

Strategies for Product Variety: Lessons from the Auto Industry



MARSHALL FISHER,
ANJANI JAIN, AND
JOHN PAUL MACDUFFIE

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Driven by the market's "pull" for increasingly differentiated products and by manufacturers' "push" to seek finely targeted niche segments, the variety of products offered in most industries has increased steadily over the last several decades. The "pull" comes from customers who seem to reward companies that can offer high variety while matching the price and quality of competitors with narrower product lines. Modern marketing methods accelerate this trend by identifying once-obscure specifics of consumer preferences. As more companies compete internationally, product markets become more crowded and product differentiation more important, both to make a product stand out in a popular product category and to help tailor a product to niche markets. The "push" comes from new firm capabilities as the increased sophistication and declining price of flexible, programmable automation bring the opportunity for greater product variety within the grasp of many more companies.

The U.S. auto industry nicely illustrates the events and forces that steadily increase product variety. Early in this century, Henry Ford achieved unprecedented productivity gains with a strategy based on low product variety, well-characterized by his famous quote, "my customers can have any color they want as long as it is black." Some years later, Alfred P. Sloan's rejoinder "a car for every purse and purpose" articulated General Motors' (GM) variety strategy of differentiated price and value embodied in GM's well-known "ladder" of product offerings from *Chevrolet* to *Cadillac*. Using this strategy, GM grew steadily to become the largest enterprise in the world, stealing enormous market share

from Ford along the way. Ironically, the American auto industry would lose that market share, starting in the 1960s, to another group of "variety competitors"—Japanese and European firms offering compact and specialty cars. This competition led to increasing product differentiation based on size and features. It also began the globalization of the U.S. auto market, leading to today's situation of nineteen global competitors, each targeting the U.S. market with its own distinct portfolio of product offerings. Innovations in technology have also steadily increased the versions of cars available by introducing new features (automatic transmission, front-wheel drive, disk brakes, and so forth) that never completely replaced the old features (manual transmission, rear-wheel drive, drum brakes). Finally, there has been dramatic growth in the sales of specialty vehicles like sports cars, minivans, utility vehicles and, soon, electric cars. Nothing so symbolized for us the state the auto industry has reached as a statistic we learned during one of our visits to the Mazda Hiroshima plant. The Mazda 323 is produced in this plant for worldwide markets in 180 different colors, including four shades of black, an ironic twist on Henry Ford's original offer of any color, as long as it was black.

While many companies struggle with variety, suffering reduced productivity and quality, we found some auto plants that organize their production in a way that allows them to absorb high levels of product variety without compromising productivity or quality. The obvious question at this point is, how do some plants manage to insulate themselves from the effects of product variety? In pursuit of answers to this question, we have spent the last two years visiting more than twenty auto plants worldwide, studying their approaches to manufacturing flexibility. Besides observing the manufacturing processes in these plants, we have interviewed engineers and managers and examined company documents on the technology, systems, and concepts used to achieve flexibility.

This chapter reports what we have learned about successful approaches to manufacturing flexibility. Although our focus will be on the auto industry, we believe the principles of flexibility we have learned would apply to many other industries. Briefly, we have seen that achieving truly effective flexibility is a challenging and elusive goal. Clearly, technology is part of the answer, but technology by itself will not create flexibility. All auto companies can buy and have bought flexible automation, but few have added to this the style of human resource management and organizational structure that are needed to use the flexible equipment effectively.

Two examples illustrate just how deeply inflexibility can be woven into an organization. The first example concerns the accounting system. In many auto companies, the unit of analysis for capital investment accounting is the new car model program. The program manager for a new model project is given a budget

with which to purchase tooling such as stamping dies, welding equipment, and molds for plastic parts. The goal under this system is to maximize the market value of the new model subject to the capital budget constraint—a goal that provides no incentive to spend more for flexible tooling than would have useful value beyond the immediate car program or what could be shared with other car programs. Indeed, new model program managers often delay or avoid investments in equipment that could be shared across several car programs in the hope that some other program manager will make the investment and give them a “free ride.” Even if top management injects flexible automation into the organization outside of the normal capital budgeting process (as happened at GM in the 1980s under Roger Smith), the flexible equipment often does not get used to its full capability. This can happen if the profit accounting system for a proposed new model assumes that all production tooling is dedicated to the new model, which must then bear all equipment depreciation charges. This results in an estimation of break-even for the model that is too high, given that tooling is flexible and can be shared across models, so a niche model can be rejected when it would have been profitable.

We have also seen a mismatch between the *manufacturing* and *distribution* capabilities in many companies. We performed a small experiment to test the ability of an auto distribution system to handle product variety. One of us visited a dealer and inquired about purchasing a popular sports coupe. We learned from the sales literature that the car could be purchased in twenty million versions of color, interior combinations, drive train configurations, and option choices. But, as ordering a car necessitated a six-week wait for delivery, almost everybody bought from the dealer’s stock. The dealer told us he had two such cars in stock on his lot, but if these did not exactly match our ideal specifications, we need not worry; he would get us a car from another dealer in the Philadelphia area. Checking the phone book we found ten dealers in the Philadelphia area. Assuming that other dealers had only two of the car in stock, we were buying from a stock of twenty for a car that came in twenty million versions.

Clearly the ability of the assembly plant to supply variety had greatly outstripped the ability of the distribution system to pass that variety on to the customer. But the assembly plant faces the worst of two worlds in this scenario. It must be able, if requested, to build any of the twenty million variants. Yet in practice, it so rarely faces a consistent demand for this product variety that it has continued to organize production for a high-volume standardized product sold mostly to fleet customers.

In this chapter, we first discuss some anomalous results from our statistical research that caused us to rethink our view of product variety. We next provide a foundation for understanding product variety and flexibility in the auto industry. We describe the production process, how variety complicates this process,

and some common devices used by all auto manufacturers to cope with these complications. In the third section, we will look at different ways of coping with product variety under the three production paradigms that have characterized the auto industry historically—craft, mass, and lean production. This framework will set the stage for our final two sections: one that explores the potential *gains* from variety, not only from the marketplace, but also in terms of capacity utilization, cost reduction, and flexibility; and one that explores the current dilemmas and opportunities facing automobile companies as they develop their product variety strategy.

The Variety Paradox

Despite the forces promoting higher product variety, many companies still view variety as a "necessary evil." They must accommodate "product proliferation" to satisfy increasingly demanding customers, but they see it as a force that complicates their operations, increases costs, and exerts a steady downward pressure on profits. The "focused factory," streamlined to produce a few carefully chosen products with high efficiency, remains the ideal for most manufacturing managers. This mentality leads to a "tradeoff" view of product variety. More variety is "good" because it increases revenue, but "bad" because it drives up production costs. Somewhere between Ford's vision of black for everybody and a fully customized product for each buyer lies the "optimal" level of product variety that trades off these good and bad effects.

This viewpoint was uppermost in our minds when we embarked on a program of research to measure the impact of product variety on productivity and quality in automotive assembly plants. We felt that developing a methodology for quantifying the cost side of product variety would be a useful contribution to help firms better make the tradeoff between market benefits and production costs of higher product variety. But along the way, we encountered a "surprise." That surprise, and the discoveries we have made in understanding it, are the subject of this chapter.

Our first research effort was a study of a single plant over time in which we correlated plant productivity each month with measures of variety in the product mix produced in that month. The results of this study fit the pattern we had expected. Greater variability in product mix within a month correlated with lower plant productivity.

We then embarked on a broader analysis that correlated the productivity of sixty-two assembly plants worldwide with several measures of product variety (MacDuffie, Sethuraman, and Fisher 1993). Here came the surprise. This study showed no correlation between plant productivity and most measures of

product variety. Apparently, some plants were able to combine a high level of product variety *and* a high level of productivity.

As we compared our studies with those of other researchers in different industries, we saw a similar pattern. For example, one study of a single head-and tail-light plant over time showed that product complexity resulted in higher costs (Banker et al 1990; Datar et al 1990), while a multiplant study based on the Profit Impact of Marketing Strategies (PIMS) database found that high variety was uncorrelated with high production costs (Kekre and Srinivasan 1990).

How are we to understand these studies that seem, at least partially, to contradict conventional wisdom about product variety? It will be helpful to draw a parallel with the evolution of thinking on product quality over the last couple of decades. Not so long ago, most managers thought of quality as a good thing, but something that came at a cost. Higher product quality meant higher manufacturing cost, and the goal of most production systems was to reduce cost subject to the constraint of "good enough" quality. Then came evidence from the marketplace that did not fit this model. Japanese competitors started offering higher quality products at lower prices. These apparent anomalies prompted some rethinking on quality. It became clear that it costs the same to produce a defective unit of a product as to produce a good one. Consequently, a focus on minimizing the cost per unit processed may not lead to the lowest cost per unit of good product produced.

For example, suppose a company is spending \$100 per unit to produce a product with a 10 percent defect rate. Then their actual cost *per good unit of product* is $\$100/.9 = \111.11 . Investing in a process improvement that *raises* the cost per unit produced by \$5 but lowers the defect rate to 1 percent actually *reduces* the cost *per good unit of product* to $\$105/.99 = \106.05 . If inspection were perfect, so that all defective units were detected and removed, then the quality of product received by customers would be unaffected by the change. But the large number of product defects encountered in the marketplace suggests that inspection is rarely perfect, so fewer defects produced means fewer defects going to customers. As a result, the process improvement that raised the cost per unit processed actually lowered the cost per good unit of product and increased the quality of products received by customers. As this example illustrates, while there may be a tradeoff between cost and the level of specifications we design into a product (design quality), when it comes to the ability of a process to conform to those specifications (conformance quality), quality can be free.

