

Production Practices of High Reliability Foremen and their Role in Accident Prevention

Panagiotis Mitropoulos, PhD
San Diego State University
San Diego, California

Babak Memarian, PhD
Arizona State University
Tempe, Arizona

This study investigated the production practices of foremen who consistently achieve very high levels of productivity and safety. Such foremen are called "High Reliability" supervisors. In-depth field studies documented the production, safety and crew management practices of HR supervisors in three trades: residential framing, masonry, and concrete. The HR foremen used a combination of strategies that aimed primarily at preventing errors and variability, while at the same time, increasing the speed of production. The study found significant differences across cases with regards to safety management practices. As a result, the workers' exposures to hazards varied from very limited to extensive. The surprising finding was that the HR supervisors were able to prevent accidents even under conditions of significant exposures to hazards. The findings provide evidence that the production practices that prevent errors and variability not only improve production, but also reduce the likelihood of accidents.

Key Words: Production system design, High Reliability Supervisors, Production Practices, Safety, Productivity

Introduction

Construction work involves many dynamic and hazardous work processes. Construction operations are subject to multiple demands for speed, cost, productivity, quality and safety. The high production pressures and workload, combined with the dynamic, hazardous and often unpredictable construction tasks and environment, creates significant potential for errors and accidents. 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). With the continuous pressure for speed, productivity and competitiveness, an important challenge for construction researchers and practitioners is to develop work systems—that is, work processes and work teams that are simultaneously highly productive and safe and can function safely and effectively in the dynamic and complex conditions of construction projects.

Construction work processes adapt to the project-specific requirements and context. Because of the site-specific requirements and constraints, the design of the production system is typically performed by field supervisors (foremen). The field supervisors operate within organizational, financial, and project constraints, but also have many degrees of freedom in how they organize and coordinate the work. The supervisors' practices determine to a large extent how the actual work is organized and coordinated (such as task allocation, sequencing, workload, pace, work coordination, teamwork, etc.) and consequently they shape the work situations that the workers face. Hence, the organization of the work and the work practices are important for both productivity and safety.

The goal of this research is to better understand how to design the production system in order to can create high levels of both productivity and safety. The research approach taken was to investigate the work practices of field supervisors who consistently achieve high levels of both production and safety. In the context of this research, such supervisors are called High Reliability (HR) foremen. Thus, the research objective is to develop in-depth understanding of the production practices of HR foremen, and how their practices support both high production and safety. The term "High Reliability Organizations" (HROs) has been used in organizational research to describe organizations such as aircraft carriers, nuclear power plants and wildland firefighting crews who operate extremely reliably under very complex, dynamic and hazardous environments (Weick and Suttcliffe 2001). In the context of this study, a "High Reliability" supervisor is one who works on a high-risk trade and consistently achieves very high levels of both production and safety, even during challenging project conditions (Mitropoulos & Cupido 2009).

Background

The background reviews research related to the role of production practices on safety, and the influence of production issues on safety outcomes. Production – safety trade-offs have been identified as an important element of the safety of production operations (Hollnagel 2009). Production employees make many large and small trade-off decisions every day (Woods 2010). 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 (Figure 1).

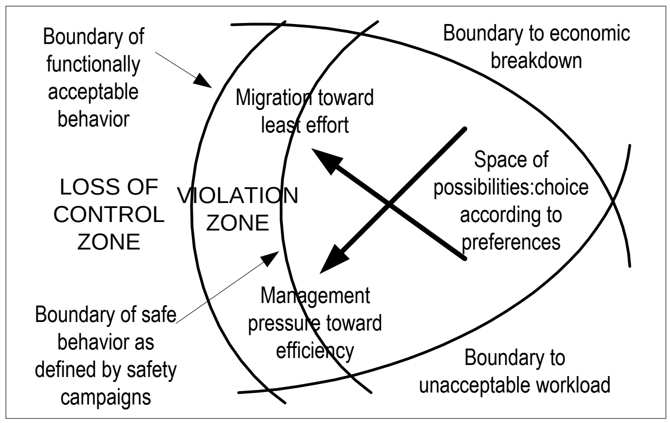

Figure 1. "Migration to Accidents" (adapted from Rasmussen et al 1994).

