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Operations management (OM) and human resources management (HRM) historically have been very separate fields. In practice, operations managers and human resource managers interact primarily on administrative issues regarding payroll and other matters. In academia, the two subjects are studied by separate communities of scholars publishing in disjoint sets of journals, drawing on mostly separate disciplinary foundations. Yet, operations and human resources are intimately related at a fundamental level. Operations are the context that often explains or moderates the effects of human resource activities such as pay, training, communications, and staffing. Human responses to OM systems often explain variations or anomalies that would otherwise be treated as randomness or error variance in traditional operations research models. In this paper, we probe the interface between operations and human resources by examining how human considerations affect classical OM results and how operational considerations affect classical HRM results. We then propose a unifying framework for identifying new research opportunities at the intersection of the two fields.

(*Multidisciplinary; Cross-Training; Work Design; Scheduling; Low Inventory; Behavioral Science; Motivation; Turnover; Worker Performance; Worker Attitude*)

1. Introduction

The fields of operations management (OM) and human resources management (HRM) have a long history of separateness. In industry, it has been rare for an operations manager to become a human resources manager, or vice versa. In academia, the two subjects have been studied by essentially separate communities of scholars who publish in nearly disjoint sets of journals. Despite this, operations and human resources are intimately tied to one another in virtually all business environments. Recognizing this fact opens many opportunities for major improvements in both research and practice.

For example, consider the case of a Big Three auto company power-train facility with a history of poor budget performance and low efficiency. In spite of a high-profile corporate emphasis on lean manufacturing and the best efforts of the company's lean engineers and six-sigma black belts, the plant continued to underperform until 2001, when a new plant manager took over. Immediately recognizing that the primary cost driver was throughput (failure to make production quota during regular time required expensive overtime), he zeroed in on the largest source of output loss, blocking and starving in the line (traditional OM topics). But, because he knew that the majority

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of stoppages were due to people-induced disruptions, the new manager eschewed the traditional OM focus on equipment-induced causes and worked instead to involve operators in the problem solving process (a traditional HRM topic).

Several months were spent educating the workforce on the drivers of performance (e.g., the importance of bottlenecks) and setting up mechanisms for formally recognizing people for their successes (in nonmonetary ways, because this was a union facility). In less than a year, the plant was transformed into one of the best performers in the company, despite a down economy.

The lesson from this story is that both human and technical considerations can be vital in the success of operations improvement programs, and integration of these two viewpoints is key. By helping workers to understand the implications of the OM design for their work and then motivating them to act accordingly, the plant turned around its performance.

But simply acknowledging human considerations such as motivation is not enough. Consider the case of a circuit-board plant of a large computer manufacturer that was also plagued by low throughput. Recognizing that worker contributions were essential, management embarked on a motivational campaign, which included shirts, pep talks, and illuminated signs with slogans such as "I love my job." Not only did these efforts fail to promote higher output, but also the workforce was put off by them and became cynical about improvement efforts in general.

Eventually, the circuit-board plant adopted an alternate approach, which made use of both OM and a more sophisticated understanding of motivation. It included training the workers to understand key success variables of pull systems, investment in additional capacity that gave work teams more ways to share and combine tasks, and installation of new control systems that the workforce understood. Throughput was doubled within months; total cycle time was slashed by three-quarters in a year.

The lesson from this story is that a clear operational focus can be critical to the success of human relations initiatives. Only when the workforce was provided with appropriate knowledge and tools were people really motivated to make changes. Understanding the operational context showed how to direct the investments in task design, communication, and rewards more precisely to those workers and tasks that made the biggest operational difference.

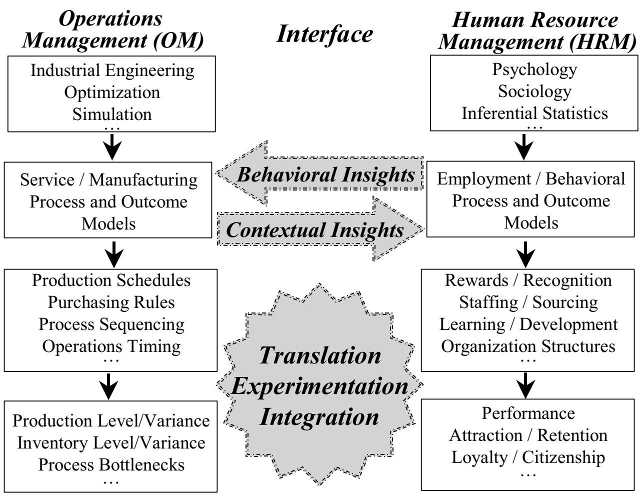
Interestingly, these results are precisely what psychological research on goal-setting would predict, as decades of behavioral research shows that appropriately difficult and specific goals produce performance superior to more vague and general goals (Locke 1982, Locke and Latham 1984) and that worker "line of sight" regarding how their actions affect outcomes enhances performance (Boswell 2000, Lawler 1999, Vroom 1964). Yet, such research findings seldom find their way into scholarly discussions of OM, and even more rarely are they known by operating managers. By the same token, behavioral scientists, HR managers, and industrial psychologists working in organizations rarely incorporate the OM context to reveal which particular goals and which particular motivational connections have the largest impact. Although these links were recognized long ago by such pioneers as Lillian Gilbreth, whose work specifically addressed the linkage between the workings of the mind and effective operation in the workplace (Gilbreth 1921), they remain a source of opportunity in both research and practice.

The OM/HRM Interface

Our objectives in this article are to call attention to the value of connecting OM and HRM, to offer an initial organizing framework for those connections, and to provide examples of past and future research that illustrate the value of those connections. Fulfilling the potential of these connections will require scholars and managers in HR and OM to work together. So, we hope to find an audience among those in both disciplines. Yet, because OM and HRM use the same terms somewhat differently, it is important that we use and define them carefully. This introduction will therefore not only describe our organizing framework and objectives, but will define several terms that we will use throughout.

We begin with the "interface" between OM and HRM, shown in Figure 1. OM models (the left side of the figure) are derived from disciplines such as industrial engineering, optimization, and simulation. They

Figure 1 The Operations Management and Human Resource Management Interface



are usually mathematical descriptions of service or manufacturing processes, including such elements as number and types of employees, customer demands, production schedules, purchasing rules, process sequences, and operations timing. OM models predict and explain outcomes such as production or inventory levels and variation, and service and production bottlenecks. HRM models (the right side of the figure) are derived from disciplines such as psychology, sociology, and inferential statistics. They describe employment and behavioral processes, and their relationships to such things as rewards/recognition, staffing/sourcing, learning/development, and organization structures. HRM models predict and explain outcomes such as performance, attraction/retention, and loyalty/citizenship. Figure 1 is not intended to represent a comprehensive inventory of the disciplines, relationships, or outcomes of the HRM and OM fields, but rather to convey our concept of the interface between them. The dots (···) in the boxes of Figure 1 convey our belief that there are many additional elements.

The OM-HRM interface is depicted in the darker areas of Figure 1. OM can provide contextual insights to significantly enhance the precision and rigor of HRM models, processes, and outcomes. HRM can provide behavioral insights to significantly enhance the precision and rigor of OM models, processes, and outcomes. These insights will develop first through "translation," as each field better understands the other's paradigms and approaches. Then, "experimentation" will identify which integrative insights hold the greatest promise for practical and scholarly significance. Finally, we foresee "integration" as each field incorporates the most promising and useful insights into its own models.

We provide richer and more sophisticated examples in later sections, but an admittedly oversimplified example can help define what we mean by the OM-HRM elements, interface, and translation-experimentation-integration. Consider a production process that develops a bottleneck, such as a workstation where in-process work inventory is backing up. OM models would focus on elements such as added resources (machines, people, speed) to the bottleneck area, and the effects on costs and total output. OM models often assume that the workers will perform at the same pace and with the same variance whether the bottleneck exists or not. Ironically, the most famous illustration of a bottleneck in the OM literature is that of a troop of boy scouts whose hiking speed is governed by the pace of Herbie, the fat kid (Goldratt and Cox 1984). Even though the bottleneck is a person in this example, OM models almost never endow bottlenecks with any human characteristics.

