



2002

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Academy of Management Review

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Academy of Management Review 2002, Vol. 27, No. 4, 594-607.



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## NOTE

# HETEROGENEITY AND VARIABILITY IN THE CONTEXT OF FLOW LINES

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We propose a model in which between-individual differences in performance (heterogeneity) and within-individual differences in performance over time (variability) affect flow line performance. The impact of heterogeneity and variability is contingent upon the flow line context, particularly the rules governing the way work moves between employees (work flow policy). We show how subtle changes in this policy can have a motivational effect on heterogeneity and variability and how these, in turn, can impact the relationship between work flow policy and flow line performance.

In this paper we develop a model of production line performance in a particular operational context, and we integrate elements of the operations management literature on flow lines and the organizational behavior literature on workgroups and motivation to develop a behavioral model of flow line performance. We show that these two bodies of literature interrelate in important ways that have implications for both organizational behavior and operations management theory and research. Given the potential difficulties of integrating these areas, we build our model by focusing narrowly on specific operating policies of production flow lines.

A production flow line involves multiple employees completing tasks that are sequenced in a particular way. Flow lines are used to produce such goods as automobiles, jet aircraft, and per-

sonal computers; this is the recommended form of production for discrete-item mass production (Hayes & Wheelwright, 1984). The detailed study of these lines is important, because flow lines are used in situations of high-demand volume, and even small improvements in their per-unit operation can yield large gains in profitability (Wild, 1972). Because of the popularity and efficiency of this type of line, it has been the subject of considerable research in the field of operations management (Gagnon & Ghosh, 1991; Ghosh & Gagnon, 1989). Another reason for the attention given to the context of flow lines is that, to our knowledge, no production method has yet been developed that can rival its efficiency.

However, historically, individual attributes have been virtually ignored in operations management flow line models, in spite of a wealth of evidence suggesting that significant individual differences exist, even for simple manual tasks (Hunter, Schmidt, & Judiesch, 1990; Schmidt & Hunter, 1983; Schmidt, Hunter, Outerbridge, & Goff, 1988), and that those differences are re-

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We thank Chris Earley, Kevin Gue, Steven Powell, Ken Schultz, Ruth Wageman, and the anonymous reviewers for their helpful comments on an earlier draft of the manuscript.

lated to individual performance. Recently, however, researchers have proposed operating policies for flow lines that not only acknowledge individual differences but also rely on them (Doerr, Klastorin, & Magazine, 2000; Zavadlav, McClain, & Thomas, 1996). Unfortunately, the operations management models of individuals are rather like "stick figures": in the more sophisticated models, the individual is represented by a number, lesser or greater according to his or her ability, and in less sophisticated models, the individual is not represented at all.

In the organizational behavior literature, however, researchers have focused not only on demonstrating the existence of individual differences in ability, motivation, and personality but on showing their effect on performance (e.g., Hunter et al., 1990; Schmidt et al., 1988). Models have been developed in the areas of job design (Hackman & Lawler, 1971; Wong & Campion, 1991) and sociotechnical systems (Cummings, 1978; Huber & Brown, 1991) that specifically address the human factors of work systems, and how variation in performance can be associated with these human factors and their interaction with the task itself. (See Wall and Martin [1994] and Ambrose and Kulik [1999] for reviews).

Unfortunately, most attempts to integrate these job design and individual behavior perspectives into models of specific production systems are vague. The models are intended mostly to apply across a broad range of operating contexts; hence, there is a lack of precision in specifying the context. For example, Schmidt and Hunter (2000) postulate that generalized intelligence is an ability that helps on all jobs, and Locke and Latham (1990) postulate that a difficult specific goal increases motivation on all tasks. Recently, however, scholars have shown greater recognition that a complete understanding of variables such as motivation, intelligence, and personality requires they be matched to specific work contexts (Mitchell, 1997; Mowday & Sutton, 1993).

The key link between behavioral and flow line research can be found in the interactions between adjacent employees on the line. Flow lines have policies that prescribe the form of those interactions. Behavioral variables will be impacted by, and have different effects upon, flow line performance as a result of the type of interaction entailed by those policies. We present a model in which specific flow line de-

sign choices affect the interaction between adjacent workers and, thus, flow line performance.

We believe an integrative model is important to both the operations management and the organizational behavior research communities. Without displaying an understanding of the impact of individual differences in performance, operations management models of flow line performance will lack predictive power and may contain costly inaccuracies. For example, Doerr and Arreola-Risa (2000) discuss one flow line work assignment that required more overtime than it should have to meet a production quota, because individual differences were ignored (i.e., by considering individual differences in performance rates and variability when allocating work, managers could have reduced overtime by 18.6 percent). Without displaying an understanding of the importance of contextual variables such as work flow policy, organizational behavior models may lack descriptive validity when applied to flow lines.