Safety programs attempt to counter the above pressures and prescribe "safe behaviors" away from the boundary. However, the pressures that push workers towards the boundary require that safety efforts are continuous. The result is a "systematic migration toward the boundary of acceptable performance (Rasmussen et al. 1994). The safety literature recognizes the trade-offs between safety and production outcomes (Zohar 2000). Zohar (2000) argues that there is a trade-off between production goals such as quality improvement and cost reductions, and safety goals such as accident reduction. Ford and Tetrick (2008) argued that workers either avoid errors or maximize production by taking short cuts and working around the safety system to meet production goals.

Production factors affecting safety

Construction researchers have identified several production factors that influence workers' safety. 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. 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 and Gordon (1979) found that crews with higher turnover also had higher accident rates. Thomassen et al. (2003) found that crews using the Last Planner system (LPS) for production planning (Ballard & Howell 1998) had 45% lower accident rate than crews in the same company performing similar work who did not use LPS. Recent studies in construction crews identify how project features and production practices influence the level of task demands (Saurin et al. 2008, Mitropoulos & Memarian 2013, Mitropoulos, & Guillama 2010). The above discussion highlights the importance of production factors for safety. Based on this, the study investigated how HR supervisors design the production system to achieve high levels of production and safety.

Method

The research used the multiple case studies method. Each case study involved in-depth field study of the production practices of HR foremen. In addition, the practices of HR foremen were compared against the practices of average performing foremen from the same contractor. The research focused on trades and operations with significant safety risk as reflected in high rates of traumatic injuries and fatalities. This paper reports the findings from the studies of framers, masons and concrete crews. The research included the following activities.

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 each foreman supervised, the number of incidents that occurred under their supervision, and the direct cost of incidents (workers' compensation costs and/or number of days away from work/modified duty). Production performance was evaluated using objective or subjective data. Where available, the foreman's production performance was evaluated using actual vs. estimated costs of work supervised. When such data were not available, the operations manager evaluated their foreman using a 10-point scale based on (1) the foremen's productivity and schedule performance, and (2) the difficulty of the projects the foreman managed. Foremen with exceptional performance in both production and safety were selected as HR foremen.

Review organizational policies 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 also reviewed to identify hazards and high-risk activities.

Document production practices

To capture the production practices, the researchers performed extensive field observations and interviews with the HR foremen, their crew members and other project personnel (superintendent, safety manager, etc.). 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 production practices observed were organized under three categories: (1) production strategies, including foremen priorities, production planning, production organization, work method selection, work sequencing, task assignments, setting production goals, production controls, etc.; (2) Safety management practices, including safety training, enforcement, safety activities, toolbox talks, etc.; and (3) Crew management strategies, including crew members selection, orientation, task assignment, training, etc.

Cases

This paper presents the findings form the study of HR foremen in three trades: (1) Residential framing, (2) Masonry and (3) Concrete. The residential framing contractor 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. The participating masonry company was a large 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 during the construction of a 7-floor residential building and had a crew of 55 workers at peak (with 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. The participating concrete company was a large contractor who performs primarily commercial and industrial work in several states. The contractor had about 30 foremen. The HR supervisor was observed during 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).

Findings

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

- **Focus on error prevention**. The primary focus of HR supervisors is on preventing errors, rework and incomplete work. All their practices and strategies supported this principle.
- **Continuous anticipation of difficulties**. HR supervisors were actively looking for the difficulties and risks on each project—average foremen operate largely based on repetition (do as before).
- **Extensive preparations to reduce unpredictability**. HR foremen prepare the activities thoroughly to avoid surprises and interruptions.
- **Work design to reduce task demands**. HR foremen organize and simplify the activities to reduce complexity and physical demands.
- **Mitigation of production pressures**. HR foremen mitigate the production pressures on their crew to prevent rushing and errors.
- **Completing work**. They organize the process for speed by using smaller batch size and completing smaller batches of work. As a result, they have less work in process at any time.
- **Informed and focused crew**. They crew management practices keep their crew informed and focused. The task assignments balance the need for efficiency with workers' development.
- **Continuous monitoring for errors**. They continuously monitor for errors, threats and difficulties, and respond to excessive workload and problems.
- **Varying safety practices**. Surprisingly, their safety practices do not necessarily prevent exposures to hazards. The HR foremen achieve high safety performance, even with limited protection from hazards.