In contrast, HRM behavioral models frequently focus on elements such as individual capabilities and motivation, and the effects of HRM practices, such as rewards and training, and their effects on job performance. Applied to the boy scout example, these models would address the factors that affect hiking speed (e.g., do motivational speeches increase speed? how does Herbie feel to be the slowest?). However, HRM models often assume that enhanced performance is desirable in every job, as long as it exceeds the costs of the practices that induce it. So, without an operational focus, HRM methods might well be applied to increasing the speed of all the boy scouts instead of concentrating on Herbie, whose speed matters most to overall performance.

For the case of a production bottleneck causing inventory backups, the HRM field can easily see how to improve the OM assumption that people will work at the same pace and variability under all inventory conditions—low inventory systems may provide feedback that causes individuals to adjust to their work situation. Similarly, the OM field can easily see how to improve the HRM assumption that enhanced job performance is equally valuable wherever it occurs—enhancing performance at a bottleneck operation may be several times more valuable than for other processes.

When these insights are translated so that each field can understand their implications for their models, and the insights are verified through experimentation, then both OM and HRM models become richer, more precise, and more effective. Behavioral HRM theories can predict when workers will adjust so that the predicted OM bottleneck may never occur, while OM models can identify which adjustments matter the most (Schultz et al. 1998). Methods for better incorporating human behavior into OM models will yield more realistic insights. Incorporating operations context into HRM theories will make general theories more contextually precise, and will help identify new ways for HR practices to add value.

These examples use particular production or service processes and individual-level reactions, responses, and behaviors. Of course, processes and individual responses occur within a larger organizational context that determines formal and informal structures, competitive positioning, and cultural norms, as well as relationships with key constituents such as governments, labor organizations, and communities. Organizational factors are important to the HRM-OM interface. We recognize them in later sections as part of the "opportunity" for individual behaviors to occur, and also in the broader framework of strategic success.

In this paper, we propose to contribute to "translation" by offering an example of an organizing framework that uses some basic elements of HRM and OM. To contribute to "experimentation," we will illustrate our framework with examples and potential research questions and studies. Finally, to contribute to "integration," we will describe how both HRM and OM theories, models, and practices can be and have been enhanced by better understanding their respective perspectives.

Researchers are not the only beneficiaries of greater communication at the OM-HRM interface. OM and HRM managers in organizations are constantly wrestling with this interface, and often with quite remarkable results. The earlier automotive and circuit-board examples were innovations by OM managers, working with their HRM colleagues. This is also a common theme in HRM. Somehow, managing people must become an integral part of the job of "line" managers in manufacturing and service operations, not simply the domain of the HR "staff function" (Ulrich 1997). The interface of OM and HRM is a key arena for the transformation of HRM from a staff function or professional practice to a decision science (Boudreau and Ramstad 2002, 2003). We shall return to this idea in §4.

For both researchers and practitioners, a framework can serve as an organizing scheme to identify interesting and important questions. We hope to make a start on an organizing framework that will stimulate OM researchers/managers to consider HRM issues, HRM researchers/managers to consider OM issues, and at least a few brave researchers to venture into the interface directly. To be sure, both groups are already wrestling with issues that reflect this interface, as our examples will illustrate. Our aim is to suggest a more explicit treatment of these issues that will help both groups collaborate more effectively, and to identify research opportunities that will have a positive impact on organizations.

Section 2 begins with the "behavioral insights" arrow in Figure 1, describing four fundamental elements from HRM and behavioral theory, and showing how they can inform and enhance OM models and applications. Section 3 turns to the "contextual insights" arrow in Figure 1, describing several OM elements and showing how they reveal the operational context and business processes that can enhance the impact of HRM theory and applications. Sections 2 and 3 demonstrate the value of research at the interface by providing specific examples of questions from each field that can be improved using elements from the other field. Section 4 develops the framework further, embedding it within a larger model of the connection between decisions about talent and the strategic success of organizations. Section 5 provides a taxonomy describing future research opportunities at the OM-HRM interface and concluding remarks.

2. How Human Resources Management Can Inform Operations Management

There is a very large set of elements of human behavior at work that might be used to illustrate the HRM-OM interface. Any textbook on HRM, organizational behavior, or organizational design contains its own model or framework of the key elements. We will not try to resolve these models into one consolidated set of behavioral elements. Rather, we will build our working framework from four elements that underlie most work behavior models:

(1) Capability: The skills, knowledge and abilities necessary to execute an action associated with the objectives of the organization.

(2) Opportunity: When individuals are provided or encounter situations in which actions can be executed with the desired effect.

(3) Motivation: The drive to execute those actions, created by a perception that they are linked to desired outcomes and rewards.

(4) Understanding: Knowledge of how an individual's actions affect the system and overall goal achievement.

The first three components are derived from a long research tradition suggesting that individual performance is a multiplicative function of ability and motivation (Vroom 1964, Maier 1955, Cummings and Schwab 1973), critiques of the simple model (Campbell and Pritchard 1976) that suggest that the environment determines the expression of ability and motivation (Gilbreth 1909, Dachler and Mobley 1973), and recent work suggesting that situational constraints and opportunity (e.g., advances in technology and changes in the political, social, and economic environment) are key to a theory of work performance (Campbell 1999, Howard 1995, Ilgen and Pulakos 1999). We have added the fourth component—understanding—to help describe the OM and HRM interface. These and other human issues have the potential to "move the needle," that is, to materially change the output of a process. For brevity, we will use the acronym *COMU* to refer to the full set of elements.

The automotive example (given earlier) illustrates a case of emphasizing opportunity without sufficient motivation, while the circuit-board example illustrates a case of emphasizing motivation without sufficient opportunity or understanding. In both cases, the solution involved integrating the COMU elements into the OM application.

Simplification is an essential part of all modeling, and OM researchers and managers are aware that their models involve simplified representations of human behavior. But they may not always be aware of the consequences these simplifications can have on decision making. To gain insight into this issue, we begin by listing some of the most common assumptions used to represent people in OM models. We then give a number of examples in which more realistic consideration of human behavior can have a significant impact on conclusions. Finally, we discuss previous and potential future research.

The following assumptions are commonly used to simplify human behavior in OM models.

(1) People are not a major factor. (Many models look at machines without people, so the human side is omitted entirely.)

(2) People are deterministic and predictable. People have perfect availability (no breaks, absenteeism, etc.). Task times are deterministic. Mistakes do not happen, or mistakes occur randomly. Workers are identical (work at the same speed, have the same values, and respond to same incentives).

(3) Workers are independent (not affected by each other, physically or psychologically).

(4) Workers are "stationary." No learning, tiredness, or other patterns exist. Problem solving is not considered.

(5) Workers are not part of the product or service. Workers support the "product" (e.g., by making it, repairing equipment, etc.) but are not considered explicitly as part of the customer experience. The impact of system structure on how customers interact with workers is ignored.

(6) Workers are emotionless and unaffected by factors such as pride, loyalty, and embarrassment.

(7) Work is perfectly observable. Measurement error is ignored. No consideration is given to the possibility that observation changes performance (Hawthorne effect).

While assumptions such as these simplify modeling and mathematics, they can omit important features. For example, consider the situation in 1985, at a plant that was a joint venture between Yokogawa Electric and Hewlett Packard (YHP) where electronic circuit-boards were "stuffed" manually with a wide variety of components. Although this plant had less automation and greater product variety than other HP plants, it nevertheless had the highest level of productivity in its category. The reasons had to do with the workers and their "talents."

We use the term "talent" broadly, to refer to the potential for workers to affect organizational processes and outcomes. Talent pools are often formally described in job titles, competencies, knowledge, and certifications, but many worker talents are less obvious. For example, a call-center operator's job description may say very little about effectively handing off work to coworkers, yet this talent may be one of the most pivotal in enhancing the effectiveness of the queuing process.

Returning to the YHP example, this plant had a simple flow-line design. Each worker was assigned several types of components, which they manually placed on circuit-boards. Work-in-process inventory (WIP) was (usually) physically limited to two boards between successive workers. Given the product variety and limited WIP, standard OM models would have predicted a large amount of blocking and starving (work stoppage while waiting for another worker to finish). However, workers and managers had come up with a scheme that avoided idle time. The key element was task sharing. For example, the first worker always placed components 1–4 and the second worker always placed components 7–10, but components 5 and 6 were placed by whichever worker was "ahead." The OM researchers who studied this called it "on-the-fly line balancing" because tasks were reassigned in real time to compensate for a temporary imbalance that would otherwise cause blocking or starving (Ostolaza et al. 1990, Sox et al. 1992).

