# Cross-Trained Labor: Perspectives on OR Models

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**Abstract**

We examine worker cross-training and some of the recent efforts to model it. We do this through the lenses of industrial cases, the modeling process itself, and ethics. The use of labor since the late 1800's sheds light on current reactions of labor and management to cross-training. We suggest that analysts should consider the potential impacts of cross-training models on workers and describe both negative and positive impacts. These models have limits; while efficacious for strategic modeling, they do not address how workers might respond to cross-training. Both management and labor can be served by cross-training when it is efficient, improves the work environment, and develops the workers' skills. We make suggestions for the responsible research and implementation of novel cross-training approaches.

**Keywords: cross-training, ethics of modeling, specialists, flexible production.**

## Introduction

One of the most prominent and persistent themes in the study of productivity is the role of labor: Is the worker to be a generalist or a specialist? Recent market pressures have made it attractive in many sectors to move away from extreme specialization, and instead to cross train workers for a variety of tasks. Cross-training models of production and service operations have been developed to identify cross-training approaches and their potential benefits. Coming out of the same community that extensively studied flexible manufacturing systems, it is perhaps not surprising that these models have focused on *flexibility* as a key characteristic of cross-training [Hopp and Van Oyen 2000]. Studies using these models have generally ignored the many ways in which cross-training could affect workers and the organization in the interest of understanding labor flexibility and its impact on operations. While these models can be very useful, we suggest a broader framework for thinking about their use.

First, some of the history of specialized labor that led to current concepts of work organization and job descriptions is relevant. When OR analysts model worker flexibility, they enter a long-running controversy, with a whole series of implications and vested interests. Recent changes in job descriptions within the organization being analyzed are particularly important.

Second, as in any use of models, the modeling process and its limitations should be considered. OR modeling is a human activity affected by the modeler's perceptions, biases, and interests. It is helpful when these influences are understood. Moreover, for cross-training models, individual human behavior can play a prominent role and the modeling challenges are significant.

Third, the OR analyst has ethical responsibilities, including the potential impact of cross-training on the workers in a specific firm or industry. As soon as we raise the issue of ethics, some readers may wonder if there is anything concrete to be said. One might argue that to do analysis in an ethical way just means being an ethical person who also does analysis. The lack of interest in adopting a code of ethics in INFORMS is indicative of the prevalence of this view, but Gass [1994] and Kleijnen [2001] argue otherwise. We frame ethical issues related to cross-training models, particularly those that have not received attention in discussions of modeling ethics.

After describing cross-training more fully, the next section uses history and case studies to discuss the social context--how is the worker affected? Next we examine modeling choices and discuss subjectivity in modeling. The last section raises ethical issues and suggests how the analyst might respond to them

**Cross-training strategies**

Cross-training, or workforce agility, refers to the ability of workers to perform different tasks. Workforce agility refers to *flexible* labor capacity that can be shifted to where it is needed when it is needed. Agility in the workforce represents one component of a firm's overall agility. Other components are agility in a firm's use of its resources, such as in flexible manufacturing systems, and in its inter-firm relations, such as its supply chain management [Malecki 1996]. The degree of worker flexibility can be described by the set of skills of each worker. Given a set of activities that are performed by the workforce, a fully cross-trained worker can perform all of them. Without cross-training, each worker can only perform one activity. Although this simple description leads to useful models, the decision to cross-train typically needs to address several dimensions of a worker's job description and training.

First, *skill breadth* can conflict with the need for *skill depth* (Figure 1a). Achieving a deep level

