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SHIFTING ECONOMIES:
CRAFT PRODUCTION TO THE FLEXIBLE FACTORY

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INTRODUCTION

The first part of this paper looks at production organizations from several perspectives, all of which treat the evolution of craft or job shops to factory models. In general, companies have pursued factory approaches as a means of moving beyond customization of single products for single customers, to the point where they can capture economies of various sorts, especially those related to scale of output and operations. These have enabled firms to offer customers products with standardized features but at low prices. By usual criteria, much of software development seems inappropriate for conventional factory practices, and reported resistance to factory practices by programmers can be explained in terms of this incongruence.

The next two sections discuss flexible design and manufacturing techniques as well as different product-process and organizational options that seek a better combination of efficiency and flexibility, with the flexible factory emphasizing semi-customization and economies of scope as much or more than scale. The software factory is also introduced as a type of flexible design and production organization contrasting with traditional job-shop or craft approaches to software development.

CRAFT SHOPS TO THE CONVENTIONAL FACTORY

For most products, design and production require several distinct steps or phases, proceeding more or less sequentially, with some iterations and overlaps. An individual worker, or members of teams or departments, begin with an idea, generated by consumers, manufacturers, suppliers, or others, that seems to define an existing or future customer need. They then experiment with concepts and create a formal concept proposal. This must be translated into a detailed design, and the resulting documentation or blueprints are then made into prototypes. When the designers and prototype builders are satisfied, the completed design becomes a production model, which can be tested and refined further.[1]

The sequence ends with the production model if there is only one job--one product, one customer. In this case, the product and the process needed to make it are "customized" in an organization one might call a "job shop," by workers that in many ways resemble the craftsmen or artisans who made a variety of products before the advent of the modern factory in the 1800s. If there is more than one potential customer, a firm can create different types of organizations aimed at replicating this design with varying degrees of efficiency and output volumes, from a few (batch production) to many (mass production). Developing a mass production or replication system may require a great deal of thought and money. Once this system is in place, the final production process might be relatively simple, such as pressing a phonograph record or copying a software program, or relatively difficult, such as assembling an automobile or a video recorder. Difficulty depends on the nature and number of the components, production or assembly processes, customer requirements, and other factors.

From the customers' point of view, a product is customized only if it is tailored for their specific needs. From the producers' point of view, however, there are several options. Some new designs they customize or "make from scratch," while in others producers reuse designs, components, tools, processes, or particular people from other projects. Volume of replication, reuse or non-reuse of components, process characteristics, as well as the coordination mechanisms needed to manage design and production, are some variables distinguishing different types of product-development and production organizations. These distinctions are important because observers from several fields, as well as managers, have used them for descriptive as well as prescriptive purposes -- to explain the principles behind both job shops and factories, and thus the logic which suggests what processes and methods of organization seem most appropriate for particular situations.

Historians have seen the factory as emerging when the maturation of certain product technologies created opportunities for firms to focus on process innovations aimed at capturing greater economies of scale. There again is present the notion that specific characteristics of an industry and its environment -- degree of divisibility of processing equipment and operations, degree of product and process standardization or complexity -- most determine whether a firm can or should move to factory-oriented modes of design and production. While factory manufacturing can be highly efficient, usually managers have considered it economically feasible only with high production volumes, due to the large capital requirements usually needed to introduce this type of a system.

The most widely cited definitions of different types of production organizations has come from industrial organization literature and the work of Joan Woodward in particular. She identified three basic types: unit or craft production (job-shop and small-batch), large-batch and mass production, and continuous processing operations as in chemical manufacturing.[2] Unit or job-shop production has non-standard inputs and outputs -- i.e. each finished product, and the components that go into it, tend to be different. Therefore, managers are unable to standardize materials or formalize development processes. Job-shop organizations typically require many "ad hoc" adjustments to make a product; to allow workers to make these adjustments, managers exert control only at a low level, that is, usually by first-line supervisors. It also seems important for supervisors and workers to be highly skilled -- hence the label "craft" seems appropriate for this mode of operation. In general, in job-shop or small batch production, the lack of standardization in processes and products, and management controls, as well as high skill requirements, make it difficult for managers to find either scale or scope economies.