What is the analogy between quality and variety? Just as it costs the same to produce a defective product as a good one, it costs the same to produce a unit of a product that nobody wants to buy as it does to produce a product distinctively tailored to the needs of an individual customer. A product nobody wants to buy

is a "market defect" and, like quality defects, market defects are expensive. For example, an auto company with limited product lines and inflexible plants may be forced to produce more of a model than can be sold, and these "market defective" cars must be pushed on customers with rebates or sold to rental agencies at a loss. Just as with quality, an investment in flexibility and an enriched product line can be more than recouped by the savings in "market defects." Also, as the breadth of a manufacturer's product line grows, it is forced to invest in systems for coping with complexity (for example, programmable automation, computerized scheduling, material requirements planning (MRP), and worker training). Once these systems are in place, further increases in product line breadth and associated complexity can be handled with little or no incremental cost.

This logic is captured in Figures 6.1 and 6.2. Figure 6.1 depicts a company operating with an existing process at a particular level of cost and quality and facing a tradeoff curve in which higher quality implies higher cost. The company can lower this tradeoff curve by investing in process improvements that increase the ability of the process to conform to specifications. The company still faces a cost/quality tradeoff, but the process improvements allow it to move to a new operating point where it has both higher quality and lower cost. If the (present value of) reduction in operating cost exceeds the investment in process improvement, the company has achieved quality for free. There is ample evidence from industrial experience of cases where this has been done.

Figure 6.2 shows curves for product variety analogous to Figure 6.1. Consider two plants, each of which faces a cost/variety tradeoff as shown in the figure. Suppose that the second plant has invested in process improvements that

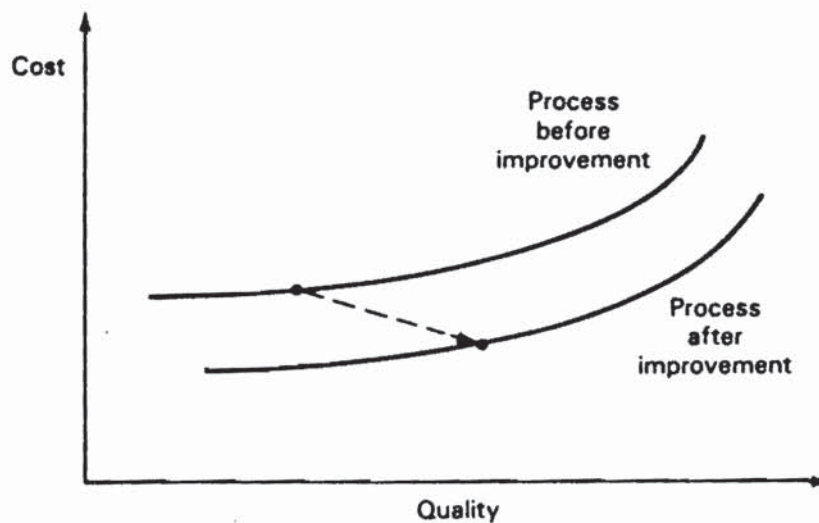


Figure 6.1. Shifting the Quality-Cost Tradeoff.

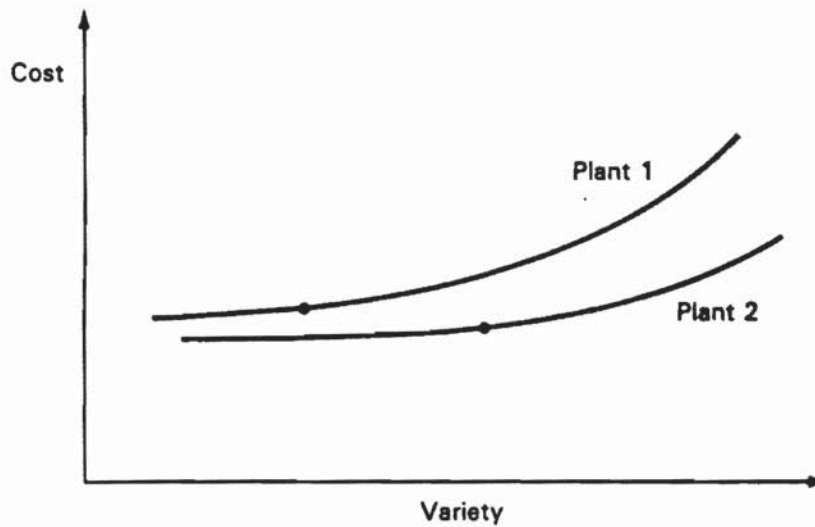


Figure 6.2. Plant Differences in Variety Productivity.

have lowered its cost/variety tradeoff curve. Then this plant can be operating at a point that has both higher variety and lower cost than the first plant. Note that this model explains the apparent contradiction between our single plant and multiplant studies. The single plant study showed a significant cost/variety penalty within a plant, and that agrees with Figure 6.2. But Figure 6.2 is also consistent with the multiplant study if the sample of sixty-two plants contained some plants like the first in Figure 6.2 and some like the second.

Product Variety in the Auto Industry

The automobile industry is a good place to explore the relationship between product variety, productivity, and quality because this industry has seen an explosion of product variety at the same time that competition in productivity and quality has intensified. Also, various manufacturers have followed different strategies in their management of variety, which provides the opportunity to compare the effectiveness of alternative approaches to variety.

Key Dimensions of Variety

Figure 6.3 shows the way auto manufacturers organize their product offerings. Most firms have five to ten basic *platforms* off which they can produce a number of different models (for example, Ford's *Taurus* and *Sable*) and body styles (for example, two-door and four-door). The various models and body styles within a platform typically share many parts, usually including the floor pan and many

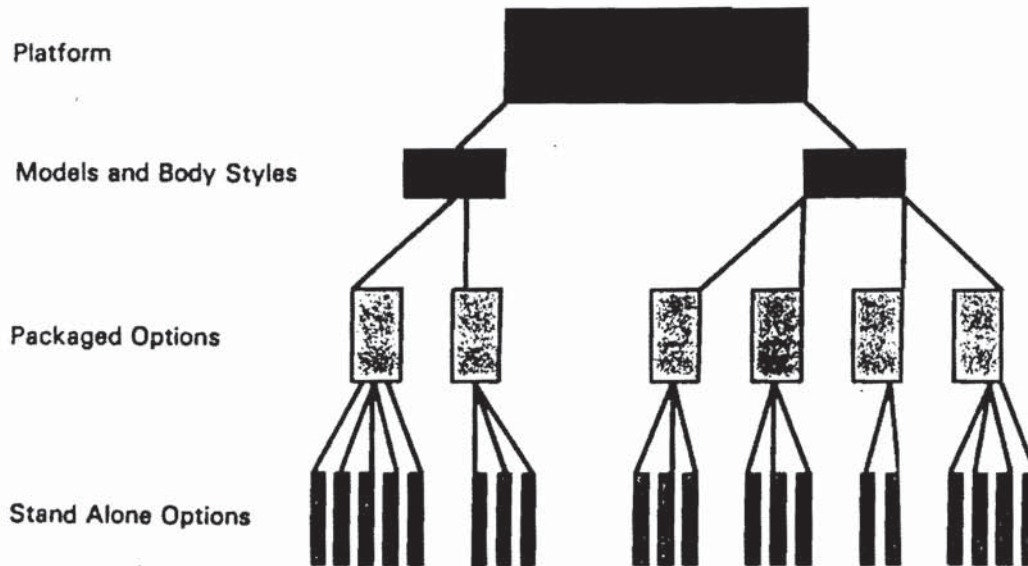


Figure 6.3. Product Hierarchy.

interior body parts. In addition, manufacturers offer a number of options from which the buyer of a particular model can choose. Common options include air conditioning, sunroof, power windows and door locks, as well as a choice of engine, transmission, and interior and exterior colors. Product variety in the auto industry is often classified as *fundamental variety* (different platforms, models, and body styles) and *peripheral variety* (different options). In our research we have also discovered that an intermediate level of *parts variety* (for example, number of engine/transmission combinations, number of interior/exterior color combinations) has become increasingly important in product differentiation. Parts variety also appears to have the greatest negative impact on assembly plant productivity (MacDuffie, Sethuraman, and Fisher 1995).

U.S. and Japanese producers have followed different strategies in providing their customers with product choices. The Japanese have typically competed on fundamental variety, offering more choices of models and platforms than their U.S. counterparts. At the same time, a Japanese model sold in North America usually has very few option choices, often just a selection between three trim levels. By contrast, the U.S. producers have had less fundamental variety but an enormous amount of peripheral variety, with millions of potential "build combinations" for a single model.

How Variety Complicates the Production Process

Let us start by walking through how a car is built. Then we will look at how variety complicates this process. Figure 6.4 shows the different steps in produc-

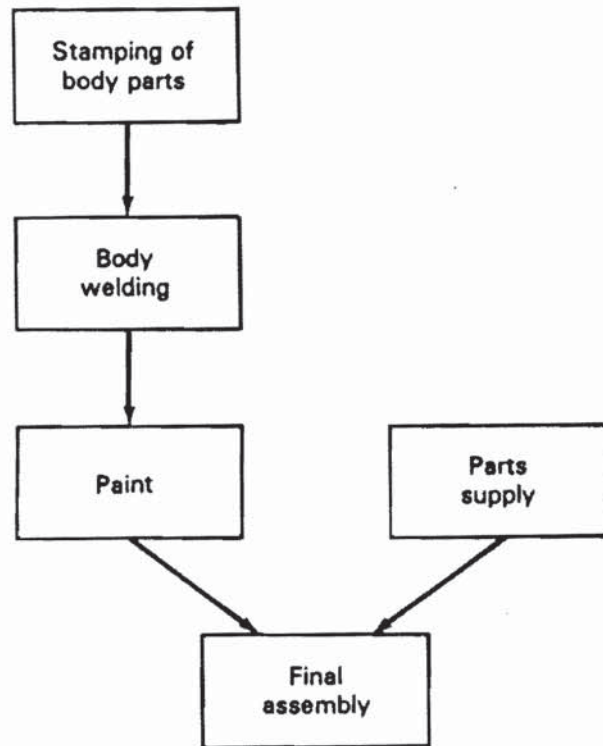


Figure 6.4. Auto Production.

ing a car. First, the body parts of the car are stamped out of sheet metal using heavy steel dies driven by massive stamping presses. These parts are welded together to form the body of the car, which is painted. The last step is to install engine, transmission, and other parts on an assembly line.