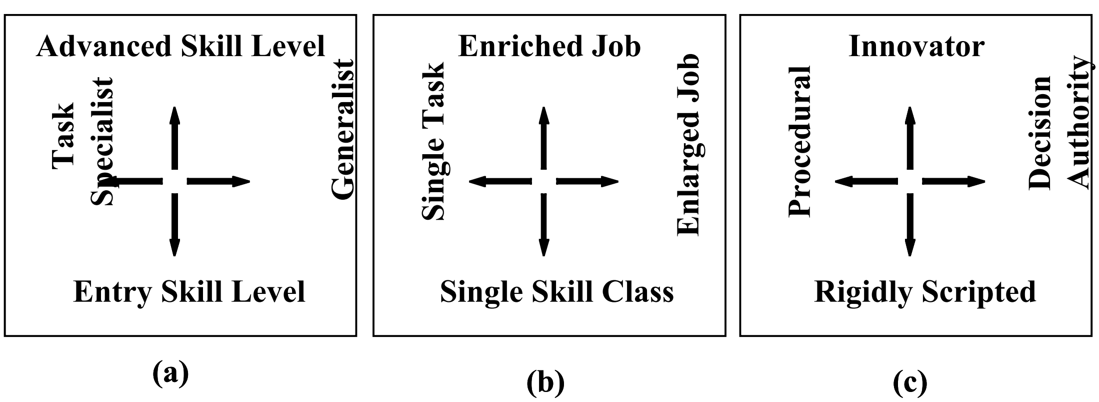


**Figure 1: Dimensions of Decision Space for Cross-training**

of skill can enhance speed and quality and enable focused, technical innovation, while breadth can facilitate broad process innovation. Second, in Figure 1b, a worker can be "horizontally" cross-trained within a class of similar skills or "vertically" cross-trained across types of skills (e.g. machine operators trained for machine maintenance, kaizen, and quality assurance). The vertical dimension, job enrichment, was championed by industrial psychologists in the 1970's. It often emphasized giving the worker increased decision-making authority. The job enrichment movement seemed altruistic in spirit, but it led to very painful organizational change and has since decreased in strength. The horizontal dimension, job enlargement, emphasizes the motivational benefit of taking jobs from beginning to end and the quality benefit gained through doing a greater portion of the job.

Part (c) of Figure 1 illustrates two more dimensions of the decision space. *Methods empowerment* refers to whether processes will be defined in a rigid way by management as Taylor espoused, or will it be left to workers themselves to continuously improve their own part of the process (an important goal of Toyota Production System). When decision authority is vested in the workers (*decision empowerment*), problems can be resolved quickly and directly without much managerial effort. At the other end of the spectrum are procedural tasks in which workers follow predetermined procedures and refer non-standard issues to management for resolution.

Quantitative analysis of the tradeoffs in Figure 1 has generally not been attempted. In principle, maintenance, quality, decision-making and planning tasks could be included in a cross-training model.

Once workers are cross-trained, a coordination mechanism is needed to allow workers to switch from activity to activity in an effective manner. These approaches fall into two categories. Distributed rules have been devised to let each worker decide what to work on next. This is especially important for manufacturing systems where workers physically move between work stations. For example, at Ruud Lighting one of their flexible assembly lines used workers with two or three dominant activities. To allocate their effort, workers used a visual assessment of the number of jobs waiting to decide which task to perform next. Although the basic guideline was to serve the station with the largest workload, workers could deviate from the guideline as they saw fit. Second, centralized allocation rules tell each worker what job and activity to work on next given the current status of jobs in the system. For example, the job with least slack in its due date might be selected from those for which the worker is trained. In call centers, routing software usually selects calls based on the longest queue length or longest waiting time, although priority rules are sometimes appropriate.

A model of flow through the system is used to assess the combination of cross-training skill sets and an allocation rule in terms of throughput or cycle time. The costs of cross-training, assessed outside of the model, can then be weighed against the resulting system performance benefits (see, for example, Nembhard et al. [2002]). The benefits that can be quantified in these cross-training models include the potential to balance a line that would be unbalanced with specialized workers, buffering against variability through the dynamic allocation of workers, and flexibility to react to changes in staffing levels, job volume, or job mix. For example, Hopp et al. [2001] addresses the question of how the skill sets of partially cross-trained workers in serial lines should overlap. For a system with the same number of workers as jobs in which each worker has the same number of skills, Iravani et al. [2002] find that partially overlapping "chained" skills are preferable to teams of workers with identical skills.

**How is the worker affected?**

*Historical perspective on specialized labor*

A scientific view of the division of labor dates back at least to 1776 with Adam Smith's *Wealth of Nations*. He argued that workers allowed to specialize in a narrow task became more productive than generalists due to the focused learning (which also enhances innovation), and elimination of wasteful movement from task to task. By 1790, British pottery manufacturer Josiah Wedgwood was pioneering a scientific approach to the organization of work using experiments, worker specialization, and synchronized assembly lines with huge success. His need for coordinated production changed the work environment dramatically; in fact, he installed the first punch-in time clock. Wedgwood's workers were highly trained specialists, so when gold trimmed dishes went out of style, his gilders lost their jobs [Olsen 1995].