Historians have suggested that factory systems tended to replace craft modes of production as firms learned how to rationalize product designs and work itself. In describing the evolution of factories during the 18th and 19th centuries in Britain, Europe and the United States, initially in the textile industry and then gun-making, Alfred Chandler noted how managers raised worker productivity and lower unit costs by standardizing and then integrating production processes in large, centralized facilities; developing interchangeable components; closely coordinating the flow of each process; dividing and specializing labor; mechanizing or automating tasks; and imposing rigid managerial, accounting, and other types of controls.[3]

Another way to interpret this evolution, as done by John Hunt, is in terms of distinct "ages," such as from craft to machinery, exemplified by the use of steam engines in factory mass production during the 18th century, to the power age after the introduction of electricity.[4] David Landes similarly describes this transition -- often labelled "the industrial revolution" -- as involving primarily the substitution of mechanical devices for human skills, inanimate power for human or animal strength, and marked improvements in materials extraction and processing.[5]

But while factory organizations provided higher worker and capital productivity, the nature of the processes, equipment, and worker job routines made it difficult to introduce new products or processes quickly and economically, or to meet the demands of customers with distinctive tastes. Because new technologies or product and processes variations continue to appear in most industries, and because not all customers want commodity products, factory-oriented design and production has never completely replaced the craft or job shop.[6] Market segmentation thus provides opportunities for firms to compete through differentiation, mixing combinations of price and product performance levels, supported by different types of processes and organizations.

Firms competing through standardized products and factory production usually enjoy considerable economies of scale -- the situation where average production costs per unit of output tend to decline as total volumes of production for a product increase, at least up to a certain limit. Economists attribute this phenomenon to several factors.[7] One involves the concept of "indivisibility." Many machines or facilities need to operate at particular volumes for a firm to be able to justify their cost. Some equipment or processes are designed with minimum and maximum operating ranges, so that they are not easily adapted to smaller volumes of a number of different products. Automated equipment especially can vastly improve both productivity and quality, but is usually expensive to introduce, thus requiring high utilization rates. Suppliers face these same constraints, and may not deliver materials to a firm unless there is a minimum size order, and offer their customers discounts for larger orders or long-term contracts. It is also to the advantage of a firm to spread fixed and variable costs related to equipment, land, research and product development, administration, and various "overhead" expenses, among large numbers of units sold. This is another form of scale economy, although the notion of scope -- spreading costs or resources across different products-- applies here as well as scale.

Yet another reason for the drop in costs is specialization and division of labor. When production volumes for a particular product or component are high enough, it often becomes possible to divide a process into a series of tasks. Workers can specialize, and more quickly accumulate experience for their assigned tasks. Through this type of analysis, firms often found more efficient methods of production, as Taylor demonstrated, although, once set, there usually are few opportunities for workers or managers to alter or improve the process. This is another reason why factory production tends to be rigid and poorly suited to accommodating change in general.

Writers on production and operations management such as Abernathy, Utterback, Wayne, Hayes, and Wheelright have been especially concerned with the characteristics of different processes, and the specific product and market characteristics that should accompany each. A key notion, similar to conclusions by historians, is that industries (or products) tend to mature, in a sort of "life cycle." In this interpretation, product innovations usually decrease over time, allowing firms to take advantage of accumulated experience and focus less on product development and more on process innovations aimed at reducing unit costs while standardizing quality.[8] At the facility level, this has involved moving from project or job-shop modes of design and production to batch processing and then various types of large-scale engineering and factory manufacturing (Figure 1.1).