The mathematical model of on-the-fly line balancing provides a clear OM explanation of why the new operating method should be effective—Worker flexibility was used to smooth out variations in workload and thereby reduce idle time caused by blocking and starving. The on-the-fly model assumes that workers switch tasks at appropriate times and that the new system will make no difference in the quality of component placement. From an HRM perspective, such assumptions have significant implications for talent. In terms of COMU, workers must have the opportunity to modify the design of their work space and the capability to place the additional components, understand when to switch tasks, be motivated to take on the extra work at the appropriate time, and understand how their task-switching decisions improve overall throughput and avoid idle time. Also, the task-sharing approach meant that it was very difficult to observe individual contributions (point 7 above). Workers must develop loyalty to their unit and willingness to cover for each other on breaks and for tiredness (points 3, 4, and 6). Even the enhanced OM model with task-sharing did not incorporate these effects, nor did it explain how training, selection, and other HRM variables might enhance the positive results of this system. Hiring practices must also recognize that some workers will not thrive in an environment that requires a high degree of responsibility. For example, in a GM training program (Guilford 2002) many workers dropped out after GM used a setting where workers determined task allocations and enforced quality standards. Notably, the workers had in large part designed the production line in question (Guilford 2001).

This realization applies to many other situations that have long been studied by OM scholars. For example, OM research on services often addresses capacity, availability of servers and scheduling. HRM research has addressed complementary issues such as how services can be designed to improve performance (Cook et al. 2002, Batt 1999). These are but a few examples where HR and OM have complementary roles and where research at the intersection may shed light on innovations that integrate OM and HRM to move the needle.

2.1. Translating Behavioral Insights into the Language of OM Models

OM models frequently use mathematical modeling of production and service settings to identify previously unrecognized optimization opportunities. Thus, one way to translate behavioral insights into the language of OM is to consider how these mathematical models might integrate behavioral principles and findings from HRM. If the OM-recommended policy is either more effective or less effective than predicted by the model, then the question arises of what human factors might explain the difference. For instance, in the previously cited example of a Big Three powertrain plant, a standard transfer-line model would predict a much higher throughput than was being observed. This would be a clue that important human factors may have been overlooked.

Once a feature of human behavior has been recognized, incorporating it into the analysis can lead to better OM models. For example, many classical operations models assume that people are like machines, effectively identical to one another and exhibiting only random performance variation (e.g., Hillier and Boling 1967, Conway et al. 1988). Yet, individuals differ in skills, speed, and many other characteristics; this is the most basic of HRM and industrial psychology insights. So, it is not surprising that some of these classical models do not match reality. Some OM models recognize that people possess different skills that allow them to be assigned differently to a set of tasks (e.g., Bartholdi and Eisenstein 1996a, b; Buzacott 2002; Hunter et al. 1990). But these models retain the assumption that within-individual variation is random (or perhaps nonexistent), which conflicts with the HRM insight that workers observe and respond to the context of their work in nonrandom ways. OM models that include such factors could create a link between OM and the HRM investments that attract, retain, and develop workers and affect their responses to their environment.

Flexibility has been a hot topic in the OM literature. Many of the models focus on cross-training, which enables workers to help each other in a manner that avoids some of the counterproductive effects of variability. Examples include analyses of bucket brigades (Bartholdi and Eisenstein 1996b), dynamic line balancing (Ostolaza et al. 1990), and "worksharing" (Bischak 1996, Zavadlav et al. 1996, McClain et al. 2000). But whether and where cross-training will actually increase productivity in practice depends on a number of HRM concerns. Do frequent changes of tasks interrupt the rhythm of an operation, causing workers to slow down? Worker perception of fairness affects whether and how they help one another (Bowen et al. 1999, Rousseau and Shalk 2000, Hartman et al. 1998). Does that help or hinder system output? Reward systems affect how people respond to work instructions (Luthans and Davis 1990, Ichniowski et al. 1997, Ichniowski and Shaw 1999). How does method of pay affect worksharing operations? Workers lose proficiency in skills that are used infrequently (Goldstein 2002, Noe 2002). When skill loss is taken into account, can we identify a limit on the benefits of cross-training?

Ideas for better incorporating HRM issues into OM modeling and practice can come from theory and experience. We can use HRM theory to refine an OM model by more accurately representing human behavior, or we can observe the OM concept in practice and adjust the model according to human responses. In either case, we propose that OM researchers consider refining their mathematical models using behavioral elements like these.

Unfortunately the required collaboration among OM and HRM researchers will not be easy because the two fields tend to think in different paradigms. Translation will be necessary. Most HRM and behavioral principles are not expressed in specific mathematical terms. Nonetheless, the findings from behavioral research often contain a great deal of useful information about direction and magnitude, which provides a starting point for including behavioral effects into mathematical OM models. Boudreau and Ramstad (2002, 2003) encouraged behavioral researchers to refine their work into the "necessary and sufficient conditions" for such things as learning, motivation, etc. Necessary and sufficient conditions are a common feature in mathematical OM models, but not in HRM.

2.2. Experimental and Field Research Bringing Behavioral Insights into OM

While mathematical modeling is one OM approach to predicting and explaining service and manufacturing processes, there is also a rich opportunity for experimentation at the OM-HRM interface. Experimentation may also prove useful in suggesting specific enhancements to mathematical OM models. Because almost all operations systems involve people, the list of specific OM results that might be affected by human behavior is virtually unlimited—A comprehensive list is not feasible. Instead, we offer the following areas as examples of situations where mainstream OM results may be affected by human considerations. For each, we note the classic OM insight and a contrasting HRM observation. These are chosen to address potential "unaddressed talent issues," which might allow or cause workers to move the performance needle, and thus could alter the OM insight. Research already exists for some of the topics, but for most the HRM effects on the OM result remain conjectures in need of research attention.

Inventory as a Buffer. Use of inventory buffers to mitigate the impacts of variability is a practice as old as manufacturing itself. Indeed, some of the oldest results of the OM field (e.g., base-stock formulas) deal with the problem of setting appropriate inventory levels.

OM. In serial production lines with variable tasks, more storage space for WIP reduces blocking and starving, and hence increases output.

HRM. In some cases, workers speed up when a queue grows (Edie 1954). WIP provides a signal to workers. Observing the rise and fall of WIP indicates "who is getting more work done," which might induce a change in work pace. Changes in WIP are less obvious when inventories are very high. Therefore, workers are more likely to link their speed of operation to "changes in WIP" in a low-inventory system than in an operation that has large amounts of WIP.

Previous Research.

(1) Doerr et al. (1996) and Schultz et al. (1998) compared work pace in low-inventory lines and high-inventory lines. This research suggested that average work pace is faster in low-inventory lines, enough so as to compensate for loss because of blocking and starving (17%). However, results differed for slow workers and fast workers.

(2) Schultz et al. (2003) studied motivational effects of different forms of visible feedback and concluded that visible performance feedback increases work pace. Reducing ambiguity of feedback enhances this effect.

Server Pooling. Scheduling and assigning labor resources has long been a focus of OM research. Recent years have seen an increase in the practice of cross-training workers to cover multiple task types (see, e.g., McClain et al. 2000) and on the effects of queue length on customers and workers (Taylor and Fullerton 2000, Zohar et al. 2002, Schneider et al. 1996).

OM. Pooling (servers sharing the same source of customers) reduces idle time by avoiding the situation where one server is idle while another has a queue of customers or tasks. In a mixed-model assembly line, pooling may be achieved by cross-training and flexible task assignments. A similar effect occurs in call centers, where cross-training not only provides pooling but also increases the likelihood that a given customer's needs can be met by a single worker, thus avoiding time loss caused by handing off a task.

HRM. Theories of learning suggest that practice enhances and maintains proficiency, so there is likely an upper limit to the effectiveness of cross-training (Gill 1997). If too many tasks are trained, lack of regular use as well as cognitive limits may cause productivity losses as a result of forgetting (Goldstein 2002, Noe 2002, Argote and Epple 1990).

Proposed Research. Schultz et al. (2003) studied the effects of short work interruptions and found that short work interruptions reduce average work pace, but not for all workers. More work is needed to explore how efficiency is affected by incorporating occasional tasks in environments that use cross-training.

HRM. Individuals are more motivated when they perceive they have choice, discretion, and some control over their work (Hackman 1978, 2002). Individuals tend to choose tasks they do best, that are the easiest, most familiar, or most satisfying. Do they choose the "wrong" task (operationally), rather than the one that does the system the most good?