Meanwhile, the industrial revolution was changing the nature of work and creating a variety of backlashes, including romanticism and socialism [Olsen 1995 p. 347]. The romantic poet William

Wordsworth wrote about Wedgwood's system of shift bells and viewed industrialization as "the soul-wrenching regimentation of labor that came about from considering human beings as objects and tools … rather than as fellow humans with active and important desires" [Olsen 1995 p. 366]. Karl Marx gives a similar critique, writing that factories "degrade [the worker] to the level of an appendage of a machine, they destroy the actual content of his labour by turning it into a torment; they alienate from him the intellectual potentialities of the labour process in the same proportion as science is incorporated in it as an independent power" [Marx 1977, p. 799].

Setting the stage for the second industrial revolution, Frederick Taylor (1856-1915) founded "scientific management" with his analysis and measurement of work. Soon Henry Ford's moving assembly line using interchangeable parts (attributed to Eli Whitney) ushered in the technology of mass production. Most craft-based production was eliminated. Scientific management broke work down into discrete tasks, creating an ever-more finely specialized workforce. More and more operating decisions were taken out of the hands of the worker, who was given specific operating procedures and repetitious tasks. There is reason to believe that Henry Ford intentionally took Adam Smith's principle of division of labor to an extreme. By intentionally keeping jobs so simple that almost anyone could do them, Ford was able to meet his growing labor demands using less expensive unskilled labor. At the same time, it allowed Ford to keep labor in a weak bargaining position. Focused on paying sufficient wages to attract labor to his arduous factories, Ford's emphasis was on productivity and profitability. The needs of labor were far from primary. Without any scarce labor skill to offer, any worker that demanded improved safety and working conditions could easily be replaced. From this perspective, extreme division of labor and "deskilling" of the workforce appears as an enemy of the worker, keeping them from taking up their rightful, dignified place in the production enterprise.

In this environment, unions proliferated despite stiff management opposition. They advocated for improved working conditions and seniority-based job security, as well as wages. Unions have also sought to protect the pace of work and control the training of the next generation of workers. Today, perceived threats include skill displacement by technology, uncompensated increases in responsibility, and job displacement arising from organizational change, outsourcing, or plant relocation to cheap labor markets.

Although they achieved many protections for the worker, unions were unwilling or unable to do much about deskilling. As the economy shifted toward mass production, more and more low-skill jobs were created, mostly in difficult work environments. Testifying before a Senate subcommittee in 1972 for the United Auto Workers, a union leader described his view of worker alienation: “A guy has about thirty-six seconds to do an operation. The jobs are so fragmented that he is offered very little as far as input to that product. He cannot associate with it or he does not realize what he is doing to it.” [Brynner and Clark 1972].

*Reasons for the growth of cross-training*

At the most basic level, the organization of production depends on the stability of a firm’s markets. The Fordist production approach flourished in the years following World War I, a time characterized by stable markets and limited global competition [Piore and Sabel 1984]. The global recession in the early 1980’s marked the transition from Fordist production to “flexible production” [Knudsen and Boggs 1996]. As dominant bases of competition shifted from price to the richer blend of price, quality, time (speed), and customization, the preferred production paradigm shifted toward flexibility in an increasing number of industries. In an environment of dynamic markets and increased product differentiation, the imperative to pursue economy of scale was enlarged to include the pursuit of economy of scope: having a variety of production capabilities that can be combined to effectively add value as an ensemble greater than the sum of the parts. Because rising global competition provides a continuing driving force, there is good reason to believe that the shift to flexible production will continue. However, the shift to flexibility is difficult and slow for the many firms that have developed a structure and culture of mass production for decades.

Early efforts at achieving flexibility focused on agility in the use of resources, particularly machines. More recently, attention has been given to Japanese approaches under the names Toyota Production System (TPS), Just In Time (JIT), and lean manufacturing, that employ workforce agility and achieve short cycle times and less work in process (WIP). These approaches include organizational change, implicitly recognizing that "flexibility is much more an organizational property than a technical one" [Bessant and Haywood, 1988]. JIT/TPS has achieved high productivity and quality levels while using multi-skilled labor and a dramatically smaller number of job classifications.

JIT/TPS employs a very rigid production control system, demanding precise timing of flows and low inventory. Thus, it requires alternative forms of buffering to replace work in process (WIP) and lead time. Cross-trained workers who respond to dynamically to the system have been part of the solution. Techniques including colored lights (andons) describing workstation status were created by Toyota to help workers decide which tasks to perform and to respond to flow and breakdown/quality problems. Thus cross-training that includes teaching workers problem solving skills using the scientific method have been an important element of TPS that creates an innovative, performance-driven work culture that cannot be attained simply by the addition of technology or technical manufacturing and control approaches (see Spear and Bowen [1999]). Next, we report on two firms grappling with the use of cross-training.