A key problem, however, is the inflexibility a firm often encounters while moving toward large-scale factories and continuous production, because designs and processes became difficult and expensive to change. Abernathy and Wayne, for example, used the experience of Ford and its Model T production facilities in the 1920s to demonstrate how a company can face bankruptcy by pushing process rationalization and scale economies too far -- for example, assuming product technology or consumer tastes were more stable than they were, and making investments in expensive and rigid factory systems that took long periods of time to change to accommodate new models or production techniques.[9]

Figure Competitive priorities and key tasks on the product-process matrix

Process Structure—Process Life Cycle Stage	Product Structure—Product Life Cycle Stage I Low-volume/low-standardization, one of a kind	II Low-volume, multiple products	III Higher volume few major products	IV High-volume high-standardization commodity products	Priorities	Key Management Tasks
I Jumbled flow (job shop)					Flexibility-quality Product customization Performance	Fast reaction Loading plant estimating capacity Estimating costs and delivery times Breaking bottlenecks Order tracing and expediting
II Disconnected line flow (batch)						Systematizing diverse elements Developing standards and methods, improvement Balancing process stages
III Connected line flow (assembly line)						Managing large, specialized, and complex operations Meeting material requirements Running equipment at peak efficiency Timing expansion and technological change
IV Continuous flow					Dependability-cost	Raising required capital
Priorities	Flexibility-quality →			Dependability-cost		
Dominant Competitive Mode	Custom design General purpose High margins	Custom design Quality control Service High margins	Standardized design Volume manufacturing Finished goods inventory Distribution Backup suppliers	Vertical integration Long runs Specialized equipment and processes Economies of scale Standardized material		

Source: Hayes-Wheelright, p. 216.

Another school of management and organization research, contingency theory, explains the existence of different types of production organizations as a function of environmental demands or conditions, or specific historical situations.[10] There seems to be no one appropriate structure for a given situation or technology, although specific types of organizations and methods of coordination and control should fit particular conditions better than others. For example, Henry Mintzberg and others have characterized the environments in which firms operate as a mixture of stable or dynamic, and simple or complex. An environment that is complex and dynamic should be met with organizational responses of "adhocracry" and "mutual adjustment" -- denoting craft modes of operation rather than factory-type structures that would better fit characteristics such as "machine bureaucracy" and work process standardization (Figure 1.2). If these characteristics determine which products should be made in what organizations, then new and unstandardized technologies, or products customized for particular users, would seem to be poor candidates for factory production. A mismatch between the product and the process organization might result in an inability to meet customer needs adequately or adapt to change, and might even cause employees to resist incongruent structures, such as factory-type standards and controls in a dynamic and complex environment.

Figure 1.2: ORGANIZATIONAL ENVIRONMENT AND STRUCTURAL FIT[11]

Environment Characteristics	STABLE	DYNAMIC
COMPLEX	Professional Bureacracy (skills standardization)	Adhocracy (mutual adjustment)
SIMPLE	Machine Bureacracy (process standardization)	Simple Structure (direct supervision)

Note: The brackets indicate the basic method of coordination for each structural configuration.

Various disciplines have thus suggested reasons why the factory evolved and how it offered managers a more efficient means of production than craft-like organizations, but with limitations. The factory has never been appropriate for all types of products but worked well for designs suited to mass production and mass consumption. The craft approach, typified by the job shop, offers a less efficient process but, despite the introduction of factory production for commodity products, continues to serve specific markets niches, such as new technologies or products tailored for individual needs. Table 1.1 presents a simplified comparison of the basic strategies, characteristics, and tradeoffs that might accompany a conventional factory and job-shop type of organization.

Table 1.1: CONVENTIONAL JOB SHOP AND FACTORY COMPARISON

JOB-SHOP

Strategy:	Meet Individual Customer Needs with Differentiated Products
Characteristics:	Non-Standard Materials (Inputs) Non-Standard Processes (Tools, Procedures) Non-Standard Final Products (Outputs) Little Division and Specialization of Labor and Equipment Low Level of Automation High Worker Skill/Knowledge Low Level of Management Control Few or No Economies of Scale Some Economies of Scope
Tradeoff?	Product-Process Flexibility vs. Process Efficiency

FACTORY

Strategy:	Raise Worker/Capital Productivity to Lower Unit Costs
Characteristics:	Standardized Inputs Standardized Tools and Procedures Standardized Final Products Integrated Management of Production Processes Division and Specialization of Labor and Equipment Mechanization and/or Automation Reduced Dependence on Worker Skill/Knowledge High Level of Management Control High Economies of Scale Some Economies of Scope
Tradeoff?	Process Efficiency vs. Product-Process Flexibility