The different steps in the process present different kinds of challenges to achieving flexibility. The upstream stamping and welding stages are highly capital intensive. For example, a full set of dies for a model will typically cost about \$300 million, as will tooling for body welding. Traditionally, these dies have tended to be model specific, so high model-lifetime sales were required to break even on the huge capital investment. As product variety grows, it reduces model volumes, making it hard to recover capital investments.

Final assembly and parts supply are labor intensive rather than capital intensive. The challenge here is coordination of numerous small steps as tens of thousands of parts come together to form a car. The whole premise of an assembly line is to achieve efficiency by reducing variability to the absolute minimum. Ideally, each worker requires exactly the same amount of time to perform his or her task on a car, so no worker is forced to remain idle waiting for others to complete their tasks. Even if all cars produced on a line are identical, a perfect balance is generally unattainable. But as the variety of cars produced on a line grows, particularly when the total labor content of various cars differs,

balance losses can increase sharply, resulting in reduced labor utilization. In extreme cases, tasks requiring extra time may not get finished on the line and require expensive rework to complete. (We will see some exceptions to this later.)

Product variety complicates the parts supply process because more parts require a greater coordination effort to get the right part into a worker's hands at the exact instant a car approaches the worker's station on the assembly line. Traditionally, if different cars required different parts at a production step, an inventory of each part type would be stored "lineside" by the worker who was responsible for selecting and installing the right part for each car. The cost of variety under this system is the time for the worker to walk among the stock points and a risk of getting the wrong part, particularly with hard-to-distinguish parts like wire harnesses. Recently, manufacturers have been working to improve the "presentation" of parts to line workers. For example, large parts like seats and fascia may be sequenced off-line and delivered via a separate conveyor at exactly the right time. This reduces the assembly line cost of variety, but adds the overhead of performing the sequencing function.

Having more part types also reduces the production volume per part, thus eroding economies of scale. It is also harder to perform statistical process control on parts with a limited production history, so conformance quality suffers.

Building Blocks of Flexibility: Hardware, Software, and Human Skills

The most conspicuous and readily acquired building block of flexibility for product variety is hardware. In automotive manufacturing, flexible programmable automation is heavily applied in the capital-intensive body welding and paint shops. Flexible automation can also be found in the labor-intensive final assembly process, but this is a relatively recent trend and opportunities for automation are still relatively limited. When hardware is flexible, the amount of capital investment that is model-specific is limited, allowing capital costs to be spread across multiple models.

A second building block is software. Interpreted narrowly, software includes coordination systems like sequencing algorithms to control balance losses and materials requirement planning (MRP) software to coordinate parts supply. More broadly, "software" can embrace procedures and decision processes and would include faster setup routines, Kanban systems for controlling work-in-process, or revised accounting procedures to better measure cost in a world of shared flexible capital.

The way that human skills are organized is the third important building block for flexibility. Organizational and human resource capabilities play a dual

role in handling product variety. First, the effective utilization of flexible hardware and supporting software tools often depends on the existence of a broadly skilled work force that can carry out maintenance and programming tasks, managers and engineers who are skilled at cross-functional coordination, and a process of organizing work tasks and allocating people to tasks that can be easily modified in response to changing conditions. Second, these same skills and organizational processes can exhibit flexibility in dealing with the many aspects of product variety for which there are no easy hardware solutions, for example, insuring the correct installation of parts on a high variety assembly line.

Strategies for Variety in the Auto Industry

Auto manufacturers around the world face similar challenges from product variety, and all have similar access to hardware and software that can increase their production flexibility. But different companies put the building blocks of flexibility together in very different ways—particularly with respect to the organization of work and the utilization of human skills—with very different consequences for how product variety is handled. In this section, we take as starting points the three types of manufacturing that have characterized the automotive industry historically—craft production, mass production, and lean production. We describe both the challenge that each manufacturing approach faces with respect to product variety and the technical and organizational capabilities that each brings to this challenge—and the associated problems and dilemmas. We focus in this section on how the three types differ in their ability to *absorb* variety-induced complexity and return in the next section to the proposition that high product variety can be a direct source of *gains* to manufacturers who acquire flexibility.

Mass Production

THE VARIETY CHALLENGE

Mass production has been the dominant manufacturing approach in the automobile industry for most of this century, making it a good starting point for our discussion of different approaches to product variety. It also occupies the “low variety” end of the spectrum, in contrast with craft and lean production, both of which are organized to produce high variety. Indeed, mass production is virtually defined by its twin reliance on high economies of scale and a standardized product, which together allow a finely detailed division of labor for both people (narrow, highly rationalized production jobs and a hierarchy of specialists) and

technology (equipment totally dedicated to a single product). The "logic" of mass production with respect to product variety is, essentially, to eliminate it. Henry Ford's "any color, as long as it's black" quote about the *Model T* captures this logic quite well.

This "pure" form of mass production—one truly standard product made in massive quantities—was largely superseded by Alfred Sloan's innovation of providing a product for every market segment. From the manufacturing point of view, however, this change had a modest impact, since most of the variation Sloan offered customers was "cosmetic," in the sense that core design features remained the same, while body styling and peripheral features were modified on different models. Over time, this strategy of product differentiation advanced to the point where the sheer number of peripheral features (commonly referred to as "options") came to pose a substantial problem of manufacturing complexity. But the underlying premise of a small number of core or fundamental designs, with each design matched to a dedicated manufacturing plant, remained unchanged.

Today's international automotive market no longer conforms to this mass production ideal. As competitors offering many different core designs gain market share, companies with more dedicated facilities and a mass-production orientation toward minimizing variety are put at a disadvantage. Thus, the challenge for companies using the mass-production model has been how they should cope with market demand for more variety without sacrificing the advantages of "focused factories."

TECHNICAL CAPABILITIES

Mass-production companies have developed three technological responses to this challenge. The first is the use of parts sharing to maximize the variety that the customer sees while minimizing the complexity that the manufacturing plant faces. The second is the increased use of flexible automation. The third response is designing production facilities to combine some high-volume, dedicated production lines for standardized products with some flexible lines for handling a variety of products.

Parts sharing. Through parts sharing, companies hope to maximize the number of common parts across models that are invisible to the customer, thus minimizing manufacturing complexity, while still preserving the styling and peripheral features that are attractive to consumers. The simplest gains from parts sharing can come from standardizing fasteners and other commodity parts to minimize purchasing, inventory, and delivery complexity. But parts sharing can also include complex mechanical and electrical components, interior instrumentation and trim, and even certain stamped or molded body parts.

The emphasis on parts sharing has been spurred on by several developments: product development teams organized to coordinate design decisions for components across multiple products (Nobeoka and Cusumano 1993); the increasing use of Computer-Aided Design (CAD) databases to record and communicate part designs; and the incentive of global economies of scale as a means to cost reduction in stagnant market conditions. For companies traditionally strong in mass production, this approach offers a way to reestablish the conditions under which they can use their manufacturing expertise most effectively.

However, parts sharing has proven to be both difficult to coordinate and costly, at least when attempted on a broad scale. Ford attempted in the early 1980s to make the *Escort* a "world car" with a common design in the United States and Europe; in the end, there were two separate designs and almost no parts were shared. Ford's more recent "world car" project, introduced first as the *Mondeo* in Europe and targeted to replace the *Tempo/Topaz* in the United States, has a relatively high percentage of parts shared across the European and American models—about 60 percent—but the overall project cost an estimated six billion dollars, nearly double the cost of a conventional project (*The Wall Street Journal*, March 23, 1993).

Flexible automation. The use of flexible automation by mass producers is also motivated by the desire to minimize the complexity experienced by the manufacturing plant. High-speed transfer presses in the stamping area, automated for rapid die change, eliminate much of the downtime penalty associated with changing models. Robots in the weld shop can be programmed to change the number, sequence, and placement of welds from model to model without requiring separate body lines. Even body framing, the process of bringing together the roof, floor pan, and two sides of the car to form its body, can be made flexible with a "robogate" framing station, originally developed by Comau (a Fiat subsidiary), that uses model-specific fixtures to hold body panels in place while an array of programmable robots applies welds. Paint robots and other programmable automation allow for instantaneous changes of color and painting pattern, even from one vehicle to the next.

Despite major investments in flexible automation, many mass production companies do not substantially boost the amount of product variety they can handle in a given assembly plant. This is partly due to their failure to reorganize the production process and train the workforce to take full advantage of the capabilities of flexible automation, as discussed below.

It also reflects a different strategy for capital investment than in the past. Many auto companies have begun investing in flexible automation for its advantages in making multiple model changes of a given product over time, rather than for multiple products being manufactured simultaneously. As the costs of programmable automation have dropped, companies find it is cheaper to install

flexible rather than fixed automation, even if they only intend to produce one model at a time on the equipment, because the model changeover process (typically five to eight years for mass production companies) can be much shorter and cheaper. However, while this reduces the capital investment associated with model changes, it does not substantially boost the product variety a company can produce, since with single-product loading of each plant, variety is limited by the number of available plants.