*Line balancing at Ruud Lighting*

The authors observed the implementation of cross-training on a demand flow line at the Ruud Lighting Corporation located in Racine, Wisconsin. Just a few years ago, their lighting fixture assembly line was paced with a constant belt speed that required all workers to perform their operation in a fixed time interval. Problems with such an approach include: (i) stress put on the worker to match his/her pace to that of the line, (ii) lost time idling when a worker finishes a task early, and (iii) reluctance of the workers to participate in an accurate determination of the maximum practical line speed. Cross-training has always been part of Ruud's approach, partly because they don't want individuals to "own" processes or information. Workers were partially cross-trained but did not change tasks dynamically on the paced line. Because the line required a significant period of time for set-up, a lot size of at least 250 products was needed to efficiently make a run.

With the switch to a redesigned, fully cross-trained "demand flow" line, workers work at their own pace, and switch tasks dynamically to operate the entire line efficiently. With over 75,000 products overall and thousands of models built on the same line, cross-training offers a large performance benefit by enabling dynamic line balancing. By teaching assemblers to read standard wiring diagrams, they have fully cross-trained line staff for all assembly operations. For the coordination policy, workers have a base station, but then help out neighboring workers to their right and left. Workers rotate every two hours so that work is fairly distributed in the long run and ergonomic stress is reduced. Set-up times have been greatly reduced; lot sizes can now be very small (e.g., 10 jobs). The performance of the new system is so good that they are converting their old assembly lines to the new demand flow paradigm.

Workers have reacted very positively to the changes. It should be noted, however, that there is little job insecurity due to process change. Ruud places an extremely high value on providing employment security to its people. Change is also part of the culture, so that employees expect their jobs to change over time. The employee handbook states "At Ruud Lighting there is no such thing as, 'It's not my job.' Doing whatever is necessary to meet Company and customer needs is EVERYONE'S job." In fact, one group of workers was hired with the expectation that they would do assembly in the morning and shipping in the afternoon, meeting a need for labor and helping reduce lead time.

*Improving response time at Elgin Digital Colorgraphics*

EDCG is a division of R.R. Donnelley and Sons Co. that provides customized graphic arts products such as fliers and mail order catalogs. EDCG receives photographs/images and text material and combines these elements into a publication with proper color and layout. They have to deal with rapid technological change, cost and quality pressures, and highly variable demand. Between 1996 and the present, EDCG underwent a dramatic and successful transition from a specialized workforce to a highly dynamic, cross-trained workforce with broad skill sets. Cross-training and redesigned business processes that tap the new potential for speed have helped EDCG meet stiff competition. Back in 1993, it was rare to fulfill an order in less than a week. In 2002, the turn-around time is 12-24 hours.

Part of this change has been the formation of three large work teams from about 95 staff. Having three teams rather than one keeps communication efficient and fosters a healthy competition and drive for innovation across teams. There have been times when very large jobs have required two teams to work together to meet a deadline, but this is easily done. With broad cross-training, workers are empowered to decide as a team how to schedule their tasks and coordinate with each other.

Although EDCG has without question achieved business success as a result of their cross-training initiatives, there have been obstacles to overcome. First, the scarcity of particular machines sometimes prevented cross-trained workers from using them. Fortunately, with technological change, the cost of some key resources has declined. Second, some processes such as color markup defied cross-training (parts of this process require considerable artistic talent and an eye for color). Third, some of the workers, particularly top-performing specialists, opposed the change. Demographics matter as well – young workers are eager to receive more cross-training while older workers tend to be much more suspicious of it. Management has worked hard to explain to workers the need for change and asked them to make some personal adjustments. EDCG has recruited recent high-school graduates, because they were able to adapt to the new processes without preconceived ideas. As an industry, the digital graphic arts have recently shifted from a trade or craft orientation to a process flow orientation because of technological change. EDCG is non-union, but other union graphic arts shops have struggled to adjust to change and have tended to cling to specialization based on traditional job descriptions. In those systems, the “top” workers are graphic artists; cross-training tends to level the roles.