THE CONVENTIONAL FACTORY TO FLEXIBLE DESIGN AND PRODUCTION

Conventional notions of the factory assume that organizations adopting this type of production system accept a tradeoff -- more efficiency versus less flexibility in processes, which affect the variety of products that can be produced (see Figure 1.1). But in several industries, including automobiles, machine tools, semiconductors, office equipment, and software, new techniques and technologies have been reducing this tradeoff of flexibility and efficiency. The general effect is to shift competitive emphases from either low-cost production or production differentiation to differentiated products at low cost, achieved not through simple economies of scale based on the mass production of particular products, but through economies of scope based on the optimal use of resources in and about the firm across a variety of products.

One technique facilitating this shift can be termed small-lot production, pioneered in the Japanese automobile industry after World War II and subsequently adopted by firms throughout the world in a variety of industries. This involves the mastery of largely manual techniques allowing efficient manufacturing in small rather than large batches or lots of components and final products. An underlying concept is to standardize as many components and production methods as possible, design components in modules so they can be configured in different ways, develop tools and workers that are versatile, and then have workers and machines assemble the components to make a variety of products in final assembly, with little if any loss in productivity (or quality). Producers of machine tools, textile machinery, office equipment, and many other products have used similar approaches to combine job-shop flexibility in end-product variety with the productivity, standardized quality, and low cost structure of large conventional factories.[12]

A second technique can be termed group technology, the idea of putting together similar parts, problems, or tasks to facilitate scheduling of parts production, arranging factory layouts, or rationalizing product design and engineering. The underlying principle here is clearly economies of scope, rather than of scale measured by the number of identical components produced through a given process. Critical to any group-technology scheme is a coding system, similar to library references, that makes it possible to classify characteristics related to manufacturing, engineering, purchasing, or other functions. For example, in engineering, parts might be classified by geometric similarities, and matched with process plans and machines capable of making parts to those specifications. Or designs for certain categories of parts might be coded and filed, so that engineers would have ready access to old drawings and not have to "reinvent the wheel" more than once. Recent developments in computer processing capacity and in programming sophistication have facilitated development of the coding and retrieval systems needed for group technology to work well for large numbers of items, leading to extensive monetary savings in firms. The basic concept, however, is as old as interchangeable parts.[13]

A third technique is the use of tools for computer-aided, integrated design and manufacturing, focused on the building of semi-customized products from standard cells. This resembles small-lot production, but employs coding schemes relying on what are, essentially, group technology concepts, and automation support for the selection and modification of standard cells. Integrating computer-aided design tools with flexible computer-aided or computer-integrated manufacturing systems (referred to as CAD/CAM, FMS, CIM) makes it possible to test different design and processing ideas on a computer screen, and then transfer completed digitalized designs to automated manufacturing tools, with little or no penalty associated with low production volumes, because automation largely eliminates costly labor-intensive processes. The result is that customers do not have to pay high prices for fully customized products; nor do they have to put up with standardized commodity products that are inexpensive but do not fulfill their needs satisfactorily.

In addition to automated program generation in software, an important demonstration of this capability is in application-specific integrated circuit (ASIC) design, one of the fastest growing areas of the semiconductor industry. One method is to mass produce gate-array chips, which contain transistors laid out in fixed rows. A designer then uses an automated tool which follows programmed design rules to create "custom-routed" connections to fit different applications. Another approach is to develop standard cells, which contain small logic combinations, which can be configured in different ways. At even higher level of abstraction and standardization is the alternative of building standardized "megacells" -- such as graphics controllers, arithmetic logic unitors, or microprocessors -- which, using computer-aided design tools, can be configured easily into different chip designs. CAD tools can select routing combinations or configurations on the basis of programmable rules, as well as perform simulations and testing functions to aide the design process. One U.S. company, VLSI Technology, Inc. (VTI), has even standardized around design tools simple enough for non-specialists to use, and created what management refers to as an ASIC "design factory":

