

Managing Flexible Automation

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How can industry capitalize on the manufacturing technology developments of the last decades? These innovations have created a range of programmable automation systems that seem to allow for a much greater flexibility in manufacturing; but what challenges does a shift towards greater flexibility generate for management? In particular, what human resource management policies can support these more flexible operating models? This article suggests some guidelines to tackling these difficult issues.

The challenge posed by the new, flexible technologies is primarily that posed by their higher "knowledge intensity." The relative importance of knowledge compared to that of labor or capital resources increases for two reasons. First, there is the increased importance of individual and organizational learning in systems that can not only manufacture a larger range of pre-specified products but can also adapt more easily to new product designs. Second, knowledge intensity is also increased by the programmable nature of the new technologies—which is at the origin of their flexibility—since this adds yet another dimension (software) to the range of types of knowledge (electrical, electronic, materials, mechanical, etc.) objectified in machine systems.

The management of the development and the utilization of systems so "dense" in knowledge poses new challenges. But while the management of knowledge has become the central task of firms wanting to survive in a world of rapidly evolving technological possibilities, knowledge management is an activity for which we have few models.¹

This is a revised version of a report to the Organization for Economic Cooperation and Development. It has benefitted from comments by M. Graham, S.C. Wheelwright, and two *California Management Review* reviewers.

The difficulty is that knowledge is an asset with particular properties. It is even more peculiar than the standard public good which doesn't get used up by being used, because with most forms of knowledge, the more you use, the more you have. The management of the production and distribution of this asset therefore imposes special challenges for management. Neither decentralization nor centralized planning, nor even any astute combination of these two modes of organization is entirely satisfactory. The emerging management literature is rich in insights into new forms of organization that are appropriate to the challenge of knowledge management.

The central argument of this article is thus that developing more enlightened forms of knowledge management is perhaps the key to unlocking flexible automation's potential.

Towards Flexible Computer Integrated Manufacturing

While the range of recent technological developments in the manufacturing area is staggering it is breadth—encompassing new processes, new materials, and new products—the central tendency has been the convergence of three strands:

- *design automation*: computer-assisted drafting, design, and engineering;
- *manufacturing automation*: computer-controlled processes in the fabrication/assembly industries (particularly in extensions of machine tool Numerical Control); automatic materials handling; automatic storage and retrieval systems; and
- *administrative (or control) automation*: computerized accounting, inventory control systems, and shop-floor tracking systems.

A recent report by the U.S. Office of Technology Assessment described the principal elements of these technologies.³ The most compelling aspect is their convergence towards what is now commonly called Computer Integrated Manufacturing (CIM):

- The linking of design and manufacturing is the most established initiative in this area, with numerically controlled machine tools permitting the designer to automatically generate tapes for machine control. Direct Numerical Control now permits the designer to download the program directly to the machine. The communication is, moreover, not only one-way: criteria of producibility can be built into design databases alerting the designer to the constraints of the available manufacturing technologies before, rather than after, the design is sent to Manufacturing.
- Links between design and administration permit the establishment of Bills of Materials and process plans directly from the design database.
- Links between all three elements—design, manufacturing, and administration, such as we find in Flexible Manufacturing Systems—permit the direct control of inventory and materials flow integrated with tightly coupled DNC machine systems.

The value of the new automated technologies can be assessed on several dimensions:

- *Cost*: dramatic improvements can be made not only in direct manufacturing costs but also, and perhaps more importantly, indirect personnel costs, materials costs, inventory carrying costs, and space costs.
- *Quality*: not only can defects be reduced by a greater degree of conformance to specification, but, more fundamentally, new performance characteristics become possible with the enhanced process capabilities.
- *Time*: throughput time for a given product can be reduced, but even more important can be the impact of reduced setup times and shorter change-over times on the ability to switch between products and the impact of CAD/CAM integration on the new product development cycle time.

For any given industry, a more refined analysis would also include other dimensions, such as Service. But in the general discussions of cross-industry effects, it is the third dimension, Time, that has attracted the most attention. Indeed, the new technologies seem to open up the possibility of a dramatic reorientation of industry away from the long runs of standardized commodities that seem to have been at the heart of the post-WWII prosperity.³

From this perspective, the key promise of the new technology would seem to be in shorter design cycles (through CAD), shorter turnaround-times for prototype testing (through CAD/CAM links), and faster manufacturing startup (through integrated manufacturing capabilities like FMS). These new parameters would allow for more rapid product turnover and for a broader range of products to be economically produced in the same facility—what Goldhar and Jelinek term “economies of scope.”⁴ The cost analyses of Boothroyd⁵ and Hutchinson and Holland⁶ confirm this potential.

An “Era of Flexibility”?

From a managerial perspective, a key question is whether greater flexibility will be the hallmark of the new automation’s actual implementation. Will we see a major change in the variety and turnover of products? This is less obvious than it may seem, if only because managers might find the other dimensions of automation’s advantages more important than flexibility. Programmable automation could shift management priorities towards greater flexibility because it can dramatically reduce the cost and quality penalties of improvements in the time dimension, but there will no doubt remain some trade-offs to be made between these three terms, and business strategy will need to assess which benefits offer the greatest competitive leverage.

The prospects for a major change in the degree of manufacturing flexibility are further conditioned by the managerial context: one of the scarcest

resources in the firm is management attention, and flexibility consumes a lot of it. Managing the complexity of these new systems and managing the learning required to realize their flexibility potential require not only a new level of expertise in manufacturing, but also a greater focus at general management levels on the manufacturing function. Will these be forthcoming?