Primary focus: Prevent errors, rework & incomplete work

All HR supervisors had a strong focus on preventing errors, rework and incomplete work. According to the framing foreman, the largest productivity losses happen when he has to go back and fix something. 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 delays in order to complete all the planned activities every day, and meet the aggressive operation schedule. This emphasis on avoiding mistakes and rework drives many of their work practices.

Continuous anticipation of 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 framing details or options that his crew was not familiar with. He discussed the difficult areas 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. For the concrete operation, the short schedule and the high temperatures posed significant challenges. He was continuously considering the potential difficulties and risks on every activity, and took actions to reduce them.

Extensive preparations to reduce unpredictability

All three HR foremen put significant effort in making 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 and that no components were missing. The concrete supervisor assigned crew members dedicated to preparing the material, equipment, tools, for the activities. The masonry foreman checking all the material delivered, "knowing" that there was always something missing. 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.

Work design to reduce task demands

The HR foremen were looking for opportunities to simplify and standardize the work methods. The concrete supervisor selected methods and components that required less onsite assembly (aluminum tables configured for ease of installation), 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. When 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, the masonry foreman raised the scaffold more frequently to reduce cutting block due to rebar. 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, method or tools—even then, he was using longer than usual temporary braces for truss erection that made the installation easier. These strategies reduced the physical demands, and task complexity, which reduces the potential for errors.

Mitigation of production 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.

Continuous monitoring for errors

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.

Informed and focused crew

The crew management practices of the HR foremen 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 company 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 be built and where, and they crew had clear directions 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 to new workers the same tasks that experienced workers do, 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 used the complex details 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 for speed

The HR foremen 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 although all HR foremen had exceptional safety record, there were significant differences across cases with regards to the safety measures taken to control the workers' exposures to hazards. For the framing crew, the most significant risks were falls from elevation, saw cuts and nailgun injuries. However, the residential framing work was exempt from conventional fall protection requirements. 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. The jobsites did not have a dedicated safety professional. The crew did not have safety toolbox talks. For the framing crew, the protection from hazards was limited and the exposures to hazards were high. Even under such conditions of significant exposures, the framing supervisor was able to prevent accidents.

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. For the tower scaffolds (used for the outside walls), the masonry foreman had four laborers dedicated to inspecting, monitoring and raising the 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 hazards were falls, crane safety, overhead loads, falling objects, 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 by the supervisor. To minimize exposures to falling objects when the forms were lowered, the area was taped off for all other workers. To prevent dehydration, they provided extra water and rotated workers to work in shaded areas. The safety measures significantly reduced the workers' exposures to hazards.

Discussion

The findings provide significant empirical evidence that the production practices that prevented errors and variability are essential in preventing accidents. To some extent, the HR supervisors' practices reduced hazards and exposures. However, what appears to have a greater impact on safety is that as a result of the production practices, the crew members were able to cope successfully with the hazards and the work demands even when they were exposed to hazards.

- The extensive activity preparations minimize unpredictable situations and reduce unexpected problems, such as not having the right tools and material, and reduce frustration, rushing and errors. Such situations involve higher potential for errors and accidents.
- The management of production pressures reduced rushing, and reduced the need for shortcuts or violations to meet production goals.
- The assignment of more capable personnel to more demanding tasks prevented overloading crew members.
- The crew management practices reduce 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.