Proposed Research. Study the effect that "allowing choice of task" has on output, especially in situations when it is optimal to limit choice for OM reasons.

HRM. Training costs are significant, as are pay differentials to retain cross-trained workers. Opportunity for cross-training may enhance the ability to attract workers, but cross-trained workers may also be more marketable and prone to leave (Batt and Osterman 1993, Bishop and Kang 1996). Increased behavioral costs of compensation, turnover, attraction, and retention (Cascio 2000) may materially affect the estimated returns from cross-training in OM models. OM models are generally naive with regard to such costs, which may have significant effects on the optimal levels of cross-training.

Proposed Research. Study the effect of cross-training on attraction and turnover, and on system output. Study differences across workers. Estimate the cost implications of increased rewards, turnover, etc.

Production and Workforce Planning. When demand varies in a semi-predictable manner, companies often plan changes in capacity to avoid excessive inventories during slow periods and shortages during demand peaks (Thomas and McClain 1993). Workforce capacity may be increased temporarily by using overtime or by hiring temporary workers. These measures have the advantage of being removable when the extra capacity is no longer needed. Permanent hiring is another alternative, and the resulting workforce has different characteristics in terms of performance and cost. Greater use of temporary workers may, in some cases, increase the agility of a firm in a market such as commercial aircraft manufacture (Matlack and Holmes 2002).

OM. There are specific cost trade-offs that determine when it is most beneficial to use overtime versus temporary hiring, and permanent hiring rather than either of the others.

HRM. Motivation and/or loyalty may be different for temporary versus permanent workers. Temporary workers may not always be available when needed. If worker flexibility is an integral part of the operation, it may be difficult to find temps who are interested, qualified, or able to learn the requisite skills and procedures.

Proposed Research.

(1) Develop OM models that reflect limited and unpredictable availability of temps, reduced quality of output, recruiting and training delays.

(2) Develop OM models of mixtures of flexible and inflexible workers. In a serial line, should the inflexible workers be concentrated or dispersed? Will a small number of inflexible workers have a disproportionate effect?

(3) Using the OM investigations (above) as a guide, experimentally study the effects of incorporating temporary workers in flexible work environments, and different ways to accomplish it. Is it possible to mix inflexible temps with flexible full-time workers? What motivational, performance, and retention effects will result?

Team Build. Recent OM practice has seen a trend toward using teams of various types in the workplace. In contrast to the highly specialized division of labor prevalent in most assembly lines, teams offer the potential for workers to share labor in a dynamic fashion, after suitable training (Siekman 2002). An extreme version of this practice is that of "team build," in which a group of workers collaboratively produce a product from beginning to end. (Volvo's experience with this will be discussed later.)

OM. Hand-offs between production stages may cause idle time. When workers collaborate on a job and follow it through all production stages, the blocking and starving that would otherwise be caused by worker variability can be eliminated, and variation in task time can be accommodated by flexibility of skills and assignments. Hence, "team build" should outperform "specialized work" (Van Oyen et al. 2001). A team setting may also allow the most effective worker to do a larger fraction of the work (Buzacott 2002). Many OM authors have written about how best to utilize teams to achieve the desired objectives of speed, quality and cost (Iravani et al. 2002; Suri 1998, 2001, for example).

HRM. Proficiency varies with skill similarity. Can people get good enough at a wide variety of tasks? A "complete product perspective" requires that workers understand the connection between the complete operational result and their own individual efforts and rewards.

Proposed Research.

(1) Vary skill similarity and/or work variety across production tasks. Observe changes in task speed and the total effect on productivity in a specific context.

(2) Vary visible completion of a product, working in teams, and combinations of these factors. Vary or measure task identity (Hackman 1978, 2002) and team ability to assign tasks (Brannick et al. 1997, Guzzo and Salas 1995).

Customer Contact and Quality. Since the 1980s, the OM field has had a strong focus on quality, both internal and external. Many practices were motivated by the desire to improve product and/or service quality.

OM. Industry examples where "team build" systems were adopted, at least partially, to improve quality of customer contact include Deere and R. R. Donnelley (Van Oyen et al. 2001). Can OM models help to specify the optimal levels of such quality variables, depending on the costs and revenue effects? Also, the types of errors that lead to service failures tend to be predictable, through application of knowledge and methods from cognitive psychology research (Stewart and Chase 1999).

HRM. There are service-quality and time trade-offs in any customer interaction. OM may be able to identify the optimum quality level, but can employees be trained and motivated to analyze trade-offs accurately? What internal models do employees create to guide their decisions about a service level that is "good enough"?

Proposed Research. Create a laboratory situation with a clear, measurable objective based on service. Vary the training and information available and analyze overall performance and the mental models workers use to set their quality standards. Compare to predictions of OM models.

Bucket Brigades. A specific form of worker organization designed to facilitate work sharing in a serial production line is called "bucket brigade." In this system, a worker who has finished an operation moves "upstream" and takes over whatever task the next (i.e., previous) worker is doing. This hand-off often occurs mid-task and so requires special training to accomplish without loss or error. Such systems have been described for sewn products (Bartholdi and Eisenstein 1996a), warehouse picking (Bartholdi and Eisenstein 1996b), and other environments.

OM. In bucket brigade production, putting the fastest worker last achieves a stable system, often with maximum output (Bartholdi and Eisenstein 1996a). However, if bumping is not allowed (i.e., workers must complete an operation before handing a job off to another worker), the optimal order may change (McClain et al. 2000).

HRM. Processing time is affected by the speed of proximal workers. Specifically, the position of fastest worker may affect the speed of surrounding workers.

Proposed Research. Vary the position of the fastest worker in bucket brigade and other work-sharing systems. Observe the effect on proximal-worker speed and the implications for system output.

Low-Inventory Operation and the Toyota Production System. Since being made famous by Toyota in the 1970s, pull production has been both widely used and intensively studied. A particularly active line of research has been on how to implement production systems based on the "pull" of demand rather than the "push" of a schedule. Although Toyota actually used a variety of implementations, the version of Kanban originally associated with Toyota rigidly controlled each station in a line by not permitting production until consumption of inventory at a downstream station provided authorization. Because Kanban was intrinsically restrictive, authors and practitioners have proposed a variety of more flexible versions of pull systems.

OM. Fewer constraints improve system performance. Kanban systems restrict the amount of inventory at each station of a line, whereas CONWIP (Spearman et al. 1990) only restricts the total inventory. Hence, CONWIP should achieve higher levels of throughput (Spearman and Zazanis 1992, Spearman 1992).

HRM. Processing times are affected by between-worker communication. Does the act of "pulling in" Kanban markers improve communication and problem resolution?

Proposed Research. Implement variations of pull systems in a system with complex and changing task requirements to measure effect of learning and communication induced by pull activities.

OM. One of the benefits of low-inventory operation has been attributed to better problem solving because of a shorter time lag between incidence of a defect and its discovery. Yet, in a Toyota Motor Manufacturing case (Mishina 1992), workers did not remember anything unusual about defective seats, when asked several days later.

HRM. Behavioral research demonstrates that defect detection and action are related to HR practices (Daniel and Reitsperger 1991, Longenecker et al. 1994, Stansfield 1998). This includes worker training (DeFeo 2002, Reis and Fahrenbruch 1968, Shammas-Toma et al. 1996), incentives (Anand 1999, Longnecker et al. 1997), job and process design (Bhatnager et al. 1985, McFarling and Heimstra 1975, Williges and Streeter 1971), and "zero defect" team culture (Garvin 1986, Hales 2001, Strecker 1996).

Proposed Research. Investigate whether training and/or communications initiatives can improve recollection of the sources of defects, and whether there is a synergy between such initiatives and the lag-reducing benefits of low-inventory operation.

A recent study (Spear et al. 1999) has shown that the effectiveness of the Toyota Production System depends strongly on the behavior of individuals. While production methods are very strictly defined and followed, the system is nevertheless extremely flexible, with continual measurement against standards and reengineering by the workers themselves. This sometimes leads to paradoxical results. For example, Toyota does not pool inventories of the same item that have been created for different purposes. If buffer stock is needed against demand variability and cycle stock is needed to accommodate setup times, each of these stocks is separately maintained and is designated an owner. This provides measures of how well those two sources of variability have been attacked, and how specifically incentives for the workers are designed to motivate work on reducing the variability so that the inventories may be reduced in turn.