The reluctance of U.S. managers to exploit opportunities which would disrupt established *modus operandi* has been described in vivid terms by Hayes and Abernathy,⁷ Reich,⁸ and Buffa.⁹ Their basic argument can be summarized in the convergence of the following factors:

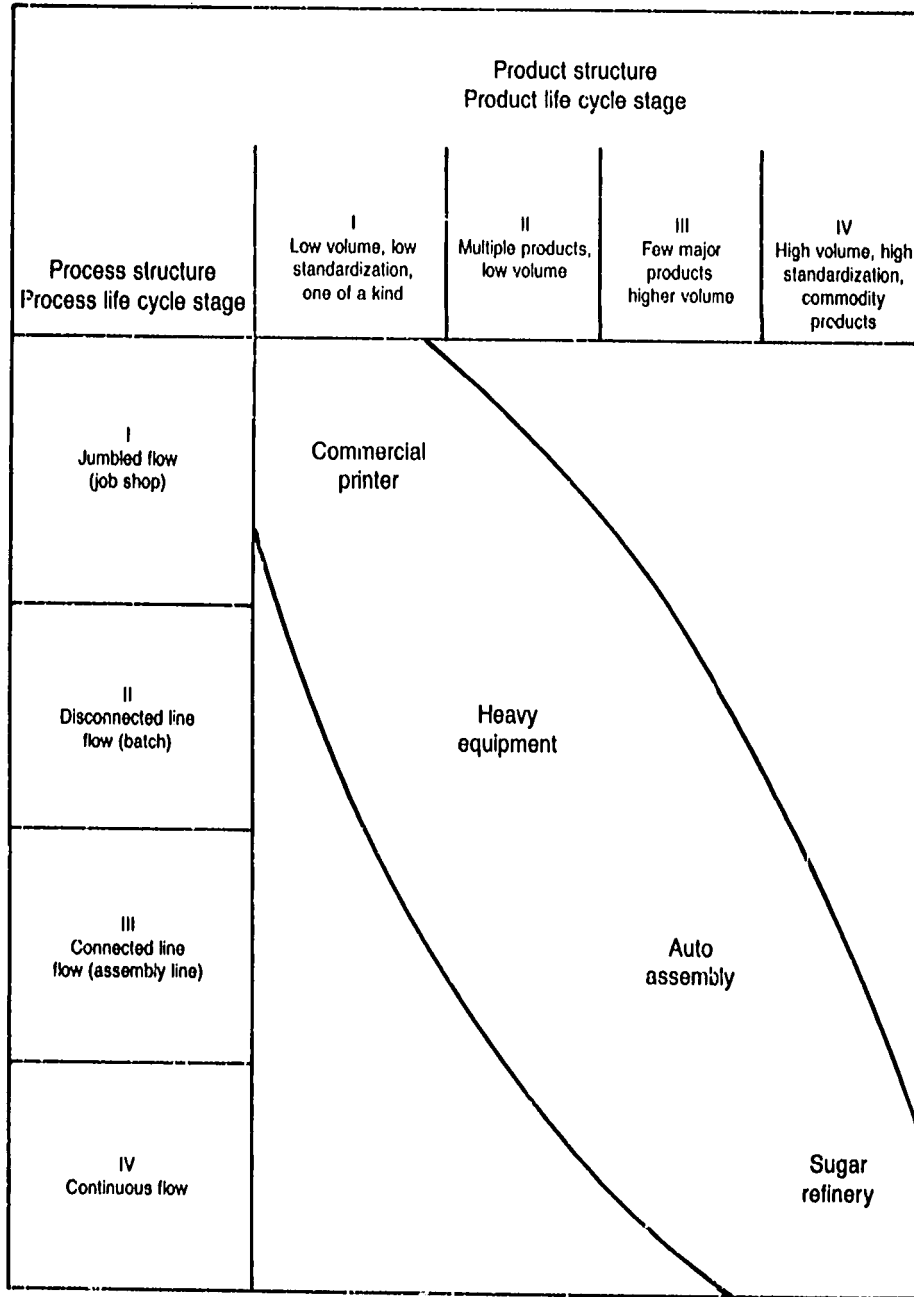
- financial considerations have dominated corporate strategy in the U.S. more than elsewhere;
- this has given precedence to the objective of a well-diversified portfolio so as to minimize risk across a set of given opportunities, rather than to the more entrepreneurial objective of creating new opportunities;
- the low organizational status of production engineering as compared to design engineering has both expressed and reinforced the absence of manufacturing as an active element of corporate strategy;
- the predominant philosophies of organizational design and management have served to encourage over-specialization and lack of integration; and
- competition has tended, as if by tacit agreement, to focus on non-manufacturing dimensions—distribution, packaging, advertising, etc.

This diagnosis has become widely accepted, albeit with important nuances between authors. Analysis of the origins of these proximate causes has, however, been scanty. The most plausible explanation would appear to be the "fat and happy" hypothesis: the position of world dominance enjoyed by U.S. industry in the 1950s and 1960s left U.S. producers without the challenge necessary to keep the entrepreneurial spirit sharpened.

While the current economic turbulence may subside, the likelihood that any new stability in markets will be at a somewhat higher level of flexibility is pushing management to explore flexibility with a new aggressiveness.