Mixing dedicated and flexible production lines. A final strategy for mass production companies now appearing in Europe is to segment demand into the high volume, low variety portion, which is produced on lines with dedicated automation following traditional methods, and the low volume, high variety portion, which is assigned to flexible automation "islands" or separate lines. One problem with this strategy is that it requires fairly accurate forecasting of demand for the core, standardized product and for the more customized product variants in order to keep the capacity of these separate facilities fully utilized. As such, this approach is simply an accommodation of a traditional mass-production strategy—allocating models to dedicated plants in accordance with projected demands—to the realities of lower volume per model, without affecting the way most production lines are configured.

ORGANIZATIONAL CAPABILITIES

Common to these technical responses to the variety challenge is the goal of maintaining or recreating the conditions that allow high-volume, standardized production to occur. This is reflective of powerful organizational tendencies in mass-production companies to continue minimizing and eliminating product variety, and means that flexible technologies are often underutilized. As Jai-kumar (1986) found in his study of flexible manufacturing systems (FMS), U.S. companies with a legacy of mass production tended to use their equipment to produce high volumes of a relatively small number of parts, in comparison to European and Japanese competitors. This was partly driven by high thresholds for return-on-investment for new equipment and other accounting conventions that favor economies of scale for single products, and partly by habit and organizational routines.

As noted above, mass production companies rarely make changes in organizational or human resource capabilities to match their investment in flexible automation. They adhere to a narrow division of labor in the production process, staffed by low-skilled production workers and a hierarchy of technical specialists whose job is to minimize disruptions to the meeting of daily production goals. In this context, technical strategies for product variety can face several problems.

Various empirical studies now suggest that the net effect of new automation is often to raise the average skill requirements of jobs, since the jobs eliminated by automation are often low-skilled jobs, and because programmable equipment has different set-up and maintenance requirements than fixed automation (Adler 1988; Attewell 1987; Cappelli 1993). Yet mass-production companies tend to offer relatively little training to their employees, either because they do not believe it is necessary, or because of concerns about a loss of training investment due to worker turnover, or because of a low-level of basic reading and math skills among their employees (MacDuffie and Kochan 1995). Furthermore, it is not necessarily easy for firms to lay off existing lower-skilled workers while hiring replacements for the new, more skilled machine operator jobs, because of union agreements, a shortage of applicants with the necessary skills, or a reluctance to lose the job-specific knowledge of experienced employees.

Under mass production, workers are viewed as an adjunct to the production line, a variable input that should be adjusted routinely with volume swings. Workers are only expected to contribute effort and have little motivation to think or solve problems on the job. Yet new technologies often require an extensive period of debugging to work effectively. Furthermore, any piece of production equipment has idiosyncrasies that must be learned before it can be operated at its full capacity. The machine operator is the most likely to learn about those idiosyncrasies, but under mass production, he will rarely have any incentive to use that knowledge to improve the productive output of the equipment. When staff specialists, such as industrial engineers, try to incorporate the presumed advantages of new equipment into work standards and cycle times, the stage is set for one of the oldest struggles in the industrial workplace: to discover (for the industrial engineer) or conceal (for the worker) the true content of the job.

The European trend towards separate lines for standardized vs. high-variety production within the same facility poses other problems on the organizational front. If the flexible line requires higher skill and motivation from its workers than the dedicated, high-volume line, management must cope with the complexities of selecting workers from two different labor pools and then training and compensating them differently to match the different job requirements. This dual workforce within a single facility can create potentially serious problems of equity, not to mention the managerial challenges of overseeing two very different kinds of employees. The organizational culture that develops around these different parts of the plant could differ greatly as well, leading to a dysfunctional "culture clash" of the sort that can often be found across plants or divisions in a given company—witness the tensions between Saturn and more traditional General Motors plants.

SUMMARY

A company using the mass-production approach may be able to accommodate modest increases in product variety through the technical mechanisms described above: parts sharing, flexible automation, and mixing fixed and flexible lines within the same facility. But the basic logic of mass production still points towards a minimization of variety. Furthermore, mass-production companies find it harder to match changes in technology with corresponding changes in organizational and human resource capabilities, since they have traditionally relied on a narrow division of labor requiring minimal skills from production workers and a hierarchy of experts trained (and rewarded) to focus on economies of scale and reductions in direct labor costs. Thus, we expect distinct limits to the amount of product variety a mass-production company can absorb without adverse impacts on cost and quality.

Craft Production

THE VARIETY CHALLENGE

At its essence, craft production is about infinite product variety—"one of a kind" creations where the uniqueness of each product emerges from the idiosyncrasies of the craft itself and enhances the product's value. The early automotive industry deserves to be classified as "craft production" not only because the initial automobiles were built-to-order for wealthy patrons with distinct ideas about the product, from decor to engine design. It was also the case that products were literally unique because of the absence of standardized parts, with the resulting "dimensional creep" and need for skilled "fitters" in the assembly process. (Hounshell 1984; Womack, Jones, and Roos 1990) Today, the carriers of this craft tradition are the small makers of expensive sports cars, such as Porsche, TVR, Lotus, Maserati, Lamborghini, and Ferrari.

While craft producers benefited from mass production's achievements in the standardizing of parts, many of the other dimensions of craft production remain relatively unchanged: very low volume (often only a few cars per day); simple but flexible tools; job-shop scheduling, with buffers to mitigate bottlenecks at key processes; highly skilled workers trained through long on-the-job apprenticeships, during which much firm-specific knowledge as well as craft knowledge develops; craft standards of quality oriented towards post-process "tuning" of each product; and a broad division of labor, with craftsmen involved in both design and manufacturing issues.

The "variety challenge" that interests us for craft production is how this approach to manufacturing can maintain high variety and quality while achiev-

ing enough efficiency to bring product costs within the reach of mass-market consumers. Thus we are less concerned with the small "pure" craft producers of expensive sports cars, and more with how certain craft philosophies and practices have affected the production systems of larger automobile companies. We will examine the emergence of a "neo-craft" approach that seeks to provide low-volume production of mass-market products with craft levels of variety and quality, focusing on two examples reflecting different production processes: the body-welding shop of Kurata Corporation, an affiliate of Mazda in Japan, and the assembly shop at Volvo's Uddevalla plant.

TECHNICAL CAPABILITIES

Kurata, the Mazda affiliate, has developed an innovative approach to handling the welding requirements of a low-volume, high-variety plant. Rather than a moving line that carries the various stamped parts and subassemblies past long rows of welding robots, the Kurata system has essentially one work station. The body is held on a pallet, and there is a short section of track adjacent to the work station, shaped like a T. One set of welds are applied while the pallet is held stationary, with robots moving around the vehicle. Then the pallet moves down the track, out of the way, and the robots move around the work station to reset the jigs that will hold the body for a new set of welds. The pallet returns to its position in the work station, the jigs move in to hold the body, and the robots apply another set of welds. After a few iterations of this process, all welds are completed. The entire welding area takes up about one-tenth the space of a conventional body line.

Uddevalla is the most recent of Volvo's experiments in innovative work redesign. From the start, Uddevalla was seen by proponents of both union and management as an opportunity to test a new technical design that would free automobile workers from the tyranny of the moving assembly line. As such, it marked a substantial step beyond Volvo's first famous experimental plant at Kalmar, where job cycles were lengthened to four-to-six minutes during which teams of workers carried out multiple tasks on a stationary vehicle. At Uddevalla, the line would be completely eliminated, and a work team, starting with a painted body sent from Volvo's main plant in Gothenburg, would assemble an entire car from start to finish.

The technical innovation of "no moving line" was the core feature of Uddevalla, from which its other design parameters emerged: one completely flexible work station at which all assembly tasks could be carried out by a single team; six physically distinct "minifactories," each containing eight-to-ten teams; very long cycle times (up to 3.5 hours); and automated routing of materials from a central warehouse to each "minifactory."

One area of potential difficulty with this approach is material handling, as was most apparent at Uddevalla. With the vehicle built at a fixed location, and hence limited storage space adjacent to the work station, all parts must be routed in sequence from a central warehouse. This is a relatively complex task even when only a single model is being built, but becomes much more complex as variety increases.

Thus the technical features, broadly described, of Kurata and Uddevalla are quite similar. The moving line is eliminated, in favor of a very flexible work station at a fixed location. Little physical space is required. Work cycles are very long. Materials must be routed flexibly to the fixed work station, with precise timing to match the sequence of activities carried out there. Each work station can hypothetically handle a variety of models, or variety can be generated by assigning separate models to different work stations or "minifactories."

ORGANIZATIONAL CAPABILITIES

The organizational and human resource characteristics of these two examples are quite similar. Kurata had a flat organization, with a team of multiskilled workers supporting each flexible work station and handling maintenance and quality inspection, as well as some of the programming. Uddevalla also had very few organizational layers, with team leaders reporting directly to the manager of each miniplant, completely autonomous teams making decisions about hiring, schedule, work assignments, and work methods, and a very high level of training to prepare teams to absorb staff (maintenance, quality control) as well as management functions.

One problem with the Uddevalla approach was the lengthy training period for work teams, who were required to learn all the assembly tasks for an entire vehicle. This made the cost of turnover extremely high. Despite Volvo's hope that turnover would be virtually eliminated because of the attractiveness of the Uddevalla jobs, it remained at around 10 percent—better than other Volvo plants but still high. Team efficiency was thus perpetually constrained by the lead-time needed to train new team members.

Also, it proved to be very difficult to design the warehouse jobs to offer the same kind of variety and autonomy as jobs on the self-managed assembly teams. The warehouse employees continue to be bound by the "moving line" of the materials flow. This created discontent because of perceived inequity in working conditions for different groups of employees.