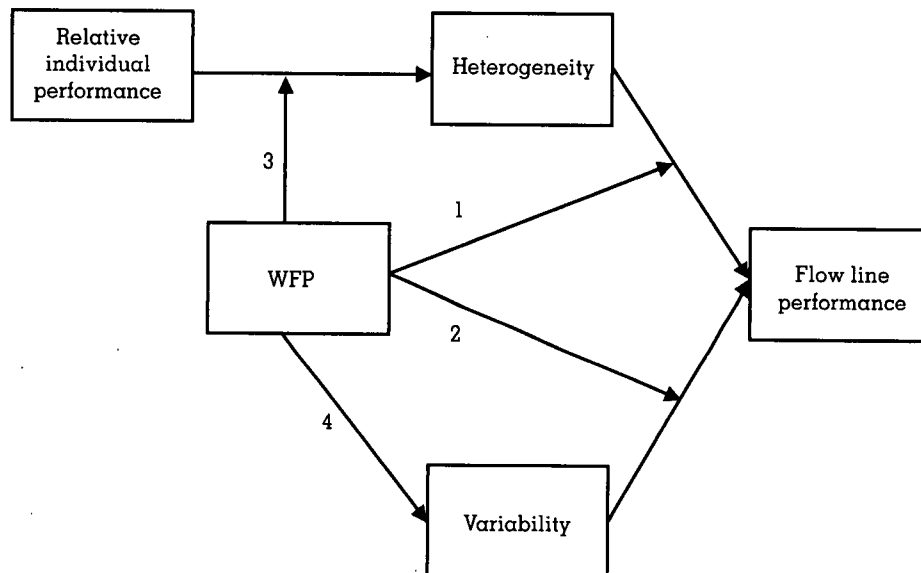
Specifically, we propose in our model that operating policy moderates the relationship between heterogeneity (between-individual differences in mean performance) and line performance, as well as the relationship between variability (within-individual differences in mean performance over time) and line performance. Furthermore, we propose that, partly through a motivational process, operating policies *change* the levels of heterogeneity and variability. An overview of our conceptual model is shown in Figure 1. Note that while our model refers to relative individual performances and to individual variability, our level of analysis is at the group level. Heterogeneity, variability (averaged across the workgroup), and flow line performance are all group-level constructs.

Next, we briefly review the literature on flow lines, which is our context. We then examine heterogeneity and variability in the context of flow lines and offer four theoretical propositions that integrate flow line policies and heterogeneity and variability as predictors of flow line performance.

## FLOW LINES

In the context of a flow line, *work flow* describes the way work moves between employees on the line. We use the term *work flow policy (WFP)* to describe all of the methods manage-

FIGURE 1  
Conceptual Model



ment has available to control work flow. There has been a great deal of research on different aspects of WFP, since it impacts inventory levels, throughput, and capacity of a flow line (e.g., Agnetis, Ciancimino, Lucertini, & Pizzichella, 1995; Baker, Powell, & Pyke, 1990; Buss & Lawrence, 1995; Doerr, Mitchell, Klastorin, & Brown, 1996; Gagnon & Ghosh, 1991; McClain, Thomas, & Schultz, 2000; Powell & Pyke, 1998). Our main concern with WFP in this paper is the impact it has on the interaction between adjacent employees on a line. To our knowledge, WFP has not been examined from this perspective.

Each time an employee finishes his or her tasks (each cycle), he or she must pass work downstream and receive work from upstream. The WFP controls employee interactions at the beginning and end of each cycle by controlling how, when, and where work is exchanged. On the one hand, if an upstream employee is not finished when the downstream employee finishes, the downstream employee may become idle (*starved*). Also, if the downstream employee is not finished when the upstream employee finishes, the upstream employee may become idle (*blocked*). On the other hand, one employee may be allowed to take away (*preempt*) the work of another, rather than become idle, but this preemption may itself cause idle time. And, preemptive or not, passing the work along also requires some amount of physical effort and

communication (*coordination*). (Note that we use "coordination" here in a narrow sense, to refer to specific interactions that take place as work is handed off from one worker to another—for example, the physical handoff of material, tools, order forms, the communication about problems, and what has or has not been done.) The primary impact of starvation, blocking, and coordination time on the productivity of a line is observably negative.<sup>1</sup> The WFP determines to whom, how, and when this idle or coordination time will occur.

One WFP parameter is the batch size (number of items/tasks). A larger batch size can be used to reduce starvation, blocking, and coordination time, since it reduces the number of interactions between employees. (For a more general discussion of batch sizes, see Rummel [2000].) Another WFP parameter is the buffer size. Buffers are physical spaces between workstations where inventory is allowed to accumulate. Buffers allow employees to share work without direct interaction—there is no need to coordinate the

<sup>1</sup> This assumes that productivity inputs are measured in terms of time spent, rather than in terms of fixed dollar amounts. Depending on whether the work is to a production quota, or at a piece rate, and whether the employees have other productive work to attend to when they are idle, this assumption may be more or less accurate. For many production contexts this seems to be a reasonable assumption.

handoff of work unless there is a special instruction or quality issue that needs to be addressed. When work times are variable, buffers also allow an upstream employee to work faster than a downstream employee during one cycle, and slower during the next, without incurring any blocking or starvation. (We refer the interested reader to Baker et al. [1990] for further development of the impact of buffers.)

A third WFP parameter, and our main focus in this paper, is what we term the *boundary rule* for assigning work from cycle to cycle. The simplest rule is a *static boundary*. With a static boundary the workload assigned to each employee is a set of (usually contiguous) operations, fixed from batch to batch. The workload is performed in a limited physical zone, or *workstation*, and the coordination necessary between employees at adjacent workstations is highly constrained: employees do the same things every time and pass the work along in the same way every time.