In this context, certain ideas have reinforced and contributed to U.S. managers' apparent conservatism. Amongst them is the long-held belief that in general higher levels of automation are by nature less flexible. This generalization can be found expressed in the work of Woodward¹⁰ and was at the origin of the association implicit in the "product-process matrix" developed by Hayes and Wheelwright.¹¹ (See Figure 1.) The axes of this two-dimensional matrix trace the life-cycle of products (ranging from one-of-a-kind to higher volume and finally to standardized commodity) and of

Figure 1. Hayes-Wheelwright "Product-Process Matrix"

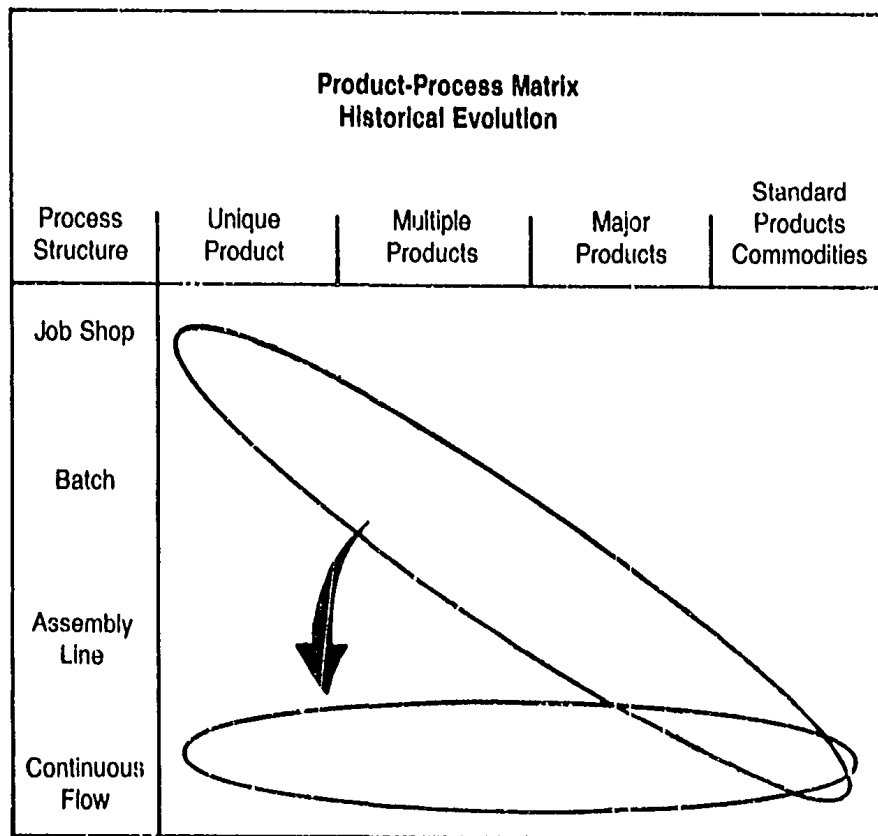


Source: R.H. Hayes, S.C. Wheelwright. *Restoring Our Competitive Edge*. New York: John Wiley and Sons, Inc., 1984.

processes (from jumbled flow of the jobshop to batch processing to assembly line and finally to continuous flow refinery). In this perspective, the more "mature" processes are also typically more automated. The competitively viable positions are generally on the diagonal, other positions being typically inefficient mismatches of product and process: one-of-a-kind products, for example, should optimally be produced in jobshops, not on assembly lines.

Flexible automation has challenged the managerial wisdom of the preceding decades that was captured in this proposition. It now appears clear that the matrix's normative implication is valid only at a given level of technology. In a more dynamic perspective, we need to consider the implications of recent automation tendencies which make it possible to envisage the production of less standardized products in a quasi-continuous process. Analyses like Boothroyd's¹² suggest that the new matrix's diagonal should be flattened (or at least bowed out downward), as in Figure 2. Such is the new argument of Hayes and Wheelwright¹³ and Ferdows.¹⁴

Figure 2. The Effect of Automation on the Product-Process Matrix



The implications of such a revision are profound. It undermines a deeply and widely felt intuition of a corollary between efficiency and rigidity. The proposition that there is a fundamental tension between innovation and efficiency—and consequently a dilemma for management in the choice between them—is one of the themes of Abernathy's landmark study of the auto industry¹⁵ and reflects widely-held beliefs culled from the last few decades' experience.

These challenges to conventional managerial philosophy are reinforced by the recent associated critique of the more mechanical applications of product (and process) life-cycle theory. The old idea according to which products and processes went through a life-cycle that took them along the respective axes of the product/process matrix has been challenged by the recent experience of many industries, starting with the auto industry.

When, during the 1970s, the U.S. auto industry came under serious competitive pressure from the Japanese and the import ratio began climbing, a debate emerged as to the nature of this challenge and the appropriate public policy response.¹⁶ Life-cycle theories would suggest that this was a natural—and unavoidable—evolution based on the inevitable standardization of the product, and that this evolution naturally gave the Japanese lower labor costs greater competitive significance. The policy implication is that the U.S. should get out of the auto industry. But closer examination by Abernathy and others suggested that the product design, far from becoming more standardized, was undergoing a profound transformation. The Japanese were not beating the U.S. producers primarily by virtue of their lower wage rates, but by a combination of new product and new process designs.

In numerous older and supposedly more "mature" industries, international competition and new technologies have recreated the kind of uncertainty regarding basic product and process parameters that we normally associate with the infancy of an industry. The auto industry served as a compelling example for the analysis of this process of "de-maturation" presented by Abernathy, Clark, and Kantrow.¹⁷

A new dimension of flexibility is opened by this double-ended attack on old assumptions: the ability to pursue a path of constant product and process renovation at speeds which may vary sharply from one period to the next—flexibility, in other words, not merely within the parameters of a given product generation and process type, but in the ability to pursue painstakingly detailed manufacturing cost-reduction programs and marketing refinements at the same time as the company maintains its ability to make the next breakthrough in basic product technology or in marketing concepts. (Abernathy, Clark, and Kantrow provide a framework—the "transilience matrix" for mapping the degree and type of change.)

