management practices**

The crew management practices of the HR foremen also aimed at preventing excessive workload, rushing and mistakes.

**Absenteeism.** Preventing absenteeism was critical for the concrete crew, as they were under time pressure and working overtime, and every absence would mean excessive workload for the rest of the crew. Absenteeism was high in the masonry
operation, where the crew was “over-manned” by the management which was very tolerant to absenteeism.

**Crew planning.** Keeping the crew informed and aware of their next step was essential. Every day, the concrete crews reviewed the timetable, specifying what time each task had to be finished. The crew had a clear work plan which specified when, where, and how to do the work. To keep the crew focused, the workers were assigned one task at a time. In the masonry crew, the foremen and leadmen had very clear plans about what to build and where, and production goals.

**Task assignments.** In the concrete crew, task rotation was used for some physically demanding tasks. Tasks that required high accuracy were assigned to specialized crew members—the most skilled carpenters worked at the areas that required higher accuracy of the edge form. A leadman with strong engineering background was performing the layout. A dedicated grader was used to set the table legs at the correct elevations. In the framing crew, only the leadman and another carpenter were allowed to perform the high risk tasks (setting trusses and install the first row of plywood). The masonry leadman and foreman prepared and checked the layout, and a dedicated group of four laborers was responsible for the scaffold.

**Workers’ development.** Task assignments are directly related to the workers’ development. The masonry foreman was assigning the same tasks to the new workers as the experienced workers, so the new workers can learn how to perform all tasks. At the same time, he was assigning an experienced worker to monitor and correct the inexperienced ones. He also gave opportunities to crew members to take more responsibilities (e.g. manage the rebar). The framing foreman framed the complex details himself and used them as an opportunity to train his crew members. Because of the very high schedule pressures of the concrete operation, the supervisor assigned crew members based on their capabilities, rather their learning opportunities.

**Organizing the process for speed**

The HR foremen also organized the work process for speed by reducing the batch size, overlapping operations, and managing the dependencies. The masonry foreman divided the crew in smaller groups, who worked at different locations on the same floor. He focused on completing each area fast by assigning several masons in one area—masons were working closer together, which also reduced their walking “empty-handed. To accelerate the concrete operation, the supervisor divided each floor in two sections so the deck and walls operations could overlap. This overlapping created new resource dependencies: the concrete crews and crane. Each operation was assigned to a different crew so they could proceed independently. The dependency due to the crane was managed with better planning to reduce the number of lifts, and allocate the crane time to the different crews.

**Differences in safety management**

An unexpected finding was that despite the exceptional safety record of the HR foremen, there were significant differences across the cases with regards to the safety measures taken to control the hazards and exposures. For the framing crew, the most significant risks were falls from elevation, saw cuts and nailgun injuries. The framing company had established specific work process and safety requirements (PPE, proper...
use of ladders, housekeeping, etc.) and performed safety audits on every house framed. Both the HR and average foremen had high compliance score. However, the protection from hazards was limited and the exposures to hazards were high. At the time of the study, the residential framing work was exempt from conventional fall protection requirements. The jobsites did not have a dedicated safety professional and the crew did not have safety toolbox talks or other type of safety training.

For the masonry crew the most significant safety concerns were scaffold safety, saw cuts (as the project involved extensive cutting due to the rebar design) and heavy load lifting. The masons belonged to the union and had the 10-hour OSHA safety training, but the laborers were not union and did not have it. A safety manager was assigned part-time on the project and safety toolbox talks were held once a week. Scaffold inspection was performed daily. The masonry foreman had four laborers dedicated to inspecting, monitoring and raising the tower scaffold. The masons also used traditional scaffold frames for the interior and some exterior walls, which did not require guardrails up to 6 feet. Overall, the safety efforts were good but the remaining exposures to hazards were considerable.

For the concrete operation, the main safety concerns were falls, crane safety, overhead loads, falling objects during lowering of the table forms, and dehydration. Extensive safety measures were taken to reduce the exposures. All foremen and supervisors had the 30-OSHA safety training, as well as First aid/CPR training. The crew had daily planning and safety meetings, and there was a full time safety professional on the project. Perimeter railing and 100% tie-off policy with zero tolerance were used to reduce exposures to falls. The crane activities were planned extensively and monitored closely—often directly by the crew supervisor. To minimize exposures to falling objects when the forms were lowered, the areas were taped off for all the other workers. The risk of dehydration was mitigated by providing extra water and rotating workers to work in shaded areas. The safety measures significantly reduced the workers’ exposures to hazards, and the exposures were relatively low.

Despite the significant differences in safety measures, the HR supervisors were able to prevent accidents even under conditions of significant exposures to hazards.

**DISCUSSION AND CONCLUSION**

The findings provide significant empirical evidence that the production practices that prevented errors and variability were essential in preventing accidents. An important finding is that safety was achieved with greater emphasis on production controls, rather than hazard controls. To some extent, the HR supervisors’ practices reduced exposures to hazards. For example, raising the scaffold more frequently reduced the ergonomic demands on the masons, using lighter components reduced physical demands, and performing less rework prevented exposures to related hazards. However, what appears to be the most significant positive impact on safety is that the production practices generated “high quality” work situations and mitigated the task demands on the workers.

- The management of production pressures reduced rushing, and the need for shortcuts or violations to meet production goals.
The extensive activity preparations minimized unpredictable situations—such situations involve higher potential for errors and accidents, and reduced unexpected problems (such as not having the right tools and material), frustration, rushing and errors. The extensive activity preparations also reduced the workload and pressures during the installation activities. These preparations were different than safety pre-task planning, which typically focuses on a review of the main task hazards and controls.

- The assignment of more capable personnel to more demanding tasks prevented overloading crew members with excessive task difficulty.
- The crew management practices reduced distractions and frustration.
- The extensive monitoring increased the ability to cope with “boundary situations”—that is, recognize excessive workload and redistribute it in a way that minimizes production loss, recognize coworkers’ difficulties such as fatigue or dehydration and address the threats.

In conclusion, the investigation of the work practices of HR foremen among different trades provided significant converging evidence that the production system is critical for safety because it generates the work situations that workers face. An ineffective production control system generates low quality work assignments that create high-risk work situations with increased task difficulty and increased opportunities for errors and violations. Even with significant safety effort, there is extensive friction with production, and the safety outcomes are likely to be poor. This is not to say that strong safety efforts are not important, but they are not sufficient to overcome the problems of an ineffective production control system.

The findings provide support for some accident causation theories, such as the adjustment-stress theory (Kerr 1957), and the distractions theory (Hinze 1996). These theories emphasize the importance of the workers’ cognitive factors, rather than the control of hazard sources. The findings of this study indicate that the practices of HR foremen effectively manage the work conditions in a way that reduce pressures, complexity, confusion, stress, and errors. As a result, the crew members were able to cope successfully with the work demands even when they were exposed to hazards. The findings are tentative as more cases are being developed and analyzed. The small number of cases is a limitation with regards to the generalizability of the findings. As part of future work, the findings of this study will be validated against a larger number of foremen.

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