Finally, the high degree of autonomy for each Uddevalla work team made it difficult for knowledge about work methods to be systematized and shared across teams. As Adler and Cole (1993) have noted, Uddevalla created ideal

conditions for individual learning, but did not foster widespread organizational learning.

While we know most about these problems at Uddevalla, there is good reason to believe that they may be inherent in the "neo-craft" approach of fixed-location production combined with long job cycles and broad task assignments. Unfortunately, we have no way of knowing whether or not Uddevalla could have overcome these problems, because it is now closed. In 1992, Volvo found itself with a severe overcapacity problem due to stagnant or declining demand in the United States and Europe. As a result, it decided to close the Kalmar and Uddevalla plants, both "assembly-only" plants, rather than closing its fully integrated plants elsewhere in Sweden or in Belgium.

SUMMARY

In these examples, we can see the shape of a modern craft model, capable of greater efficiency in low-volume production than traditional craft methods, yet still allowing a high degree of customization in a complex product mix. Unfortunately, we have little data to assess the full variety-handling potential of such a model. Uddevalla made only one model in the years before it closed, although the variety of options was extremely high. Similarly, the Kurata system has not yet been applied to a high-level of product variety. Both of these low-volume production facilities suffered by being established just before the worldwide slump in auto sales in the early 1990s.

Nevertheless, this "neo-craft" model appears to have the potential for handling a considerable amount of product variety. Each flexible work station at Uddevalla or Kurata could potentially be devoted to a different product. Within the parameters of the low volume associated with niche products, volume fluctuations could be handled by raising or lowering the number of flexible work stations, making a certain product, given low capital investment requirements, very low changeover costs, and flexible labor.

The disadvantages of this approach are logistical complexity, as noted above, and overall efficiency. Although Uddevalla was reportedly more efficient than other Volvo plants, its efficiency was far from matching that of competitors at the time of its closing. Kurata's system was clearly quite efficient at very low production levels because of the low capital investment cost, but it is unclear whether that advantage would be sustained at higher volumes, given the investment and coordination costs associated with multiple welding stations.

Thus the "neo-craft" approach raises more questions than it answers. Can the products built in neo-craft facilities command a high-enough margin in the marketplace to offset the absence of scale economies and relatively high labor costs? Or can these systems multiply their production modules to handle higher

volume products while achieving efficiency consistent with the lower margin these products may command in the market? These questions are particularly salient as we turn to examine the third approach to manufacturing—lean production. If lean production can produce similar levels of variety and quality as neo-craft systems at much lower cost, as we will argue, there is less chance that the neo-craft approach will survive and diffuse.

Lean Production

THE VARIETY CHALLENGE

Although lean production is best known for its ability to combine high productivity with high quality (Womack, Jones, and Roos 1990), it is also strongly associated with high-product variety, both historically and at present. The early innovations of lean production at Toyota in the 1950s—small lot production, quick die changes, Just-in-Time inventory systems, the switch from a “push” to a “pull” system of coordinating the flow of parts and vehicles—all emerged in the context of high-product variety. Japan’s postwar market was small, the number of competitors high (in 1954, eight companies to serve a market of 70,000 vehicles, vs. four companies serving a market of 6.4 million vehicles in the United States), and the variety of vehicles (including trucks as well as cars) in demand was high. Indeed, Cusumano (1988) has argued that Japan’s market requirements for small-lot production of many models in the 1950s is what drove the development of other features of lean production. Product variety has also played a prominent role in the strategic thinking of Japanese companies. As Stalk and Hout (1990) note, product proliferation has often been used as a strategic weapon to win market share, once price and quality criteria can be successfully met by various companies.

As noted above, mass production thinking emphasizes an inevitable tradeoff between cost and variety or quality and variety. For lean-production companies, the variety challenge has been to avoid such a tradeoff by developing the manufacturing capabilities to handle greater product complexity. To the extent that manufacturing investments—in both technical and organizational capabilities—allow lean-production companies to absorb higher complexity without penalty, these companies gain more degrees of freedom for strategic decisions to increase product variety. Still, strategic decisions to boost variety may outpace a company’s ability to handle complexity in its manufacturing plants. Recent reports suggest that Japanese auto companies are beginning to rethink the level of product variety they offer, concluding that they have allowed design engineers too much latitude in developing product variants in which customers have little interest (*Automotive News*, May 17, 1993). Thus,

the current variety challenge for lean production may be avoiding *overinvesting* in flexibility.

TECHNICAL CAPABILITIES

Most lean-production companies follow a policy of making technology as flexible as possible. Heavy investments are made in purchases of robots and other programmable automation, in both new and older plants, so that the average level of flexible equipment in a lean company's plants is higher than in a mass production company, where such new equipment tends to be concentrated in newer plants only. In addition, great attention is paid to expanding the range of flexibility of key process technology to create the ability to handle very different platforms and models.

For example, both Toyota and Mazda have developed flexible body lines that allow for a very diverse product mix. While similar to the "robogates" developed by Fiat, they are based on a somewhat different design philosophy. Both Toyota and Mazda use a carrier for the body that has special jigs on its interior face that are customized to a specific model of a specific platform, but an exterior face that creates a fully standardized envelope. Any carrier can pass through a line consisting of completely general-purpose welding stations, with weld robots reprogrammed for each different model. The only model-specific development required is the interior jigs for the carrier, which can be fabricated separately and added to the storage pool of carriers as a new model joins the product mix. Parameters for maximum length and width are the only constraints to what can be built on such a line. While the investment cost for new carriers can be relatively high if the volume of a new product is high, the threshold investment for introducing a few units of a new model is minimal.

Savings from these flexible body lines can accrue in multiple ways. Since the life of the welding equipment is longer than the four-year product cycle, there is no need for expensive retooling when major model changes occur. Also, as demand for models fluctuates, the mix of products on a given line can be adjusted simply by changing the mix of model-specific carriers that circulate through the line. Products can even be moved from one line to another in this way. With this range of flexibility available, Toyota and Mazda rarely use the full variety-absorbing capacity of their body lines. They appear to value this system for giving them the ability to adjust product variety up and down, as appropriate to market conditions and product strategy.

ORGANIZATIONAL CAPABILITIES

While there are some differences between the automation strategies of lean-production and mass-production companies, a far greater difference exists in

how these two systems approach the organization of work and the management of human resources. Rather than layers of staff specialists to deal with the ramifications of manufacturing complexity, lean production relies on teams of multiskilled workers to play a major role in absorbing product variety. Workers in a traditional mass-production plant are trained in one simple task and conditioned to avoid any activity that might imperil reaching production targets. If a problem occurs, such as a mixup of parts, these are remedied not during regular production but in postprocess repair. In this situation, any increase in product variety is risky, for it requires both additional skills and a higher level of attentiveness from workers not accustomed to changes in the production routine; hence, higher product variety is likely to raise supervision, inspection, and repair costs in the traditional mass-production operation.

In contrast, workers who are members of work teams are explicitly trained in multiple skills, both off-the-job and on-the-job through job rotation. Because teams are responsible for overseeing their own quality, workers are accustomed to a more proactive, attentive stance towards production and are authorized to stop the line, when necessary, to prevent passing a production problem downstream to other work stations. A worker already attentive for quality problems is better prepared to deal with the demands of higher product variety.

Furthermore, through *kaizen* or continuous improvement activities, teams can also improve their ability to handle product variety over time. In team meetings and quality circles, workers may suggest better methods of parts presentation. Through their standardized work activities, in which teams refine their work methods to eliminate waste and improve cost and quality, various sources of line imbalance may be minimized, thus limiting the balance losses associated with the variability of options from vehicle to vehicle.

SUMMARY

The ultimate advantage of lean production with respect to product variety derives from the fact that its technical and organizational capabilities reinforce each other. For example, take the well-known innovation of just-in-time (JIT) inventory systems. When the inventory of parts for each distinct model is kept extremely low, high product variety has a minimal impact on inventory holding costs. When lineside inventory is minimized, extra space is created for the staging and presentation of parts to workers, allowing for better layout and less walking time to get parts. Furthermore, when suppliers can package parts for JIT delivery in the exact sequence they will be used on the assembly line, parts selection is much less complex for workers.

Realizing these benefits of JIT requires team members who understand the logic of minimizing inventory buffers and are motivated to identify and deal with problem conditions that are revealed. A multiskilled and motivated workforce

can also facilitate quick die changes—crucial to allow small lot production of stamped parts for different models—and improve performance through ongoing modifications of equipment layout, set up, and operations.

Lean-production companies can certainly benefit from parts sharing and other mass-production-derived techniques for minimizing manufacturing complexity, and indeed, they tend to emphasize this approach during periods of stagnant demand. But more distinctive is the willingness of lean-production companies to invest heavily in extremely flexible capabilities, both technical and organizational, often far beyond what may be utilized at any given point in time. The question this raises is whether lean production actually tends to *overinvest* in flexibility. We will address this below, in our discussion of the current efforts of the Japanese auto companies to reduce product variety.

Variety and Flexibility as Sources of Productivity Gains

Gains in the Marketplace

The market benefits of product variety derive from customers who have diverse, changing, and unpredictable needs. Such an environment rewards a manufacturer who can offer a diverse portfolio of products and whose operations are flexible enough to allow rapid adjustment of product mix as customer requirements change. For example, the popularity of small cars tends to ebb and flow with the price of gasoline. Soon electric cars will enter the scene and their sales should also be strongly correlated with the cost of various types of energy, as well as with pollution regulations. The development time for a car model is too long to allow one to predict when development is started what energy prices will be when the car is launched. But if a manufacturer's lineup includes both small and large cars, as well as electric cars, and if it has the flexibility to move production among these various types, it can insulate from the loss of sales and market share that can result from changing customer tastes.