These new developments in manufacturing thinking represent true gales of creative destruction demolishing established mental models. But whether

they correspond to such dramatic shifts in external reality is still debatable. Indeed, to the extent that current interest in manufacturing flexibility represents a reaction to the particularly unstable conditions that many markets have experienced in recent years, it might contain elements of over-reaction. The debate on long waves in economic growth continues,¹⁸ but so far little evidence has emerged that would encourage us to believe that *all* of the turbulence of the last decade is to be considered a permanent feature of the economic landscape. If, as seems plausible, the next decade sees the emergence of new, somewhat more stable configurations of demand and of supply, some flexibility efforts may prove to have been over-reactions.

The best evidence suggests that the current economic turbulence may subside, but that both survival in the interim and the likelihood that any new stability in markets will be at a somewhat higher level of flexibility are pushing management to explore the flexibility of new manufacturing capabilities with a new aggressiveness. What, then, are the implications of such an effort for management practices?

In Search of Flexibility

Pursuit of competence in more flexible manufacturing requires rethinking a considerable range of managerial practices.

Strategy—The achievement of the more advanced forms of production flexibility calls for a new status for manufacturing strategy, as outlined by Wheelwright and Hayes.¹⁹ They outline four “stages” of manufacturing’s strategic role: internally neutral, externally neutral, internally supportive, externally supportive.

A key challenge in capitalizing on the new technological potential for flexibility is to adapt organizational cultures to maximize spontaneous cooperation.

It is the most advanced stage, where manufacturing becomes a real competitive asset, that appears to be the prerequisite for capitalizing on new opportunities for flexibility: “Stage 4 implies a deep shift in manufacturing’s role, in its self-image, and in the view held of it by managers in other functions. It is, at last, regarded as an equal partner and is therefore expected to play a major role in strengthening a company’s market position. Equally important, it helps the rest of the organization see the world in a new way.”²⁰

In relation to the specific issues posed by new, more-flexible automation,

the contrast between the more and the less advanced strategic approaches is profound. To capitalize on rapidly evolving opportunities requires a "dynamic" perspective on process technology, rather than the traditional "static" perspective. In these more proactive manufacturing strategies:

- the responsibility for new technology is broadly defined to include not merely the specialists and lower-level managers, but also suppliers, workers, and senior managers;
- the process of technological change cuts across functional boundaries and is continuous over time, rather than consisting of discrete, episodic, and functionally specialized projects;
- the objective of change is the enhancement of a broadly-defined set of capabilities, rather than cost-reduction for a specific product;
- the criteria for evaluating projects include the long-term and non-financial benefits, rather than being limited to the traditional two or three year payback analysis; and
- the competitive contribution of automation is seen as deriving from a continual, incremental process of improvement, rather than occasional big steps.

The principle lesson of Wheelwright and Hayes is that the dynamic enhancement of process capabilities requires a strategic vision in each function. In other words, strategy, far from being restricted to the firm's external orientation, and far from being the sole prerogative of the general manager, is the necessary foundation of excellence in all the functions, and as such the *sine qua non* of realizing the potential of advanced automation.

It is perhaps in their commitment to this kind of strategic thinking for manufacturing that Japanese companies can be most advantageously compared to U.S. companies. The Japanese excellence in creating and maintaining taut production systems (such as Just-in-Time inventory control) is perhaps not their most powerful weapon in international competition. It merely reflects the priorities that emerged at one point in time in their ongoing efforts in the manufacturing area. Today, surveys indicate that the emphasis in Japan is on new product development. The Wheelwright-Hayes argument alerts us to the possibility that U.S. fascination with the tactic—for example, Just-in-Time—may obscure the strategic lesson, namely, that continual improvement in manufacturing is critical.

Evaluating Projects—The advantages of the new technologies pose a major challenge to the traditional approaches to the justification of capital investments.

A first difficulty lies in defining flexibility. In the Appendix, I have summarized the principal approaches. No consensus has emerged yet on the most appropriate definition. The second difficulty lies in quantifying the "value of flexibility" so as to integrate it into the standard financial methodology. Here too numerous approaches are still in competition.²¹

The biggest challenge, however, is perhaps more profound. The Manufacturing Studies Board recently surveyed the CAD/CAM scene in the U.S. and concluded that "the usual financial measures, such as return on investment, were inadequate for assessing the results of integration. . . . The best measures, these companies say, are responsiveness, productivity, quality, lead time, design excellence, flexibility, and work-in-process inventory."²²

Such eclectic approaches challenge the deeply ingrained habits of accounting. Kaplan²³ and Gold²⁴ have presented particularly incisive critiques of current practice in the U.S. in this regard. Their critiques focus on the excessively narrow range of benefits (and costs) included in the evaluation.

Hayes and Garvin went somewhat further in their critique, focusing on the myopia generated by the discounting approach—at least as it is commonly implemented.²⁵ Their key argument was that discounting practices usually give insufficient weight to the costs of *not pursuing* an investment opportunity. Hodder and Riggs recently clarified the types of misuses to which discounting has been subjected—in particular, improper treatment of inflation, over-adjustment for risk, and failure to include the effect of possible management action to mitigate risks.²⁶ Their conclusion is that Net Present Value can be beneficially used as a framework in which we can combine in a reasoned manner the more analytical and the more "entrepreneurial-intuitive" elements, both of which are needed for a sound investment decision.