OM. Cycle stock can, to some extent, reduce the need for safety stock.

HRM. Incentives and performance feedback should reflect improvements in cycle stock and safety stock separately if continual improvement is to be achieved.

Proposed Research. Investigate the relationship between visible, physical indicators (such as inventory owned by a worker) and implementation of specific incentives and performance feedback based on OM principles of continual improvement.

While this list of topics is by no means complete, these examples demonstrate that human considerations can have a powerful impact on the conclusions from an OM model, and that there are many opportunities to better incorporate HRM insights into OM research and practice.

2.3. Integrating COMU into Our Approach to OM Research

We have shown how translation and experimentation at the OM interface can bring behavioral insights more clearly into OM research and practice. Looking back over these examples, it is possible to see the beginnings of areas of integration. We propose some examples below. OM scholars are familiar with these (and often use them in consulting assignments) but often do not as explicitly incorporate them into their mathematical, simulation, and field research.

(1) Individual productivity is affected by many variables that are directly influenced by the work-design elements of OM models.

(a) Incentive systems affect motivation, including fatigue, boredom, and retention/turnover.

(b) Workload- and task-sharing affect capability through system training costs, learning, and forgetting.

(c) Flexibility and agility affect capability through dynamically changing demands on workers.

(2) Team structure affects performance of individuals and the overall system.

(a) Other workers' capabilities affect performance either positively (e.g., facilitating learning or increasing motivation) or negatively (e.g., encouraging slacking).

(b) A team setting may allow the faster worker to do more than his/her share of the work, thereby increasing productivity.

(c) A team setting allows increased communication, which can increase or reduce productivity in several ways.

(3) Information is an OM design variable that affects performance. In the words of our COMU framework, opportunity and understanding affect capability and motivation.

(a) What people know (understanding) affects their ability to identify and perform tasks.

(b) When and how people are able to get information (opportunity) can make a big difference (e.g., quick feedback, in an easily understood format, is most effective).

(c) Clarity of information and connection to organizational goals (understanding) is important to ensuring that information is converted into useful knowledge.

(4) Problem Solving is important to long-term system performance.

(a) Cross-training implies more minds to examine a process (capability) and therefore can provide better solutions and flexibility for dealing with uncertainty.

(b) Rotating workers gives them a system-wide perspective (understanding) that may motivate them or enable them to redesign the process.

(c) Shorter queues may improve the ability to understand what caused problems. (If the time between creation and detection of a defect is long, people may forget factors important to determining the underlying cause of the problem.)

The above examples illustrate positive and negative effects on productivity. We believe the total effect will depend on the details of the situation and therefore needs to be established by research targeted at specific environments. The ultimate result of such research will be OM models that are richer and more realistic with regard to how they represent humans and their interactions with operating systems.

We have seen a few examples of OM research and practice being enhanced by incorporating previously overlooked "human factors" and have suggested a number of areas in which additional research might bear fruit. COMU provides a start. Undoubtedly, future research will integrate additional elements from behavioral theory into mathematical and empirical OM models.

The implications of OM for HRM and behavioral research in organizations are equally profound. In the next section, we will describe examples of how implications for HRM research that reflect and practice might benefit from contextual insights and integration with OM.

3. How Operations Management Can Inform Human Resources Management

The effectiveness of initiatives at the interface of HRM and OM, such as cross-training, teams, and group-based pay, depend on context. This is widely recognized in HRM, but knowledge of OM can enhance the precision of HRM's contextual relevance and sophistication.

Just as COMU provided a useful convenient starting point to illustrate a working framework for the OM-HRM interface, we will focus here on several fundamental elements of the OM field and illustrate how they inform and enhance HRM.

3.1. Translating Behavioral Insights into the Language of OM Models

OM models typically use mathematical relationships and search for optimum solutions to specific service and production situations. Behavioral and HRM models often focus on conceptual relationships and search for enhanced descriptions and predictions of employee work behaviors and the effects of HRM practices that affect those behaviors. For example, HRM textbooks in compensation (e.g., Milkovich and Newman 2002) provide frameworks that describe the elements of pay systems and their parameters (such as the form of rewards, the level of rewards and the degree to which rewards vary with differences in performance or capability). These frameworks are supported by behavioral principles. For example, compensation relies on principles from expectancy theory (Vroom 1964), which proposes that motivation (the force to exert effort) is a function of expectancy (the perceived probability that effort will successfully produce a behavior), instrumentality (the perceived probability that the behavior will be noticed and will generate outcomes and rewards), and valence (the perceived value of the outcomes and rewards for the individual). Goal theory (Knight et al. 2001), which specifies how performance depends on the difficulty and specificity of goals and how individuals set their internal goals, also figures prominently in this area.

Similarly, the training and development discipline of HRM (e.g., Goldstein 2002, Noe 2002) describes the elements of training and development systems and their parameters (such as the identification of training needs, the structure of training and learning experiences, and whether such experiences should be provided electronically, in the classroom, or through field experiences). Training and development relies on behavioral principles. For example, learning theory (Noe 2002) proposes that learning and application requires that the learner believe he/she is capable of learning and performing (self-efficacy), that he/she be appropriately prepared to participate in the learning experience (readiness), that the learning experience provides sufficient engagement, feedback, and relevance, and that the work environment provides fertile conditions to apply his/her learning (transfer).

HRM and behavioral frameworks often focus on describing how organizational characteristics and conditions affect worker responses to HRM practices. They seldom focus on optimization, though increasing attention is given to whether the effects of practices outweigh their costs. Thus, translating OM contextual insights into the language of HRM and behavioral science requires identifying what OM elements might enhance predictions of employee work behaviors, or descriptions of the effects of HRM practices. Behavioral and HRM frameworks strive for general principles, rather than situation-specific solutions, so OM insights can often usefully define the service or production process elements that sets boundary conditions on these general predictions. The mathematics of OM must be translated into underlying elements of the situation or workers that can be integrated into HRM and behavioral models.

3.2. Experimental and Field Research Bringing OM Context into HRM

This section provides examples of "experimentation" by describing a number of specific research studies to illustrate the power of integrating OM context with HRM. For each area, we cite an HRM insight and then present an OM perspective that might provide context to enrich or alter the original insight. Here we often use the phrase "OM principles" to mean well-known and accepted results or approaches to problems. An example of a result that has become a principle is that the average waiting time increases ever more rapidly as the demand for service approaches capacity. An example of an approach that has reached the status of a principle is the use of sensitivity analysis to determine the most critical aspects of a system. We use sensitivity analysis extensively in the examples below.

HRM Strategy Inside the "Black Box." HRM writers today routinely note the value of "getting inside the black box" between HRM investments/practices and organization-level outcomes (e.g., Dyer and Shafer 1999, Becker and Gerhart 1996, Chadwick and Cappelli 1999, McMahan et al. 1999). Typical studies will describe an array of HRM practices, then choose particular individual behaviors or attitudes (e.g., turnover, job satisfaction, or performance ratings) and examine if they are affected by the HRM practices, and finally examine whether both practices and behaviors/attitudes relate to organizational outcomes (e.g., Huselid 1995). To be sure, such studies illuminate the particular linkages they choose to focus on, but a process context from OM could provide a more specific logic that would enhance such research.

Boudreau and Ramstad (2003) have suggested replacing the metaphor of a "black box" with a "bridge" in which precise linking elements are specified and tested. A key element of this bridge is using business processes to identify which work and workers (talent pools) are most pivotal to organizational success. OM provides an untapped reservoir of precision and insight about core business processes, offering a significant opportunity for HRM scholars to focus beyond the typical array of variables defined solely from the HRM perspective.

HRM. Organizations that report using certain HRM practices are more likely to have employees with more positive attitudes or lower turnover, and also to exhibit more positive financial outcomes.

OM. Financial outcomes are in part a result of optimization in key processes. Sensitivity analysis can identify processes that are particularly critical to delivering on specific strategic success factors.

Proposed Research.

(1) Group organizations by the core OM processes they most rely on to compete (e.g., low inventory, team-build, server pooling). Determine which processes are most enhanced by low turnover, employee longevity, and learning.

(2) Analyze whether incorporating the key OM processes improves the prediction of strategic and financial outcomes as a function of HRM practices, turnover, and attitudes.

(3) Add OM-based process outcomes (e.g., levels of WIP, bottlenecks) to the variables measured in strategic HRM research.