> Design engineers are the bulk of the work force now at VTI's dispersed design centers...One needs rudimentary knowledge of how to use the work station software -- as a CAD or drafting tool -- to copy schematics onto the system. It requires care and attention to detail -- but not extensive engineering training. A technician with a high school or associate degree is adequate. We can save engineering time for better use, and partition the design "production" process into a more elaborate division of labor, utilizing both computer and human resources more efficiently. **Work can move along like in a factory,** from person to person, task to task. The manager maintains line balances by allocating human and computer resources [italics added].[14]

Another way to interpret these developments is as a return to the prominence of the worker, not in production, but in design of products and the design of tools and systems for automated support of product development and manufacturing. R. Jaikumar gives an example of this evolution through a discussion of process control in the machine tool industry. Because production volumes are usually low and customers often require customized products, some firms continue to use craft approaches, while others have pioneered in the development of automated flexible design and manufacturing systems.

According to Jaikumar, general-purpose tools invented in the latter 18th century required considerable skill on the part of individual workers to operate but provided major advances in precision. Single-purpose equipment, interchangeable components, and industrial engineering techniques pioneered by Frederick Taylor around 1900 largely removed the need for worker skill and discretion, and replaced this with precise procedures and standards defined by management. In the next stage of development, companies introduced statistical process control techniques that were less rigid in the sense that they allowed for more dynamic changes in work processes in response to data about precision, quality, and other aspects of machine or worker performance. In recent decades, numerical control equipment has removed information processing from the work floor, while intelligent design tools and flexible, computer-integrated manufacturing systems have again made it necessary for employees to have broad skills. Accordingly, as in early craft production, management has given workers more discretion in defining work tasks and outputs, so they can use these systems to make a variety of products efficiently.[15]

In summary, while a history of manufacturing is beyond the scope of this chapter, it is important to recognize that concepts of design and manufacturing have been changing. Traditional factory approaches clearly appear unsuitable for making mixes of products where economies of scale are difficult to achieve, such as in industries that are new or rapidly changing, or where scale in production is less important than scope in design and supporting functions such as testing. But new concepts of manufacturing and design, supported by computer-aided technologies, have made it possible to combine flexibility and efficiency even in a single factory.

Table 1.2 summarizes some of the features one might expect in a design and manufacturing system emphasizing standardized but versatile processes and tools, modularized components, and the production of semi-customized products. If integrated in a single organization, this approach might also be referred to as a "flexible factory," capable of offering customers a variety of products at potentially lower prices than traditional craft production. Evidence from the design and manufacture of semiconductor chips, machine tools, and other industries, including software, indicate that this is not an abstract model but has been applied by firms seeking some combination of efficiency and flexibility in production and product variety, or efficiency and adaptability to changes in market demands or technology.

Table 1.2: "FLEXIBLE FACTORY" DESIGN AND PRODUCTION SYSTEM

Strategy:	Meet Individual Customer Needs with Differentiated Products; High Worker/Capital Productivity to Lower Unit Costs
Implementation:	Semi-Standardized Inputs Standardized Tools and Procedures Semi-Customized Final Products Integrated Management of Development/Processing Some Division and Specialization of Labor and Tools Flexible (Programmable) Automation Dependence on Worker & System Skill/Knowledge Low Level of Management Control Some Economies of Scale Large Economies of Scope
Tradeoff?	High System Development and Training Costs vs. Process Efficiency and Product-Process Flexibility

PRODUCT-PROCESS AND ORGANIZATIONAL OPTIONS

A simple way to conceptualize the distinctions among craft or job-shop organizations, conventional factories, and flexible design and production systems, is to view them along a spectrum reflecting how much emphasis each places on tailoring products or production processes to specific customers or market segments. In practice, the spectrum is probably continuous, but it can be thought of as containing three basic options:

(1) **Customization:** design and manufacture unique products, where each is different and each process -- tools, components, specific work rules, team members -- are also different.

(2) **Semi-Customization:** design a semi-customized (or semi-standardized) product, where a standard procedure is to reuse some or all components from stock and configure them in different ways for different customers.