There appears to be a consensus that evaluation of far-reaching technological changes should be conducted on an explicitly strategic foundation. It remains an open question as to whether the representations of strategy afforded by the "universal solvent" of finance are adequate to support decision making in the world of difficult-to-aggregate criteria relevant to manufacturing technology investment decisions.

Managing Change—The third set of challenges posed by the new technological potential for flexibility relates to the ability of management to identify the types of organizational changes required to pursue the realization of that potential.

A recent survey by McKinsey and Co. of CAD/CAM efforts highlights the problem.²⁷ Their discussions with 18 major users in the U.S. led them to identify three types of CAD/CAM configurations. In the first type, the CAD system was being used as an "electronic pencil" devoted to drafting. The second and more advanced group was composed of those using CAD as a tool for the whole design function and using this opportunity to rethink the operation of that function: restructuring jobs to combine design, checking and detailing, for example. Some two-thirds of their sample had progressed in developing this type of application. The third and most advanced configuration was one that "takes the slash out of CAD/CAM" to forge

direct links with the manufacturing database. Only a minority of firms surveyed had even begun down this path (and the sample was chosen to reflect best, not average, practice).

The hardware is similar across these different configurations; the software is available, although often not entirely satisfactory. Moreover, the McKinsey report estimated that the third stage would triple the benefits of CAD/CAM as measured in reduced design cycle time. But what is as yet lacking for most firms, even those actively pursuing CAD/CAM, is the managerial commitment to realizing that potential.

Our recent research²⁸ on the implementation difficulties of CAD/CAM integration in the electronics and aerospace industries has generated a framework for identifying these managerial challenges. Following Pava,²⁹ we find that the level or type of learning required to realize the benefits of a new technology varies systematically with the magnitude of the technological step being taken. Simple technical changes are implemented effectively at the cost of some retraining and the development of some new *skills*, for example, software capabilities in manufacturing engineering and process technology understanding in design engineering. More sophisticated changes require changes of *procedure* (for example, new manufacturability review procedures) and of *structure* (for example, centralizing an Advanced Manufacturing Engineering group). For the major technological changes of the kind well exemplified by the new, more flexible automation, changes are necessary in *strategy* (in particular, the development of functional technology strategies) and in *culture* (especially in the development of a more egalitarian relationship between the functions).

The final challenge, culture, is particularly critical. To make flexibility work in practice requires a cultural foundation linking new roles and new expectations. While the corporate culture fad will probably soon be supplanted by some other, Ouchi has presented a cogent argument as to why the underlying reality it refers to is an abiding one.³⁰ Forms of organization which rely on socialization and a common set of norms as the principal mechanism for control, can be shown to be more effective than either market or bureaucratic systems when "performance ambiguity" is high.

Culture thus becomes increasingly important, since both the new level and the continuing acceleration of technological change increase performance ambiguity: the new level of technology demands a higher commitment to learning rather than routine execution, and, with technology's continued acceleration, each new step in automation is a bigger one, which increases the ambiguity of objectives and of paths to attaining them. It is no accident, therefore, that many of the cases referred to in the corporate culture literature are in the more technologically dynamic industries.

A key challenge in capitalizing on the new technological potential for flexibility is, therefore, to adapt organizational cultures to maximize spontaneous cooperation. When knowledge is the critical resource, economic

theory³¹ has shown with considerable analytic rigor that under any realistic set of assumptions there can be no optimal incentive structure: a market system can create incentives that encourage the production of knowledge, but these incentives will inhibit its distribution; a bureaucracy—central planning—can mandate the optimal pattern of distribution, but fails to provide the incentives for the production of new knowledge. A third form of organization—cooperation—premised on shared values is the only form which can hope to surmount these complementary weaknesses. The challenge, however, is to create and sustain it.

Implementation—The implementation of new automated capabilities creates unique problems, the solutions to which seem to make a cultural fabric of cooperation a necessity, not merely a humanistic ideal.

The new systems' flexibility is such that a commitment to learning needs to have been well established as a culture, with the supporting strategies, structures, procedures, and skills. Failing that, fear of system underutilization and vulnerability will deter the participants from pursuing the new technological development opportunities.

Jaikumar's survey of Flexible Manufacturing Systems³² is striking in this regard, since most of the systems in use in the U.S. today show a remarkable lack of flexibility. The average number of parts being produced on FMSs in the U.S. is 8—compared to over 30 for comparable systems in Japan³³ and perhaps as many as 85 in Germany.³⁴ Many U.S. firms appear to be paying lip-service to the idea of flexibility, while in reality using the FMSs as automated assembly lines. History may yet vindicate them: when FMS technology gets cheaper, such an approach might indeed be viable, even optimal. In the meantime, however, it is a very expensive recipe for frustration.

In the overwhelming majority of cases, it is the human resource management issues that are the major stumbling blocks in implementing the new technologies.

The difficulty facing U.S. managers is to maintain the commitment to continual learning in the face of schedule constraints that are, in the U.S. context, rarely lifted for long enough to permit the development and debugging of the programs required for more than a minimal set of parts.