Managing change has been crucial for EDCG. Insecurity in the face of change is a significant issue. As the rate of technological change increases and it drives process changes, roles change and traditional skills can become obsolete overnight. This was another reason for EDCG to emphasize hiring inexperienced, “fresh” workers who do not yet have a stake in any particular organizational approach. For example, EDCG is currently piloting process-innovation supported by technological advances that would replace the current color system based on four ink colors to the RGB three-color system that can be viewed on computer screens. All workers face the uncertainty of not knowing how the change will affect their role and prestige within the organization.  Some workers who are now the most valued due to their experience with the ink color system may be rendered least important under the new system.

Workers often feel caught between conflicting fears: the uncertainty of change caused by improvement efforts and the fear of competitors taking away their jobs if the status quo is not sufficiently improved.  Kevin Hekman, a manager at EDCG, described his perspective on how best to navigate such tensions: "We have found it effective to expose our workers to the needs of the customer directly, rather than relying entirely upon traditional account representatives. By so doing they understand the real pressure we're under to constantly innovate at a pace faster than our competition, and can take some personal pride and ownership in helping develop those solutions. My hope is that if the environment is right, the thrill of rising to the challenge and learning new and useful skills will overshadow personal concerns about what any specific short-terms change will mean to the individual and their daily work activities." When asked why EDCG strongly supports cross-training, he cited increased productivity and a greatly enhanced problem-solving capability, which results in higher product quality.

*Stakeholders and consequences*

Because of the increased variety and volatility of demand, many workers now have a greater variety and unpredictability in their diet of work, characterized by short batch sizes (such as we now see at Ruud Lighting), reconfigurable work cells, continuous improvement, and a high rate of change. A brief survey of pros (and cons) of cross-training as it impacts the worker includes

- Mental stimulation and variety of work (stress in managing multiple duties and difficulty meeting a broad set of requirements)
- Opportunity for broader experience, career advancement into supervisory roles, and enhanced marketability (lack of ability to focus and heightened job insecurity and loss of clearly defined role as pace of change increases)
- Mitigation of ergonomic risks via variation in tasks (exposure to greater variety of activities for which the worker may not be suited)

- Increased compensation from increased value added and corporate competitive advantage (more work and responsibility for the same pay with less job security)
- Enriched sense of personal contribution to product (stress from deeper responsibility for quality problems or problem solving)

Thus, despite the advantages of cross-training, there are countering voices. Unions have an important role in many firms and are often suspicious of cross-training. Union shops are still heavily invested in traditional approaches to division of labor that tend to conflict with the economic pressures driving management's policies. There seems to be a desire for clearly defined jobs and trades, especially ones based on certifications and standards that make skills easily transferable across firms. For many there is a deeply held belief that having a unique capability gives an individual job security. This is often true as long as a firm continues producing similar products and quantities, but becomes irrelevant in the longer perspective as markets change, the firm faces competition, and workers tend to change firms. Clear, narrow job classifications also support hierarchies and pay grades that protect or favor more senior workers. The long-term consequences for the worker depend significantly on the economic implications of cross-training. From a societal perspective, it seems that cross-training promises to create a workforce better equipped to meet the volatile demands of fickle markets.

Opposition to cross-training on the basis that the efficient use of labor will lead to layoffs may be misguided, but the desire for labor flexibility does have a dark side: the use of contingent labor to dynamically change the size of the workforce. Arguably a positive or negative characteristic, the use of part time workers, home workers, temporary workers, and workers hired without benefits is increasing.

**Modeling the worker**

*A broad view of productivity*

To aid discussion of cross-training models, consider the following factors that affect worker productivity, measured in activities performed per unit cost:

$$Productivity = \frac{speed \times availability \times quality \times utilization}{wage} .$$

Here *speed* is the speed of accomplishing tasks, averaged over the tasks that comprise a finished job. *Availability* reflects the fraction of time lost (over a suitable planning horizon, such as the average tenure of a worker in their job) due to the need for training, supervision, injuries, or sick time. Availability can be greater for the cross-trained worker despite the increased training time, for example, when ergonomics are improved by cross-training. It can also be affected by a change in the turnover rate under cross-training. *Quality* could account for changes in the rate at which a worker introduces defects, or could attempt to capture the productivity decrease due to other quality costs such as rework and lost customer satisfaction. Cross-training can also significantly affect the average *wage*. *Utilization* measures the proportion of a worker's available time that they are performing an activity. It is a system measure that depends on the system dynamics and variability. Generally, cross-training increases utilization by eliminating idle periods during which the workers in the specialist-based system either starve or are blocked. On the other hand, there may be changeover times and walk times necessary for a worker to change tasks.