Goal Setting. The effects of goals on performance is one of the most robust and widely-researched areas in behavioral research (Knight et al. 2001; Locke 1982, 1984), suggesting that appropriately difficult and specific goals are optimal for motivation, and describing the processes through which individuals both accept externally suggested goals and also how they set their own internally established goals. Several of the examples in §2 suggest that different OM designs create different information and signals from the workplace or coworkers.

HRM. Hard and specific goals often induce greater individual performance than general "do your best" goals.

OM. Performance with regard to certain goals matters more than others. For example, in a low-WIP system, achieving goals for individual production speed may be less important than smoothing production variations that may cause bottlenecks. In a pooled-server setting, achieving a goal of proficiency on a particular task may be less important than properly switching tasks when required.

Proposed Research. Compare process performance and individual worker behavior under conditions of appropriately difficult and specific goals, based on (1) overall group output, versus (2) individual task performance, versus (3) OM-informed goals that reflect the key process parameters. Do OM-informed goals create greater performance enhancements because of their precise focus on the critical tasks that most affect total system performance?

Training. Traditional training research has revealed significant insights about necessary conditions to create learning (e.g., self efficacy), to transfer and use learning at work, and the relative effects of different training activities, such as experiential, simulation, and expository (Goldstein 2002, Noe 2002). OM models can suggest specific contextual factors that affect these traditional training questions. Training research explains how to build knowledge that will be applied, and OM explains where knowledge is most effectively applied.

HRM. Training is more effective when individuals believe they can succeed (self efficacy) and when they understand and have the opportunity to apply their training to the workplace (transfer).

OM. Cross-training is a resource that should be properly balanced by identifying tasks that benefit optimally from worker task-sharing. For example, training "in a loop" (each worker is trained on two skills so that each skill is shared by a pair of workers) is the mathematically optimal (least training cost) way to increase the worker's ability to share tasks.

Proposed Research. Compare training-transfer levels and process effectiveness under traditional HRM approaches that aim to enhance general levels of self efficacy and transfer, to approaches where self efficacy and transfer are targeted to the optimum training uses. For example, instruct workers in the optimum operational conditions to share tasks and examine if this enhances their effectiveness in transferring training and in their job performance.

HRM. Training costs and benefits are calculated by asking managers to estimate the frequency of applying the training and the dollar value of improved trained worker performance (Morrow et al. 1997).

OM. Training has its greatest effect in tasks that occur with great frequency or in situations where task sharing is most valuable. For example, call-center designs frequently allow predicting which task elements will arise for a given call and when task sharing can effectively alleviate bottlenecks.

Proposed Research. Incorporate OM predictions of task frequency, task sharing, and the sensitivity of system performance to them, into estimates of training return on investment. Compare traditional HRM cost-benefit estimates to those that are informed by more precise OM elements.

Attraction and Retention. Decades of research in HRM and I/O psychology suggests a connection between worker attitudes toward their job and their likelihood of leaving. For example, Henry Ford experienced turnover in excess of 900% during the first year of operation at Highland Park (Donkin 2001).

Massive pay increases eventually reduced this exodus. Surveys of "great places to work" (Levering and Moskowitz 2002) suggest that the opportunity for learning is a key factor in employee satisfaction and in attracting and retaining employees. Thus, it may be prudent to train workers broadly, as way to attract and retain them. However, OM models can show where the probability of any given worker actually using certain skills may be extremely low. Cross-training on infrequently used skills may engender more frustration than satisfaction.

HRM. Workers report being more satisfied and attracted to organizations that provide learning opportunities, so those that provide more training should have lower turnover and higher productivity.

OM. Cross-training carried beyond a certain point results in workers trained in skills that OM models predict will be seldom used. At the same time, OM models can identify scheduling and labor allocation options that provide greater variety in work assignments.

Proposed Research. Incorporate OM predictions about the frequency of skill use into research on the impact of training on employee attraction, satisfaction, and retention. Are seldom-used skills less effective as inducements and satisfiers? How should these insights be incorporated into task assignment policies?

High-Performance Work Systems and Line of Sight. High-performance workplace research (Appelbaum and Batt 1993, Ichniowski and Shaw 1999) suggests the value of team building, empowerment, and other "bundles" of HRM practices, often by measuring the production-level effects of those interventions (e.g., scrap, quality, production speed, etc.). It is a common finding that teams consisting of production designers, production workers, and supervisors are associated with enhanced manufacturing and operations performance. Perhaps these associations reflect workers' increased opportunity to recognize and articulate production issues and act on them (Salem et al. 1992). However, we know little about whether workers actually recognize the most pivotal elements of the production process, or if they understand the principles on which such processes are designed.

"Line of sight," or accurate perceptions about the link between actions, performance, and rewards, is a relevant component of motivation and effectiveness in these situations. Boswell (2000) suggested that how accurately employees understand how their actions link to organizational goals also affects their attitudes and intentions to stay. A pervasive assumption in much of the "total quality" and "worker empowerment" literature is that those closest to the operation (often the workers carrying out the process) know the key productivity issues and opportunities for improvement (Flaherty 2001), and that by giving workers the discretion to make decisions, those improvements can be achieved. For example, the former production-line worker who is empowered to monitor a computer display depicting the entire steel production line may now see the same data on which the OM optimization, design, and diagnoses are based (e.g., speed, bottlenecks, variation in throughput, work-in-process inventory levels). Perhaps workers naturally discern where their behavior can make the most difference in overall system performance. A similar effect might occur when workers who formerly only carried out production tasks are now placed on design teams that include operations engineers, managers, supervisors, and coworkers that span the entire production process.

OM models provide a very precise description of exactly what workers should know or figure out to optimize the process. Do workers indeed generate mental models that accurately reflect OM principles simply by working in these systems? Can they be assisted by better understanding of the underlying OM theories and mathematics? Without such assistance, do worker-involvement initiatives have their effects mainly because of enhanced (but still sometimes misguided) worker motivation, and could they be improved using OM principles?

HRM. High-performance work systems are associated with greater teamwork and empowerment and with improvements in production-level process outcomes. This may be in part because of enhanced discretion and knowledge among those "closest" to the process.

OM. There are specific process-improvement principles that create the greatest impact on production-level outcomes. Workers empowered with knowledge of these principles may direct their discretion and knowledge more effectively.

Proposed Research. Use OM principles to analyze the mental models of workers involved in high-performance work systems. Examine how closely these mental models reflect OM principles under conditions of assistance and no assistance. Compare empowered teams who are informed about OM principles to those who are not, in terms of their effect on production-level outcomes.

Compensation. Compensation research suggests that providing higher average rewards can enhance retention and attraction, provide a higher-quality workforce, and thus enhance the probability that when skills are used, they will be applied proficiently (Milkovich and Newman 2002). Such research generally analyzes compensation in terms of pay levels and contingencies in jobs or pay grades, or pay for certain skills and knowledge. OM models may allow more precise design of optimal compensation premiums for skills and behaviors, considering the operational situations in which they occur. It may be possible to link proficiency levels with resulting service and manufacturing outcomes and thus calculate the expected value of compensation incentives directed at certain capabilities or actions. Such models not only require OM principles but also must incorporate the effects of rewards on attraction and turnover, as a function of different performance levels (Boudreau et al. 1999).

HRM. Pay levels and pay based on specific skills or behaviors can increase the quality of the workforce and the level of skills or behaviors exhibited by individuals.

OM. Because worker knowledge and behaviors occur within production systems, sensitivity analysis can identify the "shadow price" of proficiency differences, in crucial skills or behaviors.

Proposed Research. Use OM principles to estimate the shadow price of pivotal employee behaviors or skills. Construct compensation and reward contingencies that reflect these shadow prices and examine resulting worker behaviors, worker attitudes toward pay equity and effectiveness, and overall system performance.

3.3. Integrating OM Concepts into HRM Research

We have shown how both translation and experimentation at the HRM-OM interface can bring OM insights more clearly into HRM research and practice. Just as in §2, it is possible to see the beginnings of areas of integration. We propose some examples below. HRM scholars often encounter these issues in the field, but often do not incorporate them as explicitly into their HRM practices, behavioral frameworks, and field research.