Ettlie has surveyed users of flexible, programmable automation and confirms the results of numerous other studies of the conditions of effective implementation.³⁵ The principal factors of success appear to be the following:

- *A close relationship with suppliers:* rather than an arm's-length transaction, the complexity and flexibility of the new technology call for an ongoing collaboration over an extended period of time. Many respondents refer to the relationship as a "marriage."
- *A good fit of the proposed new process technology and the product range:* too many firms like the idea of flexibility, but have not established the link between their range of products and the types and degrees of flexibility that would make business sense. They consequently often over-order then under-utilize.
- *A clear strategic vision on the part of the user:* to guide the user through this gold mine of opportunities that so easily turns into a minefield of problems, users need a long-term strategy for their process technology development path.
- *The training of operators:* the need to actively pursue development of the flexibility potential in-house calls for in-depth training of both a hands-on and a theoretical kind. Merely operational training is insufficient.

The concept that seems to be emerging—if only with considerable difficulty—is that of "planning for effective implementation." Traditionally, implementation has been a residual task; but with the new technologies, the learning process is both so lengthy (often three years or more for an FMS) and so critical (without it, little flexibility is realized) that implementation finally begins to assume importance amongst the competing priorities of management.

Labor Force Considerations—Of all the implementation issues, labor requirements are among the least well-managed:

- Vendors have traditionally been rarely available for advice or help—although that is now beginning to change, since the new technologies can't even get off the ground without major vendor commitments to the implementation phase.
- Vendors are also a somewhat interested party, especially when the capital expenditure is going to be justified on labor cost savings: many users of numerically controlled machine-tools or of word processing equipment were overly impressed by advertisements promising to reduce dramatically their dependence on skilled machinists and typists.
- Internally, the assessment of the skill impact of new technology is a low priority task; the choice of the new equipment is itself motivated by technical capabilities and cost savings: the skills required to make it function effectively are rarely examined. The idea that the work force capabilities are themselves a critical competitive resource may get a mention in the annual "Employee communications" sheet, but almost never plays the kind of role in strategic or even operating plans that it should command.

- Once the equipment arrives, skill and training issues often take second place to the more urgent task of debugging, getting the system up and running, and getting manufacturing back onto schedule. When Manufacturing's mission is defined in traditional, narrow terms, manufacturing managers have little room to move.
- When attention is finally paid to the question of the optimal skill mix, it is usually in firefighting mode: how to absorb the displaced headcount or how to deal (reactively) with union job classification grievances.

To the extent that the skill requirements are planned for, it is in a largely unconscious mode. The "fantasy" that governs much of this unconscious process is one I have called the "deskilling myth": received wisdom and wishful thinking encourage managers to believe that new technologies permit them to make do not only with proportionately *fewer* workers—but also with *less-skilled* workers.³⁶ Of course there are some cases where deskilling is possible, but the evidence, meagre as it is, suggests strongly that the general effect of new technologies—over-riding the local effects of any particular management's philosophy—is an upgrading one.³⁷

The problem is that firms too often "back into" this upgrading, losing many of the advantages that can be gained from a more proactive approach to the process of transforming their human resource profile.³⁸

Wheelwright and Hayes offer an insightful characterization of the manner in which firms planning to make manufacturing a competitive weapon will view their work force.³⁹ When management believes its process capabilities must evolve in a dynamic manner, work-force management has to be focused on stimulating worker learning rather than on "command and control" for execution of the standard, stable set of procedures. The contribution of workers in these more dynamic environments is via their attention rather than mere effort, since the central task is one of problem solving. Whereas in the static model of manufacturing, direct supervisory control is sufficient, in the more dynamic environment, the process specifications are rarely stable enough to avoid relying on indirect modes of control via systems and values.

Wheelwright and Hayes do not link the need to move to a more dynamic model specifically to technological tendencies. But much of the research on the implementation of advanced, programmable automation points unambiguously in this direction, as the following brief survey of some recent research in Germany, Britain, and the U.S. will confirm.

Flexible Automation and Skills: An Emergent Paradigm

Recently, several colleagues and myself have independently and informally been polling companies on the major "show-stoppers" in flexible automation projects. We were not surprised to discover that literally every company we talked to had their share of horror stories. We were, however,

surprised to discover that in the overwhelming majority of cases, it was the human resource management issues that were the major stumbling blocks in implementing the new technologies. These experiences seem to be pushing managers to reconsider their human resource policies.

Recent research might help identify the optimal policies. Indeed, a surprising degree of convergence can be found in a series of studies conducted in numerous countries, all pointing to advanced automation's new and higher skill requirements. To the casual observer, unaware of the tenor of research on automation and skill over the last 10 or 15 years, such a consensus might appear entirely natural. But in reality, it constitutes a remarkable transformation of the dominant discourse within the research community.

The automation and work research of the 1950s and 1960s was dominated by authors like Blauner, Woodward, and Mallet, who—despite considerable nuance between them—all saw automation leading to a recomposition of jobs and an upgrading of skills relative to the limited job requirements of the assembly line.⁴⁰

Partly because of the prominence of less-skilled workers in the resurgence of class conflict in the late 1960s, and partly because of the internal limits of the older research (the optimism of which seemed based almost exclusively on the narrow base of continuous process industries), the late 1960s and the 1970s saw a very different approach dominate. A series of studies originating in different countries expressed a striking convergence on the proposition that automation's potentially favorable effect on skill requirements would not be realized, since automation's mode of deployment was a reflection of its social context. Authors like Braverman in the U.S., Freyssenet in France, Beynon and Nichols in the U.K., Kern and Schumann in Germany, and Panzeri in Italy all argued various forms of a single thesis: capitalist societies would tend to deskill work in their constant search for lower production costs and greater control over the production process.⁴¹

That there was an element of polemical intent in these studies was fairly evident. Nevertheless, and in the absence of systematic statistics, case studies were used to great effect to show: a frequent gap between workers' capabilities and job requirements (underutilization); instances where efficiency did seem to call for deskilling; and other instances in which managerial ideologies led to deskilling at the expense of efficiency. The microdynamics of power relations within the firm became the focus of attention and the premise for extrapolations to overall skill requirement trends.