Static boundaries reduce the time required to coordinate the handoff of work, and they eliminate any idle time caused by preemption. An attempt is usually made to *balance* or equalize the work on a static boundary line (Ghosh & Gagnon, 1989). When employees have identical individual performance, balancing their workload minimizes starvation and blocking and may increase throughput rates, compared to imbalanced lines. Throughout this paper we assume that the static line we examine is balanced.

With a *dynamic boundary*, however, the workload assignment is allowed to change from batch to batch (Zavadlav et al., 1996). Such systems are common in the textile industry and have been used in warehouse order-picking operations (McCrary, 1994; Ruriani, 1998). A dynamic boundary may require one employee to preempt the work of another. Preemption is allowed in cases where it is relatively easy for one employee to take over the work of another mid-task, and it may reduce the amount of starvation on the line. An upstream employee must communicate the status of work to the downstream employee, and the two employees must coordinate the handoff of any required tooling or materials.

Dynamic boundary rules must have an implicit or explicit set of *forward and backward rules*, which specify how employees determine where their workload begins and ends for each

batch. In the rules we assume in this paper, employees proceed *forward* (downstream) with their current batch until they are preempted or, in the case of the last employee, until they finish the batch. If they catch up to the downstream employee, they must wait (blocking). Once the employee at the end of the line finishes, he or she walks *backward* to the adjacent upstream employee, preempts his or her work, and then proceeds forward again. Each employee, in turn, preempts the adjacent upstream employee, except the one at the beginning of the line, who begins a new batch. When we refer to a dynamic line, then, we are referring to a line with a dynamic boundary rule, which operates with these forward and backward rules.

Unlike static lines, dynamic lines obviously cannot be balanced (work equalized) in advance. But when worker differences in performance exist and are constant, dynamic lines can be shown to balance themselves (Bartholdi & Eisenstein, 1996) and should outperform static lines, as long as employees are assigned to the line in order of individual performance so that the fastest is at the end of the line and the slowest is at the beginning of the line. Hence, the assumption behind a dynamic boundary rule is that employees are significantly different in terms of performance and should be arranged so that their individual performance differences will produce efficient line performance. The assumption behind a static boundary rule, however, is typically<sup>2</sup> that employees are not significantly different in terms of performance, so the

<sup>2</sup>In papers concerning static boundary line balancing, researchers almost always assume that equalizing workload between employees is equivalent to maximizing group performance. But, of course, this is only true if individuals are identical in performance. In 1989, in a comprehensive literature review of over 150 papers, Ghosh and Gagnon (1989) found no research that incorporated individual differences in performance. Although one early paper dealt with individual differences (Mansoor [Dar-EI], 1968), this paper was mostly overlooked in the literature, possibly because the focus at that time was on establishing line balances in spite of such differences so that employees could more easily be interchanged or replaced (Parker & Wall, 1998). To our knowledge, only three line-balancing algorithms have appeared that account for individual differences in performance (Chow, 1990; Doerr et al., 2000; Mansoor [Dar-EI], 1968), and only one of these accounts for differences in variability (Doerr et al., 2000). These algorithms load faster employees proportionally more heavily than slower employees, and less variable employees more heavily, in inverse proportion

work should be assigned in such a way that each employee receives an equal load.

Other WFP parameters may affect the way work moves between employees on the line (e.g., a conveyor belt). However, in every case the primary impact of the policy on the interactions between employees is through starvation, blocking, and coordination. Thus, rather than attempt to detail the impact of each policy parameter, we focus on boundary rules and their impact on starvation, blocking, and coordination. Focusing on a single parameter will clarify the discussion. Moreover, boundary rules have been examined less often than other parameters. Even though a number of papers recently have been published in which dynamic boundary rules are examined (e.g., McClain et al., 2000; McCrary, 1994; Ruriani, 1998; Zavadlav et al., 1996), there has been no research, to our knowledge, in which their impact on heterogeneity and variability in individual performance rates has been examined.

#### BOUNDARY RULES, HETEROGENEITY, AND VARIABILITY

In this section we examine the effect of starvation, blocking, and coordination on the performance of static versus dynamic boundary rules. We will see that boundary rules (by impacting the levels of starvation, blocking, and coordination each WFP entails) moderate the effect of heterogeneity and variability on flow line performance.

We limit our definition of our dependent variable—flow line performance—to throughput rates, which are essentially a measure of efficiency. One of the goals of a WFP may be a reduction in time spent in employee interactions involving things other than working on the task (time-off-task). Increased buffer or batch sizes, or manipulations of the boundary rules, can thereby increase throughput rates (though possibly at a cost in terms of holding more inventory in the batches or buffers). When a WFP is adopted that entails an increase in time-off-task (such as a pull or just-in-time [JIT] system), it is not typically done to increase throughput rate but, rather, usually to reduce an operating cost

(e.g., a reduction in inventory cost because of a reduction in batch size or buffers) or to improve quality.