(3) **Standardization:** design and manufacture a commodity-type product, where components are interchangeable, or where components and final products are mass produced, using a standardized process.

Customization and standardization apply most directly to industries clearly segmented among users who desire either fully tailored products or low-priced commodities. But even if customers demand different products, managers might still find they can recycle at least some designs or components for some period of time, as well as reuse procedures, controls, tools, tests, and documentation. Therefore, unless each product, and the process and people required to design and build it, are entirely different, semi-customization, benefitting from at least some economies of scope, if not scale, should be possible. Furthermore, even firms making commodity products for the mass market can choose to reuse components or other inputs. Thus semi-customization is a product-process option that firms seeking to meet the needs of a broad range of customers might select.

The notion of a "professional bureacracy," suggested by Mintzberg (see Figure 1.2), might also characterize a flexible factory as in the context of software development. The environment is sufficiently complex so that workers need to be skilled professionals and use considerable discretion in their jobs, such as semiconductor chip designers or software programmers, but also stable enough so that some type of bureacracy, involving a formalization or standardization of skills, processes, and organizational structure, might arise to provide a higher measure of efficiency than an unstructured process and organization (Figure 1.3). The case studies of software factories at Hitachi, Toshiba, NEC, and Fujitsu, however, suggest several differences from

Mintzberg's description of a professional bureacracy. Japanese firms train workers to become professionals rather than hire them from the market; they appears to rely more on formal structures and planning than Mintzberg thought necessary for groups of, for example, doctors; and standards are not entirely derived from external professional associations but are also, to some extent, internally generated, or at least selected.[16] Nonetheless, the model described in Figure 1.3 does apply, and would seem to suggest that a firm might introduce semi-customization and the flexible factory approach only where there is a need for professional-level skilled workers but with at least some stability in the environment, for example, in application requirements as well as in computer operating systems and input/output interfaces. Semi-customization as a product-process option would thus allow the firm to capture repeatable elements for some period of time, while allowing for the addition of new components, tools, or processes to meet the distinctive needs or customers or to accommodate incremental changes in technology or markets.

Figure 1. 3: ORGANIZATIONAL ENVIRONMENT AND PRODUCT-PROCESS FIT

Environment Characteristics	STABLE	DYNAMIC
COMPLEX	**SEMI-CUSTOMIZATION** Flexible Factory (Professional Bureacracy)	**CUSTOMIZATION** Job Shop, Laboratory (Adhocracy)
SIMPLE	**STANDARDIZATION** Conventional Factory (Machine Bureacracy)	**CUSTOMIZATION** Job Shop, Laboratory (Simple Structure)

As in conventional product-process matrices (see Figure 1.1), the typology and organizational options should be available in any market where there is some segmentation and at least some temporary standardization of needs, basic technologies, and development processes. In the high-end, custom segment, firms might focus on optimizing product performance and process flexibility; there probably are few economies of scale or scope, but customers should pay premiums for differentiated products. On the other end of the spectrum, firms might attempt to maximize economies of scale in production, achieving profits through small margins on high sale volumes. In the middle, where semi-custom might characterize both products and processes, firms would need to master design and production skills, although the potential rewards are high. Firms might also implement these different options using either manual approaches or more automated tools, including computer-aided systems with large degrees of flexibility in the number of different products variations they can handle. Customization or semi-customization, for example, can be achieved either through manual processes or through automation -- CAD/CAM tools (Figure 1.4).

In short, the factory model as applied to a new technology or to a product and process such as software would require standardization of as many components as possible, and/or adoption of a standardized process and tool set, as well as linked procedures for worker training, quality control and testing, process improvement, control, and the like. It should be possible to make semi-customized products for some customers usually asking for customized products, or for customers dissatisfied with commodity products. Other issues that typically are part of factory management -- such as worker specialization and division of labor, or automation -- may or may not apply, depending on how well a firm can "modularize" and mechanize the tasks involved in product development and other functions.