Even its partisans had some difficulties with this deskilling thesis—in particular the multitude of counter examples, the preponderance of statistical evidence pointing to a distinct if modest long-run rise in skill requirements, and the need to include the impact of worker resistance and specific market conditions on skill outcomes. Research therefore then veered away from the "big generalizations" and began to focus on the microdynamics of automation and skill in specific institutional and market settings. This gen-

erated very worthwhile research into the "social construction" of skill definitions, into the impact of market conditions on relative bargaining power, and so forth. The *Sociologie du Travail* group in Paris can, in this respect, be compared to the research of Edwards in the U.S. and Gallie in Britain, to name but a few examples.⁴²

Over the last five years or so, a change of tone has become manifest. The dynamism of capitalist work reorganization efforts and the extensiveness of industrial restructuring seemed to call for new efforts to reach viable, if modest, generalizations. But this time, the cases cited are much more frequently those of skill upgrading.⁴³

What is retained of the preceding generation's work is an appreciation of the fact that in a market economy, these tendencies will typically manifest themselves in a chaotic manner, often leaving pockets of deskilling and redundancies that may indeed call for policy remedies. This lack of personnel planning is obviously a source of concern, both for workers who suffer and for those worried about competitiveness. (Lund and Hansen, for example, point out the serious difficulties that can lie ahead for firms which so polarize their skill distributions that there are no longer any promotion prospects for lower-level personnel—creating a morale problem—nor any internal recruiting possibilities for higher-level positions—a problem in some industries where much of the requisite production knowledge is non-codified.)⁴⁴ But despite these local and short-term issues, it seems reasonable to suggest that in general and over the longer run capitalist competition forces firms to seek out more productive combinations of machine and human capacities, and in the process the spontaneous outcome is, more often than not, an upgrading of worker skill requirements. Better labor force planning would then complement, rather than hold in check, the principal spontaneous tendency of industry.

Automation is changing our notion of skill and has added a new layer of complexity to old debates.

One of the key conceptual difficulties of the automation-skill issue—a difficulty encountered by managers, engineers, and theorists alike—resides in the fact that automation is changing our notion of skill. This change in the nature of skill has added a new layer of complexity to old debates, since prognoses of deskilling often refer to a type of skill quite different from that implicit in upgrading views.

"Skill" is not just a one-dimensional variable; jobs differ in the types of skills they require. But beneath the multitude of specific occupational

skills. one can identify certain common dimensions: one approach would be to distinguish the amount of training, the frequency of training, and responsibility, expertise, and interaction requirements. Much of the evidence of the recent research points to important changes in the content of these categories under the impact of automation. One way of mapping the nature of these changes is suggested in Figure 3.

When skills shift from behavioral, experientially-based, individual attributes that are acquired once-and-for-all to capabilities that are more attitudinal, cognitive, social, and in continual evolution, it is easy for the worker to feel as if something tangible has been lost. To take an example: when control over the cutting tool path shifts from the skilled machinist to the part programmer, the machinist might feel that numerical control has undermined his or her distinctive competence. By the same token, a plant manager might be tempted to think that the new NC technology will permit important savings in training and thus in hourly wage rates. But the research underlying the new model suggests that the payoff to that NC investment will depend critically on the workers' sense of responsibility, problem-solving abilities, teamwork strengths, and willingness to regularly expand their capabilities as the automation itself evolves.⁴⁵

Flexible automation thus increases the upside opportunity for the plant that appropriately matches new technologies with new skills. Flexible automation thus also increases the opportunity cost associated with an all-too-common form of myopia in skills management and training effort.

Figure 3. Old and New Content of Work

Factor	Old Content	New Content
Training Amount	Minimized narrow and shallow	Investment broad and tall
Training Frequency	One Time one-time investment	Continual frequent retraining
Responsibility	Behavioral <ul style="list-style-type: none"> ● responsibility for effort ● discipline 	Attitudinal <ul style="list-style-type: none"> ● responsibility for process integrity and results ● disposition
Expertise	Experiential manual or rote	Cognitive identifying and solving problems
Interaction	Low stand-alone or sequential	Systemic Interdependence <ul style="list-style-type: none"> ● team-work ● interfunctional cooperation

Focusing on the Right Stabilities

In conclusion, it may be useful to highlight one overarching lesson which emerges from a comparison between the managerial and the economic approaches to flexibility. In elementary economics, it is assumed that flexibility—flexibility of prices, of quantities, of location, of assets, etc.—is *prima facie* “a good thing.” Of course, in more sophisticated economic analysis, phenomena such as the importance of standards and the inevitability of various externalities make certain rigidities or stabilities appear as potentially beneficial in a world of “second-best” options. But these rigidities tend to be viewed with suspicion, since their presence can stop the invisible hand of the market from producing an optimal outcome.

From the managerial point of view, things appear almost inverted. Stability is a fundamental value, whereas flexibility is difficult to manage and *ceteris paribus* more costly. For managers, flexibility is potentially advantageous—and indeed, only becomes meaningful as a concept—against a backdrop of stabilities. The managerial question is therefore not simply how to reduce rigidities, but how to find the right mix of stabilities and flexibilities. That is why the deliberate introduction of certain stabilities can be a powerful policy lever: the rigidity of the Just-in-Time inventory management regime helps to uncover the production inefficiencies hidden under inventory.