The production practices of HR supervisors generated high quality work situations and prevented work situations that lead to shortcuts and errors. As a result, these practices reduced the conflict between production and safety. This study makes several contributions to the research on construction accidents. First, it provides evidence regarding the significant influence of the production system design on the potential for accidents. Previous studies have focused primarily on the influence of safety measures on accidents. Second, the study identifies work practices that relate to prevention of accidents even under conditions of exposure to hazards. Thus, the study findings indicate that high levels of safety can be achieved even under exposure to hazards. Overall, the study findings establish a stronger link between the work design and safety performance, and provide new hypotheses for explaining the safety performance of construction operations. Finally, the findings highlight that the design of the production system (not the hazard control system) has a critical role in accident prevention. The findings also identify specific production practices that are not focused on hazards, but reduce the potential for accidents. These practices provide important directions for safety improvement. One limitation of the study is that it did not investigate why other foremen may not utilize some of these practices to the same extent. It is possible, that organizational requirements (such as additional project administration responsibilities) may prevent them from spending more time on some of these practices.

Conclusion

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

Acknowledgements

The research described in this paper is conducted with the support of NSF and the CAREER Award Grant # 0645139.

References

Ballard, G., and Howell G. (1998). “Shielding Production: Essential Step in Production Control.” J. of Constr. Eng. & Manage., ASCE, 124 (1).

BLS (2013) Table A-1. Fatal occupational injuries by industry and event or exposure, All U.S., 2011. http://www.bls.gov/iif/oshwc/cfoi/cftb0259.pdf accessed 10.10.2013.

Ford, M.T., Tetrick, L.E. (2008). ”Safety motivation and human resource management in North America.” The International Journal of Human Resource Management 19 (8), 1472–1485.

Hinze, J., and Parker, H. W. (1978). “Safety, productivity and job pressures.” Journal of the Construction Division, ASCE, 104(1): 27-35.

Hinze, J., and Gordon, F. (1979). “Supervisor-worker relationship affects injury rate.” Journal of the Construction Division, 105(3): 253-261.

Hollnagel, E. (2009) The ETTO Principle: Efficiency-thoroughness Trade-off : why Things that Go Right Sometimes go wrong, Ashgate Publishing, UK.

Mitropoulos, P. and Memarian B. (2013) "Task Demands in Masonry Work: Sources, Performance Implications and Management Strategies" J. Constr. Eng. & Manage, ASCE, 139(5):581-590.

Mitropoulos, P. and Guillama, V. (2010). “Analysis of Residential Framing Accidents, Activities, and Task Demands,” J. Constr. Eng. & Manage., ASCE, 136(2): 260-269.

Mitropoulos, P., and Cupido, G. (2009). “The Role of Production & Teamwork Practices in Construction Safety: A Cognitive Model and an Empirical Case Study.” J. of Safety Research, 40(4): 265-275.

Rasmussen J., Pejtersen A.M., and Goodstein L.P (1994). Cognitive System Engineering. John Wiley & Sons, Inc. New York, NY.

Saurin, T.A., Formoso C. T., Cambraia, F. B. (2008). “An analysis of construction safety best practices from a Cognitive Systems Engineering Perspective.” Safety Science, 46(8): 1169-1183.

Scharf, T., Vaught, C., Kidd, P., Steiner, L., Kowalski, K., Wiehagen, B., Rethi, L., and Cole, H. (2001) “Toward a Typology of Dynamic and Hazardous Work Environments.” Human and Ecological Risk Assessment, 7 (7): 1827-1841.

Suraji A., Duff, A. R., and Peckitt S. J. (2001). “Development of Causal Model of Construction Accident Causation.” J. Constr. Eng. & Manage., ASCE, 127(4), pp. 337-344.

Thomassen M. A., Sander D., Barnes K. A., Nielsen A. (2003). “Experience and Results form Implementing Lean Construction in a Large Danish Contracting Firm.” Proceedings of 11th Annual Conference on Lean Construction, pp.644-655, July 22-24, Blacksburg, VA.

Weick, K. E., and Suttcliffe, K., M. (2001). Managing the Unexpected. Jossey-Bass, San Francisco, CA.

Woods, D. D. (2010). Behind human error. Ashgate Publishing.

Zohar, D. (2000). A group-level model of safety climate: Testing the effect of group climate on microaccidents in manufacturing jobs. Journal of Applied Psychology, 85, 587–596.