The productivity obtained using cross-training as opposed to specialists may be measured by the index:

$$Productivityindex = \frac{XTproductivity}{specialistproductivity}.$$

*A mechanized view of labor*

Most cross-training models address only the utilization variable in our productivity index. Like many models of operations, the only attribute of the worker is the rate at which they perform activities. It is commonly assumed that worker speed does not depend on the level of cross-training. Worker availability and quality usually do not appear in the model. We call this a *mechanized* view of labor; the worker is modeled like a machine that performs a task the same way at the same rate, regardless of what has transpired before.

Why are other factors neglected? One clear reason is generality. Worker speed may be important to the analysis, but its relation to cross-training is likely to depend on the specific type of work. For models intended to support a strategic decision of how to implement cross-training, it is likely that no data on the impact of cross-training will be available. In the absence of a general tendency or specific data, it seems reasonable to assume speed is unchanged. Moreover, the models were developed by the operations management community, while expertise in human performance in the workplace would reside in other communities. But people are not machines. Their performance is likely to change with cross-training and such change is difficult to model. Users need to keep the limitations of mechanized models in mind and be aware of the complexity of workers when major changes in working conditions are being considered.

It is crucial to note that the way the research question is framed affects the model and the range of conclusions that can be drawn from it. Framing the cross-training research by asking "What are the potential operational benefits of flexible capacity and how can it be achieved by dynamic allocation?" steers one toward a model with mechanized workers, which can be optimally "controlled" so as to maximize their utilization. It precludes consideration of other productivity factors. For example, such a model cannot provide evidence for the conclusion that cross-training sometimes hurts productivity through worker slowdown caused by demotivation, fatigue, or stress. The power of a model to focus on specific, isolated dimensions of a problem becomes its greatest weakness due to the narrowness of a model's nature.

**The responsible analyst**

*Ethical responsibilities*

Several ethical responsibilities that fall upon all analysts, particularly when they are working for a client, are relevant to our discussion of cross-training. As we discuss below, the analyst may have a preference for a particular outcome to the study. Such a preference does not preclude their doing the study, but it is important for them to decide whether their role is to be as objective as possible or to advocate for a particular outcome. The question of advocacy is central to public policy analysis and has been discussed extensively in that setting. This role needs to be disclosed to their client or audience [Kalkstein 1969]. When in the role of an objective analyst, they are obligated to represent the interests of their client, including taking into consideration the client's values. Some codes of ethics prohibit an analyst from making recommendations on an issue when there is a conflict of interest.

Another possible role of the analyst is to take moral responsibility for the effects of their work, or at least to only work on projects that are consistent with their values and for clients with compatible values. Although some codes of ethics include core values (e.g., democracy, human rights, and concern for the environment) that must be upheld by the client before taking the job [Brahms 2000], it is more important for our purposes to observe that a variety of values are held by different analysts. For many projects, it is difficult or impossible to know how the analysis will impact all the stakeholders. Thus, choosing not to work on a project because of the potential impact is usually a difficult decision and one which analysts are not well prepared to make [Mason 1994]. When working for a firm, the degree to which the analyst can consider other people's interests is also limited by their obligation to uphold the interests of the firm. Emphasizing fairness and mutual benefit, rather than competing interests, lessens this tension.

A fundamental part of good practice is to clearly communicate the assumptions and limitations of the model and to avoid over-selling the model to the decision-maker. Vincent Barabba [1994] states this principle as "never say the model says". Failing to follow good practice may not be considered an ethical lapse, but over-selling is a serious pitfall. As Richard Mason [1994] puts it, "All too frequently, however, the management scientist sides with the mathematical aspects of the model … By neglecting underlying complexities, a management scientist reneges on the covenant with reality and places the entire profession in jeopardy." The responsible analyst, then, needs to think hard about how the "model world" relates to the "real world". The strength of this relation depends crucially on the system being modeled, the degree to which the system is understood, and the intended use of the model.

*Subjectivity and limitations of models*

While scientific theories strive for generality and accuracy, Little [1994] describes the goals of OR models as (i) relevance to a particular client (or to society), (ii) understandability, and (iii) sufficiency for the task at hand. Performance analysis of queueing systems, for example, has mainly scientific aims—though there must be domains of application—while the use of modeling to select a cross-training strategy has the latter two aims.