The difference in approach derives primarily from the fact that for the manager, the reality of externalities, standards, increasing returns, etc. is the stuff of daily competitive life; while for the economists, they are concepts that only become important as higher-level refinements of the basic theory. Indeed, the tension between the two perspectives can only grow as technology becomes more important to competitiveness and the proactive management of standards and knowledge-sharing become more central.⁴⁶

Managers therefore need to focus on identifying the stabilities which offer the greatest leverage. Several candidates are:

- the stability of an explicit and credible long-term technology strategy can allow lower-level managers to be flexible in local innovation;
- employment stability can generate the good will needed to maintain a culture of cooperation;
- stable “marriages” between vendors and users of new equipment help maintain flexible collaboration in the development of new technologies; and
- a stable development growth path for worker skills can ensure that the knowledge mix evolves in the way needed for effective deployment of the new technologies.

In this context, an issue which this article has not yet addressed becomes critical: Industrial Relations. The institutionalization of employment conditions and worker-management relations is often perceived as an impediment

to the flexibility that many economists see as necessary for the invisible hand to do its magic in the labor market; in this domain at least, many managers share the economists' view seeing institutionalized industrial relations as inimical to the maintenance of a personalized, individualized relationship with their workers.

Such approaches to the issue might no longer be adequate. Walton argues persuasively that business efficiency can be significantly enhanced by a shift away from the "control" model—with its associated adversarial labor relations and its corollary of a preference for union-free environment—toward a "commitment" model—in which, rather than attempting to decertify unions, managers attempt to establish mutuality and joint planning.⁴⁷ The commitment model uses a constructive Industrial Relations climate to derive competitive advantage from the strengths of a more stable, motivated, and loyal work force. As we have seen, such advantages might become more valuable as firms adopt more dynamic technological strategies and move towards flexible automation: the studies reviewed in this article consistently point to the growing importance of lower-level personnel's problem-solving capability—and their motivation to use it.

The recommendation seems so compelling that one has to ask why more firms don't adopt the commitment model. The problem is easily identified: in order for unions to play a constructive role, they cannot relinquish the functions that have pitted them against management in their traditional adversarial role. To remain significant partners, they must continue to express and represent workers' interests. Experience, moreover, teaches that these interests are not always congruent with those of the firm's managers and share-holders. In the absence of unions, some of these divergences might be less acute, or at least less apparent. But as Reisman and Compa argue, the sources of these divergences are real enough that "if the existing unions cannot help them accomplish [their] goals, workers will find other approaches and methods."⁴⁸

To derive the benefits of the commitment model advocated by Walton would therefore seem to require the construction of a system of Industrial Relations in which Labor and Management can pursue collaborative efforts at the same time as they give organized expression to their inevitable conflicts. The culture of cooperation needed to sustain the development and effective deployment of flexible automation will need to be sufficiently robust to absorb the inevitable tensions between various stakeholders' interests.

The problem for managers is that it is difficult to construct a single island of new industrial relations in a sea whose principal currents are oriented toward the destruction of all "labor market rigidities." Not all the answers to U.S. industry's competitiveness in the use of flexible automation are in the manager's hands.

Appendix—What is Flexibility?

The new developments in technology have prompted efforts to clarify the significance of the concept “flexibility.” At this stage of research, no one approach has gained widespread acceptance. The definitions of Gerwin, Mandelbaum, Buzacott, Zelenovic, Browne, and Jaikumar have a somewhat ad hoc, domain-specific flavor.⁴⁹ The economic approach focuses on another, equally specific set of issues.⁵⁰

Attempting to synthesize these various notions, we find that the economic definition is the most generic; Zelenovic’s distinction of design and adaptation flexibility is a little less so; the others are partially overlapping.

The conceptual difficulty appears to reside primarily in linking the two key dimensions of flexibility: process and product. In each dimension, we can identify successively broader system boundaries: the process dimension encompasses individual machines, then systems, and finally the overall plant; the product dimension encompasses product mix, then design changes, then new products, and finally new product generations. (See Figure 4.)

Mandelbaum’s action and state flexibility might be thought of as another way of distinguishing process and product; but Gerwin, Buzacott,

Figure 4. Product and Process Dimensions of Flexibility

	Mandelbaum	Gerwin	Buzacott	Browne	Jaikumar
Product:	state		state		
product mix		mix		production	
design changes		design change			
new products within family		parts		} product	} product
new families					
Process:	action				
machine			} machine } job	} machine } process	
system		routing			
plant		} volume		} expansion } volume	program

Jaikumar, and Browne mix both dimensions in their typologies. For example, Gerwin's mix, design change, and parts are on the product dimension, whereas his volume and routing dimensions are on the process dimension.

From the engineers' point of view, it is the process dimension that seems most exciting: one of the most promising aspects of the current phase of automation lies in our growing ability to design into machine systems sufficient flexibility and intelligence to make them far more robust relative to a broad spectrum of process contingencies. Whether it be relative to breakdowns or to finding a given machine unexpectedly unavailable, the ability to automatically reroute products offers the promise of higher utilization rates through expanded flexibility in the process dimension.

From the societal and managerial points of view, however, the bigger challenges and opportunities seem to derive from the development of flexibility relative to changes in the product dimension. The new technologies permit the flattening of the average cost curve relative to a number of key competitive dimensions—product change-over time, new product manufacturing ramp-up time, product development cycle time. This flattening has the potential of transforming the rules of the competitive game by undercutting the cost advantage of the standardized commodity produced in long runs.

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