Figure 1.4: Typology of Product-Process Development and Organization

Market Needs	Product-Process Type	Product-Process Organization: Design	Product-Process Organization: Production	Maximize:
High-End	Custom	**Software or Conventional Products:** **JOB SHOP, CRAFT**		Product Performance and Process Flexibility
		Product & System Engineering	Batch Production	Few Economies of Scale or Scope, but Customers Pay Premiums
Medium	Semi-custom	**Software or Conventional Products:** **FLEXIBLE FACTORY**		Economies of Scope, Scale: Inputs Tools Knowledge Processes
		Product Engineering	Product Construction	Customers Discriminate on Price and Product Features
		CAD/CAM, FMS, CIM Program Generators		
Low-End	Standard	**Conventional Products:**		Low-Cost, Standardized Products
		Product & System Engineering	Mass-Production Factory	Economies of Scale through Mass Production
		Software: **PROJECT, LABORATORY** (packages)		Low Margins but High Unit Sales

With any factory-type approach, there are risks as well as benefits. Management might standardize or automate an inefficient process or system, or standardize and automate around a technology that becomes obsolete before recovering investment in developing that process or system. On the other hand, there are ways to rationalize a process and still maintain some flexibility, such as standards, tools, or training programs that are reevaluated periodically and built to accommodate future technical evolutions that seem likely to be introduced within a few years.

Another risk with factory-type approaches, especially in a field where the factory workers are highly skilled professionals, is that workers and perhaps managers might not like a constrained environment. Employees might leave the company, or simply not follow rules, and managers might not enforce them. Worker and manager training programs, which socialize employees to accept certain restrictions to improve average levels of performance of a whole organization, might counteract some of these tendencies. A more forceful set of measures would be the type of restrictive employment systems existing in large Japanese firms, where workers are hired "for life," promoted and given raises primarily on the basis of seniority, and not hired in mid-career. These would also encourage employees to comply as well as counteract the tendency of disgruntled workers to quit.

The basic problem is not solved, however, if management attempts to introduce a structure that is inappropriate to the state of the technology and the market, or does not fit the current culture or organization of the firm. For example, craft-oriented professionals resisting a shift to factory-type practices has been documented for Denmark's data processing industry. According to Finn Borum, a Danish scholar, the resistance occurred when some companies tried to introduce factory practices such as standardized procedures, close employee supervision, and divisions of labor between system analysis and programming. There may have been some "cultural" elements involved, seen in years of debates among programmers and academics whether software development is more like an art or craft than an activity suitable for engineering or factory-like discipline and control.[17] Borum's explanation, however, is that software programming for commercial data processing applications, at least in Denmark, seemed to be very dynamic and complex, requiring ad hoc responses and adjustments -- more in the mode of craft production than factories. Thus he interpreted this lack of acceptance as reflecting a mismatch between the requirements of the technology and the environment with the factory process:

> By imposing standardization and supervision of the specialists' practice at least two objectives were pursued. One was to reduce costs, another to reduce the dependency on the individual specialist. By making their working methods conform to certain norms, and their products to certain standards, the expropriation of craft knowledge, and the replaceability of the individual specialist were obtained...The division of work between programmers and analysts also falls within this repertoire of control measures.
>
> However, these efforts that essentially deskill the IT- [Information Technology] specialists was resisted by the specialists in several ways. One was to leave the organizations, if control measures that implied a formalization beyond the specialists' threshold of tolerance were imposed... The second type of resistance was to bypass the rules and regulations imposed. This is a common story from the installations with well-developed methods and standards: that they do exist, but are only utilized to a limited extent... To enforce the rules and methods is time-consuming, difficult, and in most organizations run counter to the efforts to terminate projects with a tolerable exceeding of the time and resource schedule.
>
> Thirdly, rule enforcement is complicated by the fact that the [data-processing] managers and supervisors in nearly all cases are IT-specialists themselves. Thus they know the problems connected with strict rule adherence, and perhaps share the craft values of the specialists they are supposed to supervise.[18]

Of course, another option for a firm is to avoid introducing process rationalizations where they may be inappropriate by competing in market segments where the customers and processes require either flexibility for efficiency but not both. At the high end, this would be to develop customized or innovative products for which customers will pay a high premium. Firms in this segment, in any industry, might stress highly skilled workers and process flexibility. At the low end, for customers desiring only a standardized product, such as a Model-T car or a word-processing package, managers might still want to maximize the creativity of designers and organize by job-shop oriented projects or laboratories, but with the objective of developing a product for the low-priced mass market. On the other hand, if the semi-customization strategy succeeds, this might capture customers from the low and high ends of the market.