Thus, other factors, beyond a simple consideration of speed, may be important, because they may attenuate the negative performance impact of increased time-off-task and allow a firm to reduce inventory costs, for example, without reducing throughput rates (Doerr et al., 1996; Schultz, Juran, & Boudreau, 1998). Nonetheless, although we recognize that quality and satisfaction are also important outcomes in a flow line environment, we believe that an examination of the effect of boundary rules, heterogeneity, and variability on efficiency is important and sufficiently complex in scope.

We know that heterogeneity in individual performance will interact with the operating task context to impact flow line performance. For example, thirty years ago Steiner (1972) discussed the impact of heterogeneity in ability on the performance of groups. He developed a typology of tasks, where *conjunctive tasks* are those in which the "group performance is determined by the least able member," while *additive tasks* are those in which the group performance "depends upon the sum of the individual efforts" (1972: 17). The static rules we examine are related to conjunctive tasks (although the picture is complicated by the existence of variability), while the dynamic rule is related to additive tasks (although dynamism—the idea that the "matching" of tasks to employees would change from cycle to cycle—was not examined by Steiner). As for the interaction of heterogeneity and policy, Steiner noted that for conjunctive (but not variable) tasks, "the ideal arrangement in cases of this kind is one that involves as much homogeneity as possible" (1972: 112), while for additive (but not dynamic) tasks, he claimed that heterogeneity was "irrelevant to potential productivity" (1972: 117).

In the appendix we develop a simple model demonstrating that the existence of performance heterogeneity makes a dynamic rule perform *relatively* better than a static rule. The logic presented there is simple: as performance heterogeneity increases, the (balanced) static line will incur more idle time because of starvation and blocking, since the faster employees will wait more often and longer for the slowest one. Heterogeneity exacerbates the negative effect of starvation and blocking on a static line,

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to their variability. When individual differences exist, such "imbalanced" lines will outperform "balanced" lines.

but not on a dynamic line, because, given stable differences, faster workers do not need to wait for slower workers.

However, individuals have predictable differences in their variability as well as their average performance (Doerr & Arreola-Risa, 2000; Knott & Sury, 1987). We further examine the impact of these systematic differences in variability below. The point here is that the existence of this variability means that (for a given average individual performance) a dynamic rule should perform *absolutely* better as heterogeneity increases. This is because a dynamic rule line only incurs idle time owing to blocking when one employee catches up to another. Greater heterogeneity reduces the chance that will happen and, thus, reduces the negative effect of blocking on performance.

*Proposition 1: WFP will moderate the relationship between heterogeneity and flow line performance. (a) Under a static boundary rule, heterogeneity will increase starvation, blocking, and coordination, thus decreasing flow line performance. (b) Under a dynamic boundary rule, heterogeneity will decrease starvation, blocking, and coordination, thus increasing flow line performance.*

As noted, employees exhibit characteristic differences in variability as well as performance (Doerr & Arreola-Risa, 2000; Knott & Sury, 1987). That is, the performance of employees on flow line tasks exhibits significant and individually characteristic variability: sometimes an employee works faster than other times.

On a static line the bottleneck (slowest employee) determines work pace. Without variability, this means the throughput rate of the line can be determined by examining the throughput rate of the slowest employee. When variability exists, however, an employee may be slowest in one cycle, whereas another employee may be slowest in the next. Buffers are often placed between employees, primarily to mitigate the impact of this sort of variability. Without buffers it is the throughput rate of the slowest worker in each cycle that determines the throughput rate of the line. Thus, what becomes critical is not the mean of the performance distribution of the employee who is the slowest, on average, but the

tail of the distribution of the slowest employee in every cycle.

On dynamic lines the performance impact of individual variability on flow line performance will also clearly be negative, because its existence means that, occasionally, a slower employee will "catch up" to a faster one and become blocked. But dynamic lines face the additional problematic issue of whether the rank orders of individuals' performances change over cycles. This is of concern, because the dynamic rule relies on the existence of stable differences in the rank order of performances. The existing models of performance for dynamic rule lines assume constant rank orders. Individual variability in performance rates implies that the rank orders are random variables.

Without stable individual differences in performance and without the ordering of employees from slowest to fastest, Bartholdi and Eisenstein's (1996) result will not necessarily hold, and the line will not necessarily balance itself. The impact of variability on a dynamic rule is worse then, because it makes line performance unpredictable, and therefore more difficult to plan and control.

*Proposition 2: WFP will moderate the relationship between variability and flow line performance. Greater variability in individual work rates will degrade both static and dynamic line performance, but this effect will be relatively stronger on a dynamic than a static line.*

Propositions 1 and 2 concern the moderating effect that WFP will have on the relationship between heterogeneity and variability in individual performance and overall line performance. In the next section we examine the underlying causes of heterogeneity and variability and develop the proposition that a WFP may induce changes in heterogeneity and variability. Most models of performance suggest at least two main proximal causes of performance: ability and motivation (Campbell, Dunnette, Lawler, & Weick, 1970). We turn now to motivational factors associated with WFP and performance. Although WFP is unlikely to influence ability, it certainly can influence motivation. Our last two propositions concern the effect of WFP on performance heterogeneity and variability through differing motivational responses to the WFP.