As systems become more complex and decentralized, efforts to model them become more subjective. What Ackoff calls the “mess” of the real system is replaced by simple, or at least simply described, relationships in the model. How to do this becomes less clear for decentralized systems. At the same time, controlled experiments become less possible, limiting the possibilities for validation. Still, such models look similar to models of more law-governed systems. The OR analyst, with mathematical and scientific training, might not easily recognize the degree to which the modeling process has been subjective, particularly when using standard models formulated by others.

The systems of interest to cross-training models are a blend of standard, repetitive processes and human input. Whether a model is adequate for a particular purpose will partly depend on the potential for the behavior of the workers and supervisors to change performance in unpredictable ways. For example, assuming that worker speed is not changed by cross-training may be inadequate in a model used to predict throughput and our productivity index. If predicting the effect of cross-training on worker speed is also very difficult, say because it is not known how worker motivation will be affected or what the resulting productivity will be, then the situation is truly vulnerable to complex human input. It is less law-like than a typical automated line and the change (measured by the productivity index) is difficult to predict. In such a situation the appropriate modeling question might be “What is the potential of cross-training to reduce blocking and starving?” rather than attempting to predict throughput [Van Oyen et al. 2001]. Similar observations apply to decentralized coordination mechanisms where workers select the sequence in which they work on jobs.

*How should the analyst consider the worker?*

Since the consequences of implementing cross-training are subtle and situation-dependent, the analyst needs to consider a situation carefully before performing an analysis. Whether the changes are considered good or bad for the worker depends on the application, the individual worker(s), and the values of the person making the judgement. If worker dignity and quality of life are taken seriously, then cross-training to increase productivity seems to hold more opportunity for improving the condition of the worker, through empowerment and career development, than for harm. In one company we observed, the management has been willing to increase the resulting wages to gain support for a reorganization using team-based production with extensive cross-training. Because workers will react differently to cross-training, and change in general, the way that workers participate in training should be tailored to the individual.

When performing a study for management, we believe it is appropriate and important to consider the interests of labor, particularly those that are not regulated by unions or law. Both management and labor can be served by cross-training when it creates the opportunity for efficiency, adds wholeness to the work environment, and develops the skills of the worker. Of course, not all studies will reveal such an alignment of interests. But when OR models can illuminate such opportunities, we think doing so is a privilege of the analyst. After all, OR models helped shape the factories of the twentieth century, which largely ignored the physical and intellectual needs of the worker. When automotive line assembler Dan Clark described his experience in 1972, he said that "The problems that face the workers are monotony of the job, repetition, and boredom. We are constantly doing the same job over and over again …" in an environment of excessive heat, dangerous noise levels, noxious fumes, and a perceived lack of concern from management [Brynner and Clark 1972]. Surely there is room for improvement. Cross-training models and many other approaches, when applied with consideration for the human in the system, can make operations more worker-friendly, ultimately strengthening firms and helping to create better workplaces for the future.

**Conclusions**

For the historical reasons described above, U.S. operations tend to excessively emphasize specialized labor when, in many applications, more flexible approaches could increase competitiveness. Unfortunately, we have seen that traditional labor practices often create a culture resistant to new organizational approaches. Global competition is driving a shift toward flexible production that we expect to continue. Cross-training is an important aspect of flexibility; however, the cross-training approach should be tailored to each firm. OR modeling can help clarify the proper use of cross-training from the perspectives of logistical efficiency and flexibility. Cross-training can involve a major change in the organization of work and the reward structure, creating complex human reactions. Therefore, it challenges OR modeling approaches and makes ethical considerations in modeling particularly relevant. In particular, there is a need to consider the effects of the OR modeling process on workers. If the workers' needs are properly valued and incorporated, then we can hope for cross-training implementations that strengthen a firm while developing its human resources and improving the conditions and dignity of their work.

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**Bibliography**


Barabba, Vincent P. 1994, “The role of models in managerial decision making—Never say the model says,” in *Ethics in Modeling*, ed. W. A. Wallace, Pergamon, New York, New York pp. 145-160.

Bessant, J. and Haywood, B. 1998, “Islands, archipelagoes and continents: Progress on the road to computer-integrated manufacturing,” *Research Policy* **17**, 349-62.

Brahms, J. P. 2000, “Oath of Prometheus,” European Working Group on Ethics, retrieved on June 21, 2002 from www.prometheus.vub.ac.be.