By contrast, a manufacturer with a limited product selection or inflexible plants dedicated to individual models may be forced to produce more of a particular model—just to keep the plant running at close to capacity—than the market is willing to buy. The manufacturer is then led to follow a philosophy *The Economist* (December 12, 1992, 79–80) calls “Pile them high and sell them cheap.” Price discounts are offered in the form of rebates to induce customers to purchase the unwanted production. One form this practice takes is manufacturers selling cars at deep discounts to rental agencies. General Motors has

recently received favorable publicity for taking the bold step of abandoning this policy: "Under the eye of the Strategy Board, GM abolished its policy of flooding the daily rental market with cars in order to balance production schedules. 'We figure that decision is worth \$300 million to \$400 million' in profits this year, Losh says. (Mike Losh, GM's vice-president and group executive of North American sales, service, and marketing)" (*Automotive News*, May 17, 1993).

The two modes of operation stand in sharp contrast: the first relies on flexibility and product variety to adapt production to consumer needs; the second uses price to adapt consumer purchases to production requirements. Shunji Koike, a Japanese entrepreneur who had perfected the first approach summarizes his philosophy as "we don't sell what we produce; we produce what sells," a stark contrast to Henry Ford's "any color as long as it's black" philosophy.

Another benefit of producing what sells is that your sales then become a much better indicator of true customer preferences. National Bicycle has exploited this benefit to great advantage in their custom-made bicycle operation that sits beside their much larger mass-production plant (*Fortune*, October 22, 1990, 132-35). They use the colors ordered in their custom-production facility, where they offer essentially infinite color variety, as a gauge of customer's color preference. The most popular colors are then scheduled for production in the mass-production facility.

Increased Capacity Utilization

As we have mentioned above, the growth in product variety makes it imperative that manufacturing processes become flexible. Once acquired, however, process flexibility becomes not only an important competitive weapon in the variety-driven marketplace, it also becomes a strong hedge against uncertainty in demand volumes.

The demand for many products is notoriously hard to forecast, even over a short horizon. In the auto industry, some firms have experienced an average difference of about 40 percent (both positive and negative) between forecasts one-to-three years in the future and actual sales for individual nameplates (Jordan and Graves 1991). These forecasts are crucial because they form the basis for decisions on capacity investment and tooling, which must be made one-to-three years before start of production. As product variety increases, so does the uncertainty in demand for individual models.

There are two points that need to be emphasized in this context. First, compared to dedicated processes, flexible processes can provide a big improvement in capacity utilization when demand is uncertain. When plants are dedicated to specific models, then a downturn in demand leads to underutilization of

capacity, and an upturn in demand, if it exceeds capacity, can lead to lost sales. When plants have the flexibility to coproduce different models, then the excess demand of a model can be shifted to a plant that is experiencing low sales of another model; and the system as a whole minimizes both capacity underutilization and lost sales. During fieldwork in the auto industry, we encountered numerous examples where flexibility, necessitated originally by the need to accommodate multiple models in the same plant, has also proven to be an effective way to absorb demand fluctuations without incurring low-capacity utilization. For example, Mazda now bases its plant configuration and process-design decisions explicitly on how demand variability will affect utilization.

Second, a little bit of flexibility can go a long way in hedging against the uncertainty of demand—one does not need full flexibility (that is, all processes capable of producing all the products) to get almost all the benefits of full flexibility. If each assembly line can produce a few different models, which overlap sufficiently, then the system as a whole can absorb a high-demand volatility by sharing capacity. The same logic applies to processes within the assembly line; for instance, in body framing and welding—where it is difficult and expensive to achieve full flexibility—can consist of two or more parallel lines, each capable of handling two or more models. Several auto companies we studied have implemented, to varying degrees of sophistication, their version of this concept. Toyota's FBL (Flexible Body Line), Nissan's IBAS (Intelligent Body Assembly System), and Mazda's C-BAL (Circulation Body Assembly Line) are among the most flexible systems for body welding. The investment in these systems has been rewarded by the firms' ability to keep capacity utilization high and to respond quickly and profitably to the emergence of small niche markets.

It is important to recognize that the *configuration* for achieving flexibility must be chosen carefully. Jordan and Graves (1991) demonstrate through an analytical model that with a configuration that requires barely 10 percent of the investment of full flexibility, firms can achieve more than 90 percent of the benefits of full flexibility. Under the assumptions of their model (e.g., that demands for different products are uncorrelated), they show that the "chain" configuration achieves the best results. Plants are in a chain configuration when each plant is capable of producing two distinct products and each product can be made by two distinct processes. Figure 6.5 is an example of a chain linking ten products and ten processes (the line segment between a product and process means that the former can be made by the latter).

Throughput Gains from Product Complementarity

In this section we present the argument that in the presence of flexible manufacturing processes and multiskilled workers, product variety can be a source of

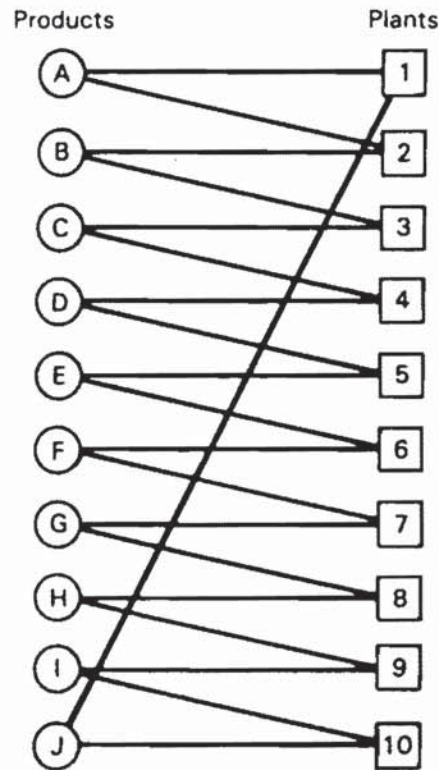


Figure 6.5. The "Chain" Configuration.

improvements in productivity. This view is contrary to the "focused factory" argument for limiting the scope of plants (and of processes within plants) to a few closely related products. While our argument is motivated partly by analytical models, our fieldwork in the auto industry also suggests that world-class firms benefit from high product variety by exploiting the opportunity that variety offers for improving productivity, capacity utilization, and lead-times in operations.

The introduction of variety on an assembly line—with different models presenting different processing requirements to the workstations—can upset the "balance" established for a line originally dedicated to a single product. In balancing an assembly line, industrial engineers attempt to minimize the unproductive time spent by workers (or machines) waiting for the next job. If it were possible to subdivide the total assembly task into equal segments, then balancing would be trivial and worker (or machine) utilization would be 100 percent. However, due to the discrete nature of many assembly tasks, equal subdivision is usually not possible. In auto assembly lines, it is often hard to achieve anything less than 15–20 percent forced idleness (or "balance loss," as it is called).

Adding variety to an assembly line would seem at first glance to exacerbate

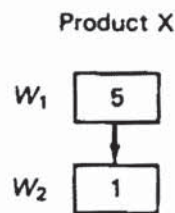
the balance loss. However, variety also provides the opportunity to *reduce* balance loss by judiciously mixing in jobs that complement each others' processing requirements. To see how "product complementarity" works, consider a simple example. Suppose that a manufacturing process consists of two operations carried out at two work stations (labelled W_1 and W_2 in Figure 6.6 below).

Suppose that no work-in-process (WIP) is allowed to accumulate between the two workstations (as is the case in most assembly lines). Consequently, if W_2 happens to be busy with a job when W_1 gets done with its job, then W_1 must wait for W_2 to finish before the former can begin the next job (since there is no in-process buffer). In this situation, W_1 is said to be *blocked*. Conversely, if W_2 gets done with its job (which leaves the process as a finished unit) while W_1 is still busy, then W_2 is forced to be idle until W_1 finishes the job and moves it down to W_2 . In this situation, W_2 is said to be *starved*.

Suppose that the above process is used to produce product X, which, due to the indivisibility of its tasks, has uneven processing requirements at the two work stations: As indicated in Figure 6.6, a unit of product X requires five minutes at W_1 and one minute at W_2 . This process produces one unit of X every five minutes (twelve units/hour), with W_2 starving four minutes in every five-minute cycle.

Consider now the introduction of product variety to this process. Suppose that another product—let us call it Y—can be coproduced on our process without any loss of time at a work station to change over from one product to the other. Suppose product Y is "complementary" to product X in its processing requirements at the two work stations: It requires one minute at W_1 and five minutes at W_2 . Now if products X and Y are produced in *alternating sequence*, we observe the following (see Figure 6.7). In steady state, when W_1 is processing product X, W_2 processes product Y. Upon completion of the respective jobs, product X moves down to W_2 and W_1 begins work on the next unit of product Y. We notice that there is a *six-minute cycle* during the first five minutes of which

Single Product



Throughput = 12 units/hour

Figure 6.6. The Single Product.

Mixed-Model Line: Two Products



Throughput: 2 units every 6 minutes
= 20 units/hr.

Figure 6.7. Mixed-Model Line, Two Products.

product X gets processed at W_1 while product Y gets finished at W_2 (each requiring five minutes). Then it takes one more minute for product X to move down to W_2 and receive processing while the next unit of product Y gets done at W_1 . Thus, every six minutes we get one unit each of products X and Y, giving us a throughput rate of twenty units/hour. This improvement over the original throughput is achieved by combining two complementary products to eliminate the unproductive idle time at workstations.