## MOTIVATION AND BOUNDARY RULES

The *Koehler effect* is the tendency for heterogeneous groups to perform better than one would expect from their individual members' performances (Hertel, Kerr, & Messé, 2001). Aspects of a WFP or the task itself may moderate this motivational impact. Work on social compensation (Plaks & Higgins, 2000; Williams & Karau, 1991) indicates that when employees are engaged in meaningful work, faster employees will speed up if they are aware of their relative ability; the more important or meaningful a task, the greater the effect. In more recent research Hertel et al. (2001) found that the Koehler effect may occur on conjunctive tasks (similar to static policies) but not additive tasks (similar to dynamic policies). Thus, there is some support for the idea that WFPs can produce a motivational response that depends on the relative performance of the employees.

A number of other studies performed on flow lines support the idea that WFP and heterogeneity interact to produce a motivational response. Doerr et al. (1996) found that the increased interpersonal interactions caused by a pull policy were associated with a positive impact on effort, but the result, as pointed out by Schultz et al. (1998), seemed stronger for slower workers. Likewise, Schultz et al. (1998) found that increased interactions caused by reduced buffers were correlated with increased perceptions of peer pressure and increased performance, but only for employees on bottleneck jobs. Depending on the WFP in effect, the production rate of a flow line may depend on the slowest employee on the line. These findings point to an important link between the effects of motivational factors, WFP, and performance variability on flow lines.

Under a WFP, one worker depends on another either to provide work or to take work as it is passed downstream (or both). Thus, an individual's performance is dependent upon the performance of adjacent employees and, less directly, upon the performance of every employee on the line. One of the specific motivational factors thought to come into play when one worker depends on another to provide work is *felt responsibility*. This is a motivational force that grows out of expectations that one person should act to maximally facilitate and minimally hinder another (Thomas, 1957).

To capture sources of felt responsibility, Kiggundu (1978, 1981, 1983) operationalized a variable termed *initiated interdependence*, which measures the degree to which one employee feels that others rely upon him or her to accomplish their work. To the extent that initiated interdependence produces a sense of felt responsibility in an employee (because, for example, a downstream employee is waiting for him or her to pass along work), it should also yield an improvement in performance. In more recent research Pearce and Gregersen (1991) showed that felt responsibility also is positively related to organizational citizenship behaviors.

Initiated interdependence is thought to improve job outcomes at least partly through increased motivation (Kiggundu, 1983). There is some evidence, however, that this relationship may be concave (inverted-U shape). Wong and Campion (1991) found a concave relationship between another type of interdependence (interdependence between the tasks themselves, rather than between the employees) and internal motivation. Barker (1993) and Graham (1993) found a concave relationship between peer pressure and performance. And Stewart and Barrick (2000) recently found a concave relationship between initiated interdependence and job outcomes for the types of jobs associated with flow lines. Therefore, there appears to be some motivational benefit for moderate levels of initiated interdependence.

Initiated interdependence describes only one-half of a dyadic interdependence relationship. To describe the other half, Kiggundu operationalized (1978, 1981, 1983) a variable labeled *received interdependence*—that felt by one employee when he or she depends upon another to accomplish work. Kiggundu did not find the positive motivational impact for received interdependence that he found for initiated interdependence. In fact, to the extent that received interdependence is associated with reduced autonomy, it is likely to have a generally negative motivational impact (Klein, 1989; Thomas, 2000).

Depending on their *relative* performance and the WFP in place, employees on a flow line may experience either primarily initiated or primarily received interdependence and, thus, positive or negative motivation. On a static line faster employees will experience more interruption of work by a peer, through the blocking and starving caused by adjacent employees. Conversely,



on a dynamic line slower employees will experience the most interruptions, relative to the amount of work accomplished. Thus, the fastest employee on a static line and the slowest one on a dynamic line are most likely to experience negative motivational states owing to the control of their work pace by another employee. Since this is likely to be perceived as a loss of autonomy, it should lower intrinsic task motivation (Klein, 1989; Thomas, 2000).

Conversely, the slowest employee on a static line will experience the most responsibility for others, because he or she is the most frequent cause of starving or blocking another employee. This experience will be shared by the fastest employee on a dynamic line, because he or she controls the end of every cycle, and the whole line resets according to his or her pace. Consequently, these employees are most likely to experience positive motivation, because they have to provide work to others and maintain the work flow. Since this is likely to be perceived as increased pressure to perform, the effect will be a positive motivational one (Kiggundu, 1983; Stewart & Barrick, 2000; Wong & Campion, 1991).

*Proposition 3: Starvation, blocking, and coordination demands will produce a motivational response in employees, depending on their relative individual performance. (a) For employees whose performance is relatively high, there will be a motivational reaction to starvation, blocking, and coordination that is positive under a dynamic rule but demotivational under a static rule. (b) For employees whose performance is relatively low, there will be a motivational reaction that is positive under a static rule but demotivational under a dynamic rule.*

Proposition 3 predicts a regression to mediocrity on static lines when there is heterogeneity: faster employees slow down, while slower employees speed up. This is consistent with the findings of Doerr et al. (1996), Shultz et al. (1998), and Schultz, Juran, and Boudreau (1999). The opposite effect is predicted for a dynamic line: faster employees, having autonomy and control over work pace and perceiving responsibility for others, speed up, while slower employees, experiencing negative feedback from constant inter-

ruption of their work flow and loss of autonomy over work pace, slow down.