Brynner, G. and Clark, D. 1972 “Worker Alienation”, Hearings Before the Subcommittee on Employment, Manpower and Poverty of the Committee on Labor and Public Welfare, U.S. Senate, 92nd Congress, 2nd session. July 25-26, pp. 8-13.

Checkland, P. 1981. *Systems thinking, systems practice*, Wiley, London.

Churchman, C. W. 1971 *The design of inquiring systems*, Basic Books, New York, New York.

Gass, Saul I. 1987, “Managing the modeling process: A personal perspective,” *Euro. J. of Oper. Res.* Vol. 13, No. 1, pp. 1-8.

Gass, Saul I. 1994, “Ethical concerns and ethical answers,” in *Ethics in Modeling*, ed. W. A. Wallace, Pergamon, New York, New York pp. 207-225.

Hopp, W.J. and M.P. Van Oyen, 2000, “A framework for model-based analysis of issues in worker cross-training and organization,” Working paper, Loyola University Chicago, School of Business Admin. Chicago, IL.

Hopp, W.J., E. Tekin, M.P. Van Oyen, 2001 “Benefits of skill chaining in production lines with cross-trained workers,” Technical Report, Northwestern University, Evanston, IL.

Iravani, S.M., Sims, K.T. and Van Oyen, M.P., 2002 “Structural flexibility and its application to manufacturing and service operations,” working paper, Northwestern University, Evanston, IL.

Kalkstein, M. 1969 “Personal involvement vs. professional information facing public issues,” in *The Engineer's responsibility to society,* ed. J. Mock. American Society of Mechanical Engineers, New York.

Keys, Paul 1998 “OR as technology revisited,” *J. Operational Res. Soc.*, Vol. 49, pp. 99-108.

Kleijnen, J. P. C. 2001 “Ethical issues in modelling: Some reflections,” *Euro. J. of Oper. Res.* Vol. 130, No. 1, pp. 223-230.

Knudsen, D.C. and Boggs, J.S., 1996 “The current transition in industrial capitalism,” in *The Transition to Flexibility*, ed. D.C. Knudsen, Kluwer Academic, Boston, MA, pp. 1-14.

Little, John D. C. 1994 “On model building,” in *Ethics in Modeling*, ed. W. A. Wallace, Pergamon, New York, New York pp. 167-182.

Marx, K. 1977 *Capital, Vol. I.* Vintage, New York, New York.

Malecki, E.J. 1996 “Technology, competitiveness, and flexibility: Constantly evolving concepts,” in *The Transition to Flexibility*, ed. D.C. Knudsen, Kluwer Academic, Boston, MA, pp. 15-32.

Mason, Richard O. 1994, “Morality and models,” in *Ethics in Modeling*, ed. W. A. Wallace, Pergamon, New York, New York pp. 183-194.

Meredith, Jack R. 2001 “Reconsidering the philosophical basis of OR/MS,” *Oper. Res.*, Vol. 49, no. 3, pp. 325-333.

Mingers, John 1992 “Recent developments in critical management science,” *J. Operational Res. Soc.*, Vol. 43, pp. 1-10.

Mingers, John 2000 “The contribution of critical realism as an underpinning philosophy for OR/MS and systems,” *J. Operational Res. Soc.*, Vol. 51, pp.1256-1270.

Mulvey, John M. 1979 “Strategies in modeling: A personnel scheduling example,” *Interfaces*, Vol. 9, No. 3, pp. 66-77.

Mulvey, John M. 1994 “Models in the public sector: Successes, failures, and ethical behavior,” in *Ethics in Modeling*, ed. W. A. Wallace, Pergamon, New York, New York pp. 58-73.

Nembhard, H.B, Nembhard, D.A. and Gurses, A.P. 2002 “Real options modeling for valuing worker flexibility” Working paper, University of Wisconsin, Madison, WI.

Olsen, Richard 1995 *Science deified & science defied: the historical significance of science* in Western Culture, Vol. 2. From the early modern age through the early romantic era, ca. 1640 to ca. 1820, U. California Press, Berkeley, CA.

Piore, M. and Sabel, C. 1984 *The Second Industrial Divide.* Basic Books, New York, New York.

Spear, S. and Bowen, K. 1999 “Decoding the DNA of the Toyota production system,” *Harvard Business Review*, September – October, 96-106.

Van Oyen, M.P., Senturk-Gel, E.G., and Hopp, W.J. 2001 “Performance Opportunity of Workforce Agility in Collaborative and Noncollaborative Work Systems,” *IIE Transactions* **33**, 761-777.

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