Data from the Harvard Business School case *Okuma Machinery Works Ltd. (A)* (1989) illustrate how complementarity can lead to productivity gains in a realistic setting. The case describes technological choices faced by a Japanese developer of flexible manufacturing systems (FMS). One of the issues in the case is the estimation of the benefits of *mixed-model* capability in a proposed FMS. While the existing system requires set ups to switch between families of parts, the mixed-model FMS would allow parts of *any* family to be processed—in arbitrary sequence and in arbitrarily small lot sizes—without tool or fixture set ups. The mixed-model FMS clearly provides savings in set-up cost and the ability to produce small lots of parts on a JIT basis for downstream requirements, thus reducing WIP inventory of parts. However, a more substantial (and less apparent) source of benefits is the productivity improvement through greater capacity utilization achieved by exploiting the complementarities that exist across different part families.

The FMS consists of five numerically controlled machining centers, which perform different operations on each part as it proceeds through the system. The processing time required by a part at each machining center varies from one part family to another; Table 6.1, reproduced from the case, contains data on the processing times needed by the existing 16 part families at the five machining centers (labelled M1 through M5).

On the existing FMS, parts within the same family are run in large batches for each set up of the system, and the throughput rate is determined by the bot-

TABLE 6.1. Processing Requirements

Machine	Processing Time in Minutes for Part Families															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
M1	1.6	1.8	1.8	2.5	2.2	3.0	3.0	2.6	3.2	2.5	3.4	1.7	1.8	3.0	2.5	1.8
M2	2.5	1.7	2.7	2.2	2.8	3.3	2.6	2.8	2.5	2.2	2.6	2.7	2.6	2.5	2.4	2.4
M3	1.9	1.7	1.8	2.4	2.2	3.1	2.9	2.7	3.0	2.4	2.5	2.6	1.7	3.2	2.4	1.4
M4	2.6	1.8	2.0	2.4	3.2	3.2	2.0	2.7	2.0	2.4	2.2	2.9	3.0	1.4	2.3	3.2
M5	2.3	1.6	3.0	2.3	3.1	3.0	2.2	2.8	1.6	2.3	1.8	3.3	3.4	1.7	2.4	3.0
Total	10.9	8.6	11.3	11.8	13.5	15.6	12.7	13.6	12.3	11.8	12.5	13.2	12.5	11.8	12.0	11.8

Source: From Okuma Machinery Works Ltd. (A) Case (1989).

tleneck operation. For instance, when the system is running part family 13, finished parts are produced once every 3.4 minutes, with machines M1 through M4 being underutilized. The proposed mixed-model FMS would allow part families to be "interleaved" to take advantage of complementarities. For instance, if parts of families 13 and 11 are produced in an alternating sequence as opposed to running large batches for each, the average time per part goes down from 3.4 minutes to 3.2 minutes, a 5.9 percent improvement. In general, the potential for productivity gains improves as more parts are added to the mixed-model sequence. Our analysis shows, for example, that combining part families 13-5-14-7-11-13 (and running them in that cyclic sequence) would bring down the average time per part by almost 10 percent compared to running large batches (see Jain (1993) for details). This gain is purely due to complementarity and does not include savings in set-up time on the proposed FMS. Figure 6.8 shows how the throughput rate improves as more families are added to the model mix on the FMS.

The idea of complementarity can be generalized to assembly lines with an arbitrary number of work stations and products and with or without intermediate buffers (Jain 1992). Determination of the grouping and sequence of products that maximizes complementarity in the general case becomes a nontrivial optimization problem that can be addressed through mathematical programming methods. As we noted above, greater product variety brings better opportunity for finding complementarities (though it also adds greater complexity to the mathematical optimization).

Throughput gain from complementarity also depends upon the mechanism

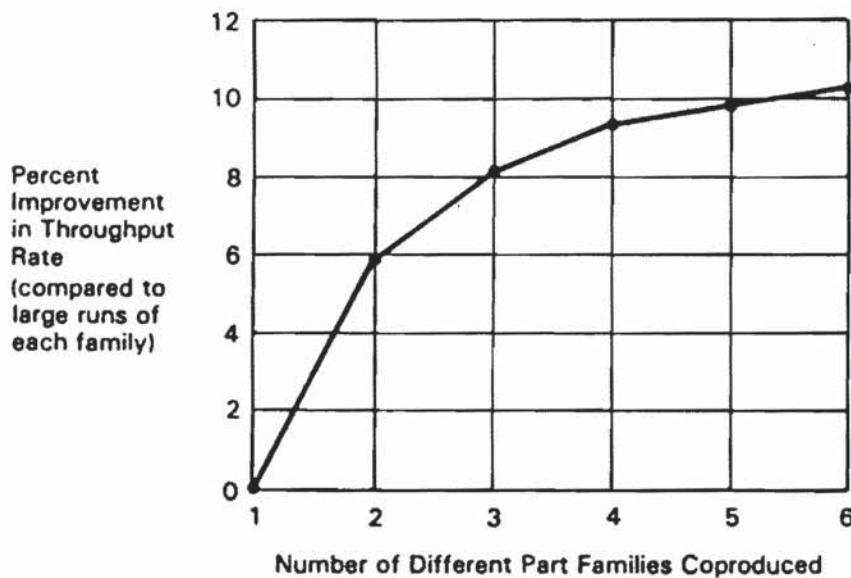


Figure 6.8. Throughput Gains from Complementarity.

governing the flow of jobs on the assembly line. The gain is highest when jobs on the line can move *asynchronously* of each other. The job flow is called *asynchronous* when each job, upon completion at a work station, can move to the downstream work station, unless the downstream work station is busy (in which case the job blocks the current work station). A *synchronous* flow places a restriction on the asynchronous discipline: the movement from one work station to the next must be simultaneous for all jobs. The most restricted case is that of the *constant-pace* line, where each job gets the same "window" of time at each work station.

Traditionally, most segments of auto assembly plants have a constant-pace line. Recognizing the benefits of asynchronous flow, however, some modern plants have begun to abandon the moving conveyor line. Their place is taken by automated guided vehicles (AGV) carrying the jobs and moving asynchronously from each other. Nissan's new assembly plant at Kyushu, for instance, has attracted much attention lately for using AGV's throughout the assembly process. Nissan's executives expect this and related innovations to make Kyushu 30 percent more productive than their other plants (*The Wall Street Journal*, July 6, 1992). Other plants have also adopted this concept. For example, the Volvo BV plant in the Netherlands also uses AGV's, which stop at work stations where teams of workers perform roughly an hour of assembly tasks before routing the AGV to the next station.

Organizational Gains

A manufacturing environment of high product variety can provide a very effective "learning system" for the organization. The organizational capabilities needed to operate effectively in a high-variety environment are also useful in dealing with many contingencies. The acquisition of multiple skills by workers in a high-variety plant can serve as an organizational "buffer" to avoid disruption in the face of problems and breakdowns. Organizations with these capabilities also absorb more effectively the discontinuities caused by volume swings and new product launches.

Organizational flexibility also leads to better utilization of "human capital" and work time. Workers who are multiskilled across different *products* will better absorb demand variability in the same way that "chaining" allows different plants to share capacity. Workers who are multiskilled across different *processes* mitigate the need for in-process buffers that are used as insurance against breakdowns. Indeed, it could be argued that the flexible skills and capacity for improvement of the work force *become* the new buffer that allows the organization to absorb contingencies. This is why Japanese companies pay more attention to labor utilization and worker skill enrichment than to equipment utilization.

Flexibility with respect to product mix and volume changes can have unexpected benefits for issues that appear to have little to do with variety. Production of the *Miata* sports car was at one point moved from Mazda's main production complex at Hiroshima to the Hofu plant eighty miles (a two-hour drive) away. The reason was Mazda's lifetime employment policy. Demand was very low for products made at Hofu, so the plant was operating at half capacity, while demand was still high at the Hiroshima plant. With a "no layoff" policy and no easy way to move workers between plants, it was easier for Mazda to balance the utilization of the work force by moving the product, even though this meant that a niche sports car had to be integrated into the production mix with the Mazda 626, a midsize family sedan. Since the mass production practice of using layoffs and hiring to adjust labor inputs to capacity was unavailable, Mazda derived considerable organizational benefit from its ability to handle changing levels of product variety at all of its plants.

Finally, the coupling of broad production knowledge, employee motivation, and a flexible system of work specification and task allocation at lean production companies creates a fertile environment for experimentation with new products and processes—something that generates invaluable feedback for product designers and improves design-for-manufacturability. For example, pilot vehicles are often built in regular assembly plants at lean production companies, with workers involved in developing task specifications for upcoming models, compared with mass production companies that utilize a specialized pilot plant with a separate work force. This willingness to use the assembly plant as a locus of learning is antithetical to the mass production view of manufacturing as a domain of standardization and not-to-be-interrupted production, and provides the most significant organizational gain from pursuing a high flexibility/high variety strategy.

Conclusions

In this closing section, we summarize our recommendations for handling product variety and look ahead at future trends for product variety in the international automotive industry.

Handling Product Variety

While effective management of product variety can provide important competitive advantages for a company, a high-variety strategy also creates some management challenges. Our first observation is that companies need a market strategy to successfully minimize "market defects," that is, product varieties that customers simply do not want. Two things are needed as part of such a strategy:

1) periodic housekeeping to get rid of dysfunctional variety in the product line that may have served a purpose once, but no longer does.; and 2) basing the introduction of new variety on true customer needs and preferences. This is hard to do because these needs and preferences are often unknown. But many companies are finding ways to encourage a high level of interaction with customers to obtain their reactions to various products, and to elicit ideas for new product development. Developing the right sort of information from customers is clearly crucial to avoiding "market defects."

Some of the difficulties of Japanese auto companies in the early 1990s can be attributed to a period in the late 1980s when designers were given free rein to develop any product variant that customers might conceivably find appealing. Many of these variants simply did not sell, not even when the market was relatively strong, and the subsequent recession and collapse of demand has worsened the impact of these design choices. Whatever the capability of "lean" assembly plants to absorb high levels of product complexity in support of a "high-variety" strategy, the best manufacturing plant cannot remedy the problem of unwanted products.