Depending on other parameters in the WFP, it is often the tail of the task-time distribution (e.g., the slowest individual performance), not just the mean, that determines flow line performance. Thus, it may be the difference between the slowest employee and the weighted average of all the employees on the line that determines the impact of heterogeneity on flow line performance, rather than the average difference between employees. Moreover, it may be (again depending on other WFP parameters) the slowest employee in every cycle that determines the flow rate of the line. Small differences in mean performance rates of individuals may translate into more substantial differences in the tails of their task-time distributions and, consequently, may have a larger performance impact than would otherwise be expected. But this means that not only the level of between-employee but also the level of within-employee variability is a significant factor affecting flow line performance.

When discussing the causes of individual variability in performance, it is important to note that variability may be driven, in part, by changes in abilities over time. The dynamic criteria issue deals with changes over time in the relationship between performance and measures used to assess individual differences (Ackerman, 1992; Austin & Villanova, 1992; Ployhart & Hakel, 1998). Of course, even a simple exponential learning curve model would predict some dynamism in performance, but most learning curves predict large changes at first and relatively stable performance after a task is well learned.

In addition to variance in underlying ability as a source or cause of performance variability, we propose that within-employee variability in performance may be caused by the WFP, partly because different policies will produce more or less clarity and simplicity in the work flow. We have already predicted that variability may reduce line performance under a dynamic rule. Here we note that a dynamic rule may also induce variability in individual performance.

By allowing employees to preempt their coworkers, a dynamic rule will enable some employees to complete more or less work in the same amount of time. Moreover, compared to a static line, a dynamic line involves more coordi-

nation time between workers, because they must preempt one another and communicate about the status of work they are passing along. A dynamic line also potentially involves a greater range of activities and more physical movement along the line than a static one. These factors will combine to affect the variability of individual work times, because (apart from any difference in mean performance that is due, for example, to the coordination, preemption, and movement time) they will create intermittent distractions in the work flow, make it more difficult to establish a predictable rhythm of work, and require a *dispersion* of effort and attention.

The idea that work context can create a dispersion of effort and attention is not new. Schweickert, Giorgini, and Dzhafarov (2000) describe the way that the decomposition of a task into a series of mental "and/or" choices can be used to characterize different *distributions* of task completion time. A dynamic policy also involves more cognitive work than a static policy. An employee must keep track not only of what he or she is doing but what he or she should or should not do next—that is, the boundary of his or her work assignment. This sort of "control" process—keeping track not only of the task itself but the boundaries between tasks—entails a dispersion of attention (Dutta, Schweickert, Choi, & Proctor, 1995) and, hence, a wider distribution of task completion time.

Other researchers have found that changes in operational context can produce changes in performance variability (Peters, O'Connor, & Rudolf, 1980). The idea that variability in work rules or in the nature of the task will produce a motivational response in employees is also not new (Wright & Cordery, 1999). What we are proposing is that dynamic boundary rules, because of the lack of assignment clarity, create a type of production uncertainty (Wright & Cordery, 1999), to which employees will respond not only with a characteristic shift in mean performance but also with a characteristic change in response pattern, or task-time distribution (Schweickert et al., 2000).

*Proposition 4: Dynamic boundary rules will be associated with higher levels of individual variability than static rules.*

In conjunction with Proposition 2, Proposition 4 implies that dynamic lines, given otherwise similar workers, will exhibit greater losses in line performance, because of individual variability, than static lines, both owing to the sensitivity of the rule to individual variability and to the variability that the rule induces in individual performance.

## DISCUSSION

We have developed a model that focuses on the relationships among WFPs, employee attributes, and the performance of flow lines. We label the two policies we have contrasted *static* and *dynamic*, based on the way work is assigned and processed. The two main employee attributes of interest here are heterogeneity and variability in individual performance.

In our first proposition we argue that heterogeneity improves flow line performance on a line when it can be exploited (e.g., a dynamic line), whereas it hurts line performance on balanced lines when work assignments are static. In the second proposition, using similar reasoning, we suggest that while variability in work rates will hinder performance on any line, it may be more of a problem on a dynamic line, which relies on a stable rank ordering of employees by relative performance. In our third proposition we suggest that WFPs produce different motivational reactions, depending on the relative performance of the employees. Employees whose performance is relatively high will react positively under a dynamic rule and negatively under a static rule, whereas the reverse is true for employees whose performance is relatively low. Finally, in our fourth proposition we argue that dynamic rules will induce variability in individual work rates.

Although the effects of starvation, blocking, coordination, and preemption on the performance of a flow line are primarily negative, cognitions and perceptions about those interactions may have a countervailing, albeit more distal, effect. Proposition 1 implies that heterogeneity in individuals' performance favors a dynamic rule, whereas homogeneity favors a static rule. If so, then Proposition 3 implies that starvation, blocking, and coordination will indirectly (through a motivational response to time-off-task) act to increase the performance of *both* types of lines, even though their impact on indi-

viduals relative to their performance is opposite on each type of line. Proposition 2 implies that variability in individual performance will act to decrease performance on both types of lines but that the effect will be stronger on a dynamic line. If so, then Proposition 4 implies that the policy itself will reinforce that negative performance impact.