Optimization vs. Maximization in HRM. A fundamental difference between the approach of OM and HRM is that OM typically strives to develop frameworks that suggest optimal solutions, while HRM research typically develops frameworks to explain how to enhance or maximize behaviors. For example, typical research on employee selection focuses on maximizing correlations between selection system scores and job performance. However, some approaches identify optimal combinations of test validity, applicant pool size, and other factors, designed to produce a desired number or level of qualifications among new hires (DeCorte 1998a, b). Undoubtedly, there is great potential for considering optimization in other areas of the HRM field.

HRM Frameworks and Predictions Can Be More Complete. A great deal of the variance in behavioral and HRM studies is unexplained, even when effects are statistically significant. Typical HRM criteria reflect broad individual behaviors, performance ratings, or high-level outcomes such as manufacturing or service output or sales (Katzell and Austin 1992, Spector 2000). Incorporating OM principles would produce more precise and granular criteria and perhaps enhance the predictive power of such research. For example, workers with greater cognitive ability or conscientiousness seem to receive higher performance ratings (Bobko 1999, Schmidt 2001), organizations that use cognitive ability tests appear to be more profitable (Terpstra and Rozell 1993), and production lines that invest in worker training and empowerment appear to have higher productivity and quality (Batt 1999, Ichniowski et al. 1997, Ichniowski and Shaw

1999). Yet, we know very little about which individual behaviors are enhanced by these investments, or whether those behaviors are the ones that OM models have identified as having the greatest effect on the manufacturing or service operations contexts. This applies to most HRM areas, including selection, training, goal setting, justice, equity, compensation, and motivation.

Thus, HRM research could explain more variance in organizational outcomes by acknowledging these contextual factors and incorporating them into models and empirical studies. Also, there is a vast array of operational measures (e.g., sales, production speed, yield, costs, etc.) available to HRM researchers, and improving information technology continually makes even more data available. OM principles can help guide the choice of criteria, reducing the tendency to choose them out of context or simply because they are available.

HRM Evolves from "Program-Delivery" to "Decision-Based Investments." The OM-HRM interface has significant implications for the way HRM programs are chosen, targeted, and evaluated. Traditionally, when HRM managers or researchers wish to estimate or demonstrate the value of HRM programs, they measure the effects of a program in terms of correlation coefficients, standardized regression weights, or *t*-values, all of which are in standard-score units, which cannot readily be weighed against dollar-valued program costs. These effect sizes must be translated into dollar values. The translation methods have been debated for decades (Boudreau and Ramstad 2003), but virtually all of them require a subjective judgment about the dollar value of differences in these individual attributes (e.g., the dollar value of the difference between a person who performs better than 50% of the workers versus one who performs better than only the bottom 15%). Often, this judgment is obtained from operations managers. There is no consensus on an accepted translation approach, and little evidence of the accuracy of these judgments. The OM-HRM interface of Figure 1 suggests a more decision-focused approach that would examine how individual differences affect key pivotal business processes and trace the monetary implications through those processes. The shift from HRM as program delivery and evaluation to HRM as decision-based investment requires a logical system to identify the talent pivot points. In manufacturing and service operations, OM models can help to provide this logical system.

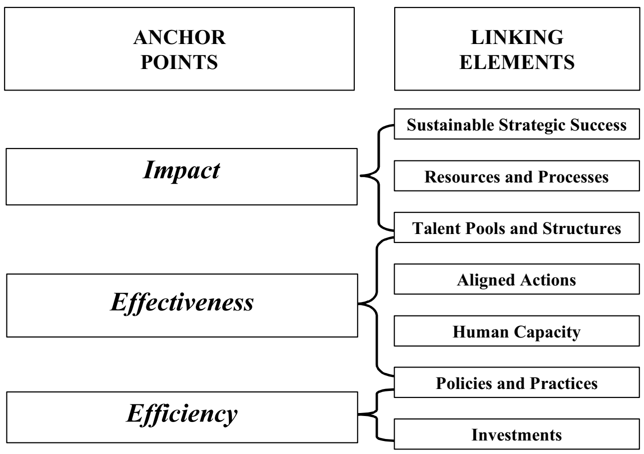
4. The OM-HRM Interface and Strategic Organizational Competitive Advantage

The HC BRidge™ framework,[1] shown in Figure 2, links human-resource investments, organizational talent, and strategic success (Boudreau and Ramstad 2002, 2003). This helps in depicting the OM-HRM interface in its larger organizational context. OM typically focuses near the top of the diagram, on issues relevant to organizational "resources and processes," such as low cost, speed, quality, and productivity. HRM typically operates lower in the diagram on "HR policies and practices" and their effects on "human capacity" such as capability, opportunity, and motivation, and "aligned actions," such as performance and turnover. The OM-HRM interface lies in the middle, the boxes labeled "aligned actions," "talent pools," and "resources and processes."

The contextual insights from OM improve the ability of HRM to use business-process principles to reveal the talent pools that are most pivotal (affect process outcomes the most), and their behaviors that create those process effects ("aligned actions"). In §2, insights from "talent pools" and "policies and practices" were applied to "resources and processes," asking what HRM elements might most enhance OM. Section 3 applied insights from "resources and processes" to "aligned actions" and "policies and practices," asking what OM context elements might most inform HRM practices and the supporting behavioral models. Figure 2 shows how important this interface is to the organization's "sustainable strategic success." We envision that enhancing the OM-HRM interface will significantly improve our understanding and ability to enhance the links between "investments" in HRM policies and practices to "sustainable

[1] HC BRidge™ is a trademark of the Boudreau-Ramstad Partnership.

Figure 2 **The HC BRidge™ Framework**



strategic advantage" supported by key OM processes and resources.

5. Toward an Integrated OM/HRM Framework

In the previous sections, we have offered a host of academic and industry examples that illustrate some of the powerful connections between OM and HRM. At a fundamental level, these two areas of management cannot exist without one another. OM policies can only be carried out by people, and HRM policies are effective only if they foster people doing organization-critical tasks. And the connection is not just theoretical. As many of our industry stories suggest, considering HRM in formulating OM policy, and vice versa, can be good management practice.

But observing philosophical connections or implementation synergies is not the same as providing an integrated OM/HRM framework. Our review of the two fields indicates gaps in our understanding of the links between them. Some of these are likely to be filled by "research as usual," but many are not. Only via a conscious effort to explore the OM/HRM interface will we be able to provide a framework to support better, more integrated management policies.

Research into an integrated OM/HRM framework will not be simple or linear. We are simply not close enough to such a system to attack the problem directly. Several very different paths must be pursued to build up the body of knowledge needed to construct a unified understanding. Hence, we conclude this paper by identifying the basic classes of research that are needed and discussing the challenges and opportunities in each.

5.1. Improved OM Models

In §2, we provided a list of HR variables that are typically omitted from OM models. A good start toward a more sophisticated generation of OM models would be systematic research into how to incorporate these issues into classical models of operations problems. Behaviors such as learning, fatigue, boredom, forgetting, loyalty, motivation, and many others can, in theory, be included in descriptive, simulation, and optimization models used to analyze and improve operating systems. For instance, there is no fundamental reason that prevents models of aggregate planning, facility layout, or scheduling from incorporating the fact that workers' speed, quality, and variability are affected by various parameters. Although the mathematics of the model might be more complicated, the real research challenge to doing this is in properly describing the relevant human behavior.

As an illustration, we consider a discussion one of the authors had with a colleague about why pull systems work. They agreed that a fundamental property of pull systems is that they delay releases based on system status, but they disagreed on whether delaying releases would necessarily delay completions. A sample-path argument "proves" that later releases could never lead to earlier completions, but this proof assumes that process times are unaffected by the pull system. In real-world systems, this may be untrue. Shorter queues might facilitate detection of quality problems and lead to less rework. Greater communication between stations could help operators eliminate mistakes. The more obvious need for smooth flow in a low-WIP system might lead to more manufacturable product designs. These and other behaviors that might be induced by use of a pull system are all dependent on how the people involved react. Far from being minor details, these mechanisms for reshaping a production environment may explain some of the most important benefits. Similar issues arise in many settings that have been studied by OM researchers, including crew scheduling, military operations, and various staffing problems.

If we knew the direction and magnitude of these behavioral impacts it would be relatively straightforward to determine whether the pull system would improve or degrade on-time delivery performance. But OM modeling often does not include behavioral impacts, and thereby may overlook fundamental insights. For this situation to improve, it is not only critical for OM researchers to be open to the idea of modeling complex human behavior; they must also have access to the types of behavioral and empirical research we discuss below.