Our second point takes issue with what is becoming conventional wisdom about handling product variety: parts sharing across models. United States, European, and Japanese companies alike have announced ambitious programs to increase the share of common parts to 30 percent across models on the same platform. We recognize the allure of a solution that promises to minimize complexity for the manufacturing plant while still allowing a wide array of variants and options for any given product. Nevertheless, we believe that the consequences of variety-reducing designs need more careful investigation before they are embraced wholeheartedly. No company seems to have a clear strategy for avoiding the "Achilles' heel" of parts sharing: products—across niches or segments differentiated by price—that look alike. Moreover, the coordination costs of parts sharing are not trivial, as past unsuccessful efforts to design a "world car" have shown. Similarly, "design for manufacturing," particularly when focused on such variety-related goals as reducing total parts count, can be accompanied by considerable costs, particularly in lengthened product development time (Ulrich et al 1993). Mass production companies may bear the greatest risk here, because their strong inclination to minimize variety makes them vulnerable to seeing parts sharing and design-for-manufacturing (DFM) as a panacea.

Third, our analysis of different company strategies with respect to product variety supports the wisdom of investing heavily in flexible manufacturing capabilities—including technology, organizational systems, and human skills.

Combined, these flexible capabilities offer far more than the ability to make multiple products simultaneously. They also offer the benefits of reduced changeover costs across product generations, the ability to adjust product mix in

the face of uncertain demand, even at volumes that would be unprofitable for a more rigidly organized facility, and the ability to use the factory as a testing ground for new products and production processes.

Indeed, it is important to note that a plant's flexibility does not need to be in use at all times to justify investing in it. The ability to avoid costly underutilization of capacity and to minimize the time and cost of a major retrofit are benefits that can easily outweigh the cost of such an investment. However, increasing investments of this kind, whether in robotics or in worker training, can be difficult in the face of accounting systems that overstate the costs and understate the benefits of flexibility. Changing the accounting mindset about flexible technical and organizational capabilities may therefore be a necessary precondition to boosting investments as discussed in chapter seven of this book.

The human resource aspect of flexibility is often overlooked because of mass production assumptions about the benefits of narrowly skilled, interchangeable employees for the standardization of production. Work force flexibility with respect to product variety is not simply a matter of more training for cross-skilling. When the problem-solving abilities of the work force are developed in the context of a plant culture that emphasizes constant experimentation with production processes, the plant has a new sort of "buffer" available. In place of the "just-in-case" buffers of inventory that provided a way to deal with various unexpected contingencies in mass production, an attentive, skilled, and motivated work force that is accustomed to rethinking work processes and respecifying work can absorb contingencies in a different way: resolving rather than hiding problems.

Finally, we urge companies to take a broader view of the potential gains from product variety. In part, this requires an "economies-of-scope" way of thinking that seeks out efficiency-enhancing complementarities across products. In part, it may require yet again more investment in flexible capabilities than is indicated by a firm's product strategy. The greatest payoff to a broader view of product variety and manufacturing flexibility may come when investments in flexibility are coupled with "quick response" strategies of distribution (Fisher and Raman 1992). This approach to distribution helps to generate a tremendous amount of valuable data for product designers and manufacturing planners. The more companies "produce what sells" rather than "sell what they produce" the lower the rate of "market defects" and the greater the market gains of variety.

Looking Ahead: Variety in the Automotive Industry

Each of the primary auto-producing regions—the United States, Europe, and Japan—has a different history with respect to product variety and appears likely to follow a different trajectory in its future approach to variety.

For the "Big Three" in the United States, decisions on variety still seem to be guided by a mass-production logic. While recognizing increasing consumer demand for variety, the Big Three have largely tried to accommodate this demand without altering their practice of high-volume production of core models in plants mostly dedicated to single platforms. When choices about variety strategy have needed to be made, the Big Three have increasingly opted for variety reduction, partly as a consequence of their determined drive to match or exceed Japanese levels of productivity and quality.

One example of this trend was the "option deproliferation" drive that swept through the Big Three during the mid-1980s. This effort sought to remedy a situation in which manufacturing plants had to be ready to make vehicles with any one of millions of possible option combinations, regardless of whether customers showed much interest in the vast majority of these combinations. Although such pruning was needed, it was linked to other efforts to consolidate platforms, reduce models and generally return to "focused factories," and hence represented a step away from variety.

A more recent example is General Motors' drive to regain profitability after an alarming loss of market share in the 1980s. Central to this effort is a steady cutback in platforms and product variants. CEO Jack Smith has established a policy that GM will focus on "core products that have the potential of leading their class in sales while delivering the best customer attributes, price, quality, and features" (*Automotive News*, May 17, 1993). The number of car platforms will be reduced to five and the number of product development teams to just three for small cars, mid-sized and rear-drive cars, and large, front-drive luxury cars. Models are being trimmed each year. In 1991, GM offered 144 car model selections (including captive imports manufactured by other companies), a number reduced to 126 in 1992 and 117 in 1993. This reduction targets variants of popular models that have not sold well.

GM's actions in reducing product variety are significant, because in relative terms, GM has been the high-variety producer of the Big Three as a consequence of Alfred Sloan's product differentiation strategy. On the whole, the Big Three's strategy toward variety in the past ten years has been to reduce it, even at a time when the number of product offerings in the U.S. market has exploded. Only recently has Ford begun to break from this pattern by offering more variants of its popular truck and sport utility models.

European companies have had a very different approach to product variety, partly out of necessity as they rebuilt their industry on an export-oriented strategy of low-volume niche products. Since many of these were luxury/specialty products, they typically contained high levels of option content, with customers being given wide latitude in custom-ordering option combinations. Because these products were exported to many countries, European companies

have long had to face export-driven variety based on different regulatory requirements, for example, catalytic converters for the U.S. market but not for Europe. As a result of these conditions and a strong tradition of craft production dating back to the early days of the industry, European companies have long been accustomed to dealing with variety.

This experience does not, however, mean that European companies have had a "no tradeoff" view of variety. Higher-cost products have long been accepted as the price European customers must pay for a wide array of product and feature choices. Furthermore, European companies have long felt the pull of scale economies and mass-production logic. Ironically, European companies moved away somewhat from a high-variety strategy in the 1980s when the sales volume for popular models from Fiat, VW, and Renault reached historic levels, with plants increasingly dedicated to these products. Nevertheless, to the extent that company capabilities to handle high levels of product variety remain competitively important in the 1990s, European companies should be well positioned. The dilemma these companies face is how to increase their productivity and quality levels to world standards while maintaining their traditional strengths in handling high product variety.

The situation for Japanese companies is particularly fluid. With the bursting of the "bubble" economy and stagnant sales, compounded by overinvestment in new plants, Japanese companies have been forced to cope with financial losses and severe underutilization of plant capacity. In 1993, Nissan decided to close its Zama plant, the first plant closing in Japan in the postwar era. Against this backdrop, the rapid proliferation of product variety in Japan in the 1980s has become a highly visible problem. Many companies have announced ambitious programs to trim model variants and to increase parts sharing in an effort to bring product variety under control. For example, Toyota has announced that it will reduce varieties of the *Corolla* model from eleven to six; Mazda has eliminated seventy-six variations of its 929 model; and Nissan has announced it would reduce its number of engines by 40 percent over the next five years (Stalk and Webber 1993).

The crucial question from our perspective is whether the current problems of too much variety in Japan should be interpreted primarily as "market defects"—versions of products that suited the fancy of designers but did not interest consumers—or as evidence that manufacturers had exceeded their ability to handle variety. In the former case, product variants may be trimmed and rationalized, but manufacturing capabilities to absorb variety would remain unchanged. In the latter case, we might expect to see companies moving their production systems back along the continuum toward mass production of more standardized products.

Early indications from our interviews suggest that Japanese companies still

place an extremely high priority on manufacturing flexibility. There is little sign that they will back away from their investment in flexible capabilities, whether technological or organizational. We have heard of no plans for cutting back on the number of platforms—not surprising, since multiproject coordination of product development for rapid design transfer across platforms has become the norm across Japanese companies (Nobeoka and Cusumano 1993)—nor of plans to trim option content. There will be trimming in the intermediate category of product complexity—fewer different body styles per model, offered with fewer engine/transmission combinations, for example. We see the current pruning of product variety as more an application of “lean” principles to the “waste” of market defects than as any retreat toward the low-variety, mass-production model.

Nevertheless, Japanese companies may continue to face difficulties in their manufacturing plants that make it difficult for them to maintain high variety without some cost or quality penalty. Labor shortages at the assemblers reduces the skill and experience base of the work force and increases the training requirements needed to achieve multiskilling. Labor shortages at suppliers can threaten parts quality at the assembly plant and supplier capabilities for in-sequence delivery to the assembly plant. If more defective parts reach the assembler and in-sequence delivery drops, the burden of variety on the assembler work force will be greater than ever.

Thus, while a “variety/flexibility” gap continues to exist between Japan and the United States, there is a great opportunity for American auto companies to move beyond their legacy of low variety. If the American Big Three could close the *variety* gap as quickly as they have been able to close the cost and quality gap with Japan, they could be even more formidable competitors. At the present time, however, the current trend of American companies toward variety *reduction* suggests that the “variety gap” will continue.

This suggests a broader conclusion. Growth in product variety seems to be an inexorable trend in many industries as customers get more discriminating and marketers become increasingly focused in their search for niche markets. Minimizing variety may not be a viable choice in such circumstances. Firms will be forced to cope with variety. Thus, the strategic stance of the firm toward variety becomes critically important. Firms that acquire and develop the building blocks of flexibility proactively can win by making product variety a source of competitive advantage. Those that get trapped in the variety/cost tradeoff stand to lose.

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