One can see that this type of model can easily become much more complex when considering other aspects of WFP. Rather than attempt to build a comprehensive model, we have pointed out the importance of context—in this case boundary rules—and the surprising complexity of the relationships with performance heterogeneity and variability even in relatively simple contexts.

One extension of the present work is to investigate a more complex model of WFP and motivation through the use of the interdependence construct. In Proposition 3 we discussed the impact of motivation, caused by initiated and received interdependence, on performance. Other forms of interdependence have been investigated in models of group performance and as related to motivation (e.g., Durham & Locke, 1998; Hatcher & Ross, 1991; Saavedra, Earley, & Van Dyne, 1993). Interdependence is a complex construct that is clearly related to flow line interactions and performance, but its many different aspects are beyond the scope of the current work.

It may seem that our focus on production flow lines is too narrow or too old fashioned. However, the literature on flow lines is quite extensive. While we have not drawn upon the entire breadth of the flow line literature, we believe a review of our propositions, especially Proposition 3, demonstrates the value of specificity: some of the relationships cannot be understood or predicted without referring to a specific context. Our propositions are limited to flow lines, but we believe flow lines are an important business context. Moreover, although our specific propositions may not apply outside the context of flow lines, we believe our paper demonstrates the potential of examining the effects of heterogeneity and variability in other work contexts.

Indeed, it is one of the points of this paper that models that examine group performance in operational settings may need to take operating context into detailed account. In examining the landscape for future manufacturing research,

John Little, discoverer of the famous "Little's Law" of queuing theory, said that grand theories (or "laws") that are meant to apply across any operating context may not explain enough to be useful, and he called instead for research to focus on the difficult work of explaining the performance of specific manufacturing systems (Little, 1992).

## CONCLUSION

One implication of our work, if support is found for the propositions, is that a WFP should be selected with the heterogeneity and variability of individual employee work rates in mind. Although it may seem overly "Tayloristic" to consider employee heterogeneity and variability in employee selection and group composition, we would point out that such a procedure would be unquestioned if applied to any other input to a production (or service) process: one of the points of quality management is the control of variability in methods and material. It is reasonable to suggest that the employees themselves, as a major source of variability (Doerr & Arreola-Risa, 2000), ought to be evaluated and managed with the same careful attention.

Research on static boundary flow lines has already demonstrated the value of matching employees' workload to their ability and variability (Doerr et al., 2000). The data requirements for such a proposal are reasonable. Software is already used in the call center industry to track employee performance on individual tasks and to then determine schedules based on predicted call volume, matching specific employees' abilities to the predicted workload (Hollman, 2000). The same data could be used to schedule groups of employees based on heterogeneity and variability of performance.

As we have already noted, the idea that individual performance heterogeneity and operating context interact is not new and was discussed by Steiner (1972) thirty years ago. However, Steiner also noted that

the critical impact that homogeneity-heterogeneity can have on group processes . . . is often neglected by theoreticians and experimenters alike. Furthermore, the consequences of homogeneity-heterogeneity are likely to be mediated in a more subtle manner by task demands than are the effects of average membership qualities (1972: 106).

Although, as noted, there has been a great deal of research on the consequences of heterogeneity (in demographic and dispositional characteristics), there is still substantial neglect of the causes of performance heterogeneity, especially regarding the "subtle" effects of "task demands" that we have tried to investigate here.

Contextual factors such as performance obstacles (Brown & Mitchell, 1988) and situational constraints (Peters, Fisher, & O'Connor, 1982; Peters & O'Connor, 1980; Peters et al., 1980) often have been investigated as moderating the relationship between ability and motivation on the one hand and performance on the other. WFP can be seen as one such contextual factor. However, we believe that WFP is a more narrowly, and perhaps more clearly, defined construct than other previously investigated contextual factors. We suggest that models involving the impact of individual-difference variables in production contexts may need such specificity in order to be useful and accurate (Little, 1992).

The components of our propositions—context (dynamic and static policies) and individual attributes (heterogeneity and variability in performance, as well as motivational reactions)—can thus be seen as part of the long-standing model of performance, where ability  $\times$  motivation = performance, given certain contextual restraints and parameters (Dunnette, 1983; Heider, 1958; Mitchell, 1997). Our propositions elaborate on this basic model by incorporating heterogeneity and variability and by providing a quite specific contextual variable (boundary rule) that impacts the underlying relationships. In further explicating the relationships among heterogeneity and variability and WFP, we believe we have shed more light on the way that motivation and ability may determine group performance on flow lines. Given that ability and motivation are deemed the major predictors of work performance (Campbell et al., 1970), and flow lines are where many of the goods that fuel our economy are produced, an integration of these variables into an overall model is sorely needed. Hopefully, the model presented here and the accompanying propositions are an initial step in that direction.

## APPENDIX

To lend specificity to the discussion around Proposition 1 and our WFP variable, in this ap-

pendix we develop a formal model of the impact of heterogeneity on two WFPs. The first policy is an unpaced, preemptive, dynamic boundary policy, with the bucket brigade forward and backward rules, a batch size of one, and no buffers. The second is a synchronous unpaced static boundary policy, with balanced work assignments, a batch size of one, and no buffers. Note, then, that the main difference between these WFPs is the difference in boundary rules.