CONCLUSIONS

A major problem that companies face is to determine an appropriate fit among their competitive strategies, organizational structures and capabilities, and external or environmental factors -- such as the characteristics of markets, or the technology they are dealing with. Whether or not a factory type of organization is suitable for software development is meaningful only in the context of management objectives, the skills and resources available to the organization, as well as characteristics of customers and the technology. What managers need not always do is choose either efficiency and standardized products, or flexibility and differentiated products. As long as there is some segmentation in a market or even temporary stability in technology and customer needs, there are options. Taking advantage of reuse of design and production inputs in a broad sense is a relatively simple way to improve productivity in engineering and manufacturing types of operations through economies of scope.

If firms choose to pursue "rationalization" of product and process development, the question then becomes, within the existing market segments and areas of stability in technology and customer demands, how to be more systematic in capturing economies of scope, or scale, as well as in general process improvement -- productivity, quality, scheduling, budgeting, and the like. One approach might be to build products from "off-the-shelf" components and tools, rather than from scratch, or investing in tool and process development and then standardizing around technologies that seem to work best. A large facility does not seem necessary in itself to improve scope economies, although scale may be important to justify the financial investment in tools and methodology development. In general, semi-customization as a product-process strategy, along with more conventional factory concepts (standardization of processes and components, tool support, worker training, etc.), and new computerized design technologies, make it more feasible for firms to emphasize "flexible factory" approaches that combine process efficiency with variety in end products and some adaptability to change.

Some firms in an industry may choose to compete perpetually as job or batch shops, making, for example, Rolls Royces instead of Model T cars. The passage of time may thus be important mainly in that experience or "industry maturity" brings with it enough experience and stability for at least some firms to move from job shops to factories with varying levels of flexibility. A challenge for managers of relatively new technologies not yet standardized in features or development processes might be how to use strategy, technology, and organizational structure to move beyond job-shop or craft modes of operation.

There is also the issue of sustaining competitive advantage at the firm level. Over time, facilities in the middle of the spectrum may become able to produce semi-customized products superior in performance to commodity products and similar to customized products but at less cost. Since process development may thus provide a firm with considerable strategic advantage, managers need to ask themselves continually if they are doing all they can to improve their product development and production operations. If some firms deemphasize economies of scope as in process standardization, integration of tools and processes, and reuse of components, while focusing essentially on the individual engineer, the individual tool, or the final product, then they may not be fully cultivating -- that is, compared to some of their competitors-- **organizational capabilities** to maximize the performance of their technical people and redeployment of resources across a broad range of products.

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12. See, for example, Michael A. Cusumano, The Japanese Automobile Industry: Technology and Management at Nissan and Toyota, Cambridge, MA, Harvard University Press, 1985; Yasuhiro Monden, Toyota Production System, Norcross, Ga., Industrial Engineering and Management Press, 1983; and Richard J. Schonberger, Japanese Manufacturing Techniques, New York, The Free Press, 1982. Also, see Ramchandran Jaikumar, "Flexible Manufacturing Systems: A Managerial Perspective," Harvard Business School Working Paper #1-784-078 (January 1984) and "Postindustrial Manufacturing," Harvard Business Review (November-December 1986), 301-308; Michael J. Piore and Charles F. Sabel, The Second Industrial Divide: Possibilities for Prosperity, New York, Basic Books, 1984; Charles F. Sabel et al., "How to Keep Mature Industries Innovative," Technology Review (April 1987), 27-35; and Diane Palframan, "FMS: Too Much, Too Soon," Manufacturing Engineering (March 1987), 34-38.

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