5.2. Improved HRM Frameworks

We believe that for HRM research to refine OM models and practices, an extended HRM model should consider questions that are focused on operational issues. For example, in the case of worker flexibility, HRM needs to consider more than the proficiency of each individual worker and the proportion of workers who can do all the tasks involved. Rather, HRM should consider questions such as the costs of adding worker fungibility, the likely motivation of workers to make efficient and effective hand-offs, and the design of the work and production process as it either facilitates or constrains the pivotal behavior—handing off work at low cost and with high quality.

Within such a framework, OM and HRM managers could consider together the cost function involved in building optimal levels of fungibility, including not only skills but also any changes in reward systems, communications, and process design needed to affect capability, opportunity, motivation, and understanding. Integrating these costs into standard OM models will enhance the ability to find an optimum design and more clearly account for the talent issues.

As the processes are implemented, the approach we propose suggests a very different role for HRM. Rather than simply delivering training or compensation programs, the HR manager would now assess worker effectiveness at making hand-offs, their overall understanding of how their individual actions relate to the outcome, their reactions and decisions based on customer pacing input, etc. The result is likely to be a more integrated or "bundled" set of HRM programs and investments that are more clearly linked to the production pivot points.

These new HRM outputs would provide OM managers with data to deal explicitly with formerly hidden issues such as the cost function for worker fungibility, process-design trade-offs in facilitating hand-offs, process designs that allow workers to link their behaviors to the ultimate objective, process designs that allow workers to translate customer pacing information into good decisions, and the cost-productivity trade-offs that are associated with all these design elements.

5.3. Behavioral Research

As we noted above, a serious impediment to including human behavior in OM models is the simple fact that we do not know how humans behave in specific operating environments. When do long queues motivate faster work? When does low WIP promote better problem solving? When does broader product responsibility lead to higher quality levels? The list of unanswered questions that are central to the choice of effective OM policies is long. Indeed, because research into behavioral issues that underlie modeling of operations systems is just getting started, we do not even have a comprehensive list of the questions.

In §§2 and 3, we suggested research to address specific areas where human issues are likely to be decisive in understanding the performance of OM policies. Although this list is still preliminary, it gives a sense of the style of research that is needed. Among the issues that might benefit from additional behavioral research are factors that affect (a) worker speed, (b) worker memory, (c) turnover, (d) ability to learn new tasks, (e) quality of work, (f) communication between workers, and (g) problem solving by workers.

The above examples suggest areas where insights into human behavior can directly inform OM models. A complementary set of questions reflects how attention to OM principles can inform HRM research, as we have noted.

- What specific behavioral issues make the most difference to key organizational processes?
- What are the "mental models" that workers and their supervisors use to make decisions about where to direct their efforts? Do those mental models reflect

the OM principles that actually describe process optimization? How are they affected by HRM practices such as training, performance assessment and rewards?

• Is "more is better" always true when it comes to HRM investments, or are there optimal levels of those investments that reflect the operational context?

Behavioral research may be the key to achieving an OM/HRM framework. OM researchers may incorporate better representations of humans in their models. Researchers in HRM may enhance their paradigms with more specificity of operating context. But behavioral research directed at improving models of OM situations is a scholarly path with little precedent.

Much of this behavioral research can be done in experimental settings. However, validating an OM/HRM framework also requires empirical study of the behavior of actual system performance at a macro-level. Controlled behavioral experiments are essential to provide building blocks. But real-world systems are always more complex than experiments. So, to find out how policies really perform, we need to evaluate their performance in industrial settings.

Do teams enhance performance in terms of both quality and productivity? What kind of teams? (Some excellent research has been done to date, e.g., Bailey 1998, Banker et al. 1996, and Banker et al. 2001.) Are pull systems profitable? Does cross-training reduce or increase turnover? Under what conditions? Has the lean manufacturing movement had a demonstrable impact on the American economy? Questions like these can only be addressed via careful empirical analysis of large-scale systems.

Empirical research is more prevalent than behavioral research in the OM literature, but we believe more should be done. Part of the difficulty is that conclusions based on statistical analysis of noisy data are necessarily less crisp than those based on detailed mathematical models. As a result, modeling researchers are prone to regarding such research as less than rigorous. But this need not be the case. Given carefully constructed experiments and careful analysis, such research can yield important insights into some of the biggest questions associated with the OM/HRM interface.

5.4. Integration Research

Finally, a style of research that could promote the type of integrated framework we are proposing here is research into integration itself. This paper could be regarded as a preliminary example of this kind of research. By surveying and classifying the OM and HRM fields, we have identified gaps and mismatches that keep some of the insights of the two fields separate. But to go further than mere identification of impediments, it is likely that future integration research will have to focus more narrowly on how to bring the ideas from OM and HRM to bear on specific problems or environments.

For example, consider recent OM research results on collaborative work environments (Van Oyen et al. 2001). They studied a serial production system in which they assumed that (a) workers are identical, (b) workers can collaborate on tasks, (c) process times are inversely proportional to the number of people assigned to the task, and (d) there is no cost or time delay to switch between tasks. They showed that average WIP and cycle time are minimized if all workers collaborate as a team, taking jobs successively from the queue at the front of the line and processing them through the entire line.

One might be tempted to conclude from this result that environments in which collaboration is efficient (e.g., workers do not get in each other's way when working simultaneously on a task) are good candidates for team-build strategies. Indeed, sometimes they are. For example, Van Oyen et al. (2001) cite their experience with Elgin Digital Colorgraphics (EDCG), a premedia printing process of R. R. Donnelley and Sons. In this system, most operations are conducted on workstations, and jobs can be divided among workers by assigning pages to individuals. Teams of workers followed jobs through almost the entire process. In addition to realizing the efficiency benefits predicted by the model, this protocol also ensured that the customer would have a single point of contact for a job throughout the system, facilitating changes and helping to ensure quality.

But this kind of team-build strategy does not always work. Most famously, Volvo opened its Uddevalla plant in 1988 with a widely touted autonomous team approach for assembling an automobile. Intended to "humanize" assembly line work in order to improve motivation and reduce absenteeism and turnover, the plant never achieved productivity levels comparable to traditional plants. It was closed in 1993 (Moore 1992, Prokesch 1991, Rehder 1992, Sandberg 1993).

In a more recent case, one of the authors observed two plants owned by Federal Signal. One produced sewer-cleaning trucks using a team assembly system; the other produced street-sweeping trucks on a progressive assembly line. The team-assembly system had been adopted to facilitate flexibility—the firm would make almost anything the customer asked for. But because trucks were built in bays, there was little pacing pressure. Moreover, because of the wide range of tasks involved, workers spent considerable time figuring out how to do things. As a result, even though the two products were similar in complexity and customization, the progressive assembly line had much higher productivity, better quality and superior customer service. It did not take long for a new management team to decide to drop team assembly in favor of an assembly line. In another example, Clark (2002) describes how Intel preserves process quality through a "copy exactly" policy by which worker (and designer) discretion is severely limited.

These examples involve many of the issues we have discussed throughout the paper. They represent systems where classical OM results argue in favor of assembly lines, newer OM results argue in favor of team-build and various HRM theories address issues of motivation, team dynamics, and training. Adding to the complexity, a small, but vocal "anti-lean" faction argues that empowered teams are a more humane approach to work, which will ultimately replace specialized, standardized procedures associated with lean manufacturing. But the preponderance of management decisions suggests that the motivational benefits of team-build have not outweighed the efficiency benefits of specialization in most manufacturing environments.

Without investigation, we would draw a simple "OM beats HRM" conclusion with regard to lean manufacturing. But rigorous research on the integration of OM and HRM could reveal something richer. The choices in work design are not only Taylorism (do one tiny thing) or team-build (do everything). There are many options in between. OM models could provide insight into where to look for the "pivot points" that may be affected by talent. HRM could offer insights into what factors affect development of the appropriate talent and the extent to which satisfaction among workers affects retention and performance. But only by truly bringing the two perspectives together will we be able to design hybrid systems that combine the motivational benefits of team-build with the efficiency of progressive-build.

Researchers are just beginning to address issues like these presented by complex operations systems involving people. We take this as a very hopeful sign that we are on the verge of a new era of OM/HRM integration. We have given an (admittedly incomplete) set of research opportunities for addressing this interface. The one thing that is clear from our review is that there are a great many research challenges that need to be addressed before the synergies of these fields, in research and practice, are realized.

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