Two common performance measures on a flow line are the cycle time and the flow time. The cycle time  $C_p$  is the average time between item completions on a line following boundary rule  $p$ . The flow time  $R_p$  is the average time it takes an item (batch) to go from the beginning of the line following boundary rule  $p$  to the end of the line (including idle time). A small cycle time and flow time are two things sought in flow line design.

Let  $X_i$  = the time employee  $i$  requires to complete his or her assigned workload and  $m$  = the number of employees. Without heterogeneity (or variability), the flow time of the static rule line can be expressed as

$$R_{\text{static}} = \text{Max}\{X_1, \dots, X_m\} + \text{Max}\{X_2, \dots, X_m\} + \dots + X_m, \quad (1a)$$

and the cycle time can be expressed as

$$C_{\text{static}} = \text{Max}\{X_1, \dots, X_m\}, \quad (1b)$$

since without buffers everyone will wait until the last employee finishes to begin a new cycle. If no heterogeneity exists and the line is balanced, we have  $X = X_i$  for all  $i$ , so

$$R_{\text{static}} = mX \quad (1c)$$

and

$$C_{\text{static}} = X. \quad (1d)$$

To examine the impact of heterogeneity on the static rule line, we must define  $X_i$  in terms of both  $\kappa_i$ —the work units assigned to station  $i$ —and  $\alpha_i$ —the speed of the employee assigned to station  $i$  in work units/time. We then have  $X_i = \kappa_i/\alpha_i$ , and the flow time of the line becomes

$$R_{\text{static}} = \text{Max}\{\kappa_1/\alpha_1, \dots, \kappa_m/\alpha_m\} + \text{Max}\{\kappa_2/\alpha_2, \dots, \kappa_m/\alpha_m\} + \dots + \kappa_m/\alpha_m, \quad (2a)$$

and the cycle time becomes

$$C_{\text{static}} = \text{Max}\{\kappa_1/\alpha_1, \dots, \kappa_m/\alpha_m\}. \quad (2b)$$

In comparing Equation 1a to 2a, one can see that the impact of heterogeneity of performance on the flow time with a static boundary rule depends on the relative positions of the employees. Still assuming a balanced line, the smallest flow time is achieved by placing employees in sequence, from the slowest at the beginning to the fastest at the end. Also, Equation 1c acts as a lower bound to 2a: heterogeneity of performance can only increase the flow time of a static rule line. Even worse, in comparing Equation 1d to 2b, it is evident that, for a given average ability, heterogeneity will increase the cycle time of a balanced line.

Turning to the dynamic rule, performance of a line without heterogeneity (or variability) is fairly easy to predict. The line would incur no blocking, because identical employees would never "catch up" to one another,<sup>3</sup> and the flow time of the line would be identical to that given in Equation 1c. However, since there are no station times on a dynamic rule line, we need to use a different notation. Let  $\alpha_i = (\sum \alpha_i / m) = \alpha$  be the (identical) individual speed for all employees, and let  $K = \sum_i \kappa_i$  be the total workload on the line. Then, without heterogeneity, the flow time of a dynamic rule line would be

$$R_{\text{dynamic}} = K/\alpha = R_{\text{static}}, \quad (3a)$$

and because there is no idle time, the cycle time would be

$$C_{\text{dynamic}} = R_{\text{dynamic}}/m = C_{\text{static}}. \quad (3b)$$

The introduction of heterogeneity changes the relative production efficiency of dynamic and static boundary rule lines. As long as employees are sequenced from slowest to fastest, Bartholdi and Eisenstein (1996) have shown that the line still will incur no starvation, because a slower employee can never catch up to a faster one. The line balances itself in such a way that a worker  $i$  performs an amount of work in proportion to his ability,  $(\alpha_i/\sum \alpha_i)$ , and stabilizes to the following flow time:

$$R_{\text{dynamic}} = (\alpha_1/\sum \alpha_i)K/\alpha_1 + (\alpha_2/\sum \alpha_i)K/\alpha_2 + \dots + (\alpha_m/\sum \alpha_i)K/\alpha_m = K/\alpha. \quad (4a)$$

In other words, unlike in the static line, heterogeneity does not reduce the performance of a dynamic line. An examination of Equations 2a and 4a reveals  $R_{\text{dynamic}} \leq R_{\text{static}}$ . Moreover, the cycle time of the static line is still determined by the slowest employee (2b), while the cycle time of the dynamic line is

$$C_{\text{dynamic}} = R_{\text{dynamic}}/m \leq C_{\text{static}}. \quad (4b)$$

The inequality in 4b demonstrates the superiority of dynamic rules over static rules, given heterogeneity but not variability in employee performance. If there is variability in employee performance, slower workers on a dynamic line may sometimes catch up to and be blocked by faster workers. Since some level of variability exists in every human system, a more heterogeneous group of employees can be seen to be less likely to catch up to one another and, thus, perform better than a more homogeneous group with the same average employee performance.

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<sup>3</sup> However, it is important to note that this statement assumes operation times are not only deterministic but stationary and continuous as well, since a "catch up" could occur even for identical employees if, for example, work requirements changed from item to item, or if an upstream employee were forced to wait while a downstream one finished on a machine.

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