BEYOND MASS PRODUCTION: FLEXIBLE PRODUCTION SYSTEMS AND MANUFACTURING PERFORMANCE IN THE WORLD AUTO INDUSTRY

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and Manufacturing Performance in the World Auto Industry

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The world of mass production is changing, due to a variety of macroeconomic and technological factors: the internationalization of economic activity, shorter product life cycles, the increasing differentiation of product markets and consumer tastes, the increased value placed on the quality of goods and services, and the increased use of computer-based information and manufacturing technologies. Many observers claim that these changes mark a fundamental transformation away from the organizational forms of mass production, towards flexible production systems. (Piore and Sabel, 1984; Powell, 1988; Jaikumar, 1986; Kenney and Florida, 1988; Womack et al., 1990)

This dissertation examines the thesis that flexible production systems are supplanting mass production systems because of their superior manufacturing performance, in terms of both productivity and quality. The research focuses on the automotive assembly plant, the prototypical mass production setting. Quantitative data are drawn from the International Assembly Plant Study, a survey of 70 plants worldwide, carried out with John Krafcik through M.I.T.'s International Motor Vehicle Program. These data are supplemented with qualitative data from observations of daily problem-solving processes at three assembly plants.

The dissertation draws on organizational theory, industrial relations, political economy, and strategy literatures to argue that flexible production systems follow a different "organizational logic" than mass production. This logic has two dimensions: structural and cultural. The "structural logic" of a production system is identified in terms of the deployment of resources, the link of core production activity to the market, the structure of authority relations, and the link between conception and execution. The "cultural logic" is identified as a way of thinking about production activities that emphasizes their integration with innovation activities. This cultural perspective, in turn, affects the approach, under flexible production, to information processing, the division of labor, and the coordination process. This view of flexible production is contrasted not only with mass production but also with other post-mass production models -- flexible specialization, flexible mass production, and neo-craft production.

The two primary hypotheses tested in the dissertation are first, that the flexible "organizational logic" is positively linked to manufacturing performance, and second, that the contribution of technology to performance is contingent upon the organizational context, i.e. that economic performance is highest when high levels of automation are combined with the flexible "organizational logic".

The dissertation takes a configurational approach, in which bundles of practices are identified and the effects of these bundles are tested with appropriate statistical methods (e.g. cluster analysis). Production systems are defined in terms of "organizational logic", rather than technology or product variety. In other words, a plant with a flexible production system is organizationally flexible, whether or not it has flexible (programmable) technology or makes a wide variety of products. In contrast, a plant with a mass production organization does not become flexible simply by incorporating flexible technology; rather, it is likely to use the technology rigidly. Consistent with this perspective, a Production Organization index is constructed that differentiates plants with a MassProd and FlexProd "organizational logic", using measures of work organization, human resource policies, and production practices.

Three subsequent chapters focus on analyses of the International Assembly Plant Study data. The first is a univariate analysis of the relationship between production organization and manufacturing performance. The second examines the "integration hypothesis", which emphasizes the interaction of production organization and technology and its effect on manufacturing performance. The third adds a set of control variables, including mix complexity, parts complexity, product design age, and scale, for a full multivariate analysis of manufacturing performance. There are parallel analyses in all three chapters -- one with the Production Organization measure, an additive index, together with other independent variables, and the other with a cluster analysis that groups plants using the variables in the Production Organization index and the technology measures.

These chapters support the thesis that flexible production organization is strongly associated with manufacturing performance. The univariate relationship is quite strong, with production organization explaining over one-third of the variance in both productivity and quality outcomes. The integration hypothesis is also confirmed, in that manufacturing performance is considerably higher for plants with high levels of technology and a FlexProd organization than for plants with similar levels of technology and a MassProd organization. Finally, these results remain essentially unchanged when the control variables are added. Alternative explanations based on Japanese management, location in Japan, and location in a low-wage country are also considered. Japan-related variables reduce the statistical significance of Production Organization slightly for productivity, but not for quality. In addition, the Production Organization measure is strongly linked to performance <u>within</u> the group of Japan-related plants. Low-wage countries have relatively poor productivity, as the conventional wisdom would predict, but much better quality than expected; these quality results are linked to the degree of implementation of flexible production systems.

Finally, a chapter on the qualitative data explores differences in problem-solving processes in mass production and flexible production plants, emphasizing differences in problem definition, problem analysis, the organization of problem-solving groups, and liaison roles. This chapter also discusses the dynamics of the relationship between process and structure in mass and flexible production systems.

Thesis supervisor: Prof. Thomas A. Kochan, Industrial Relations

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I have received abundant support during this interminable project from advisors, colleagues, friends, and family, as well as the people at assembly plants and automobile companies around the world that provided the data for this dissertation.

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Other essential advisors have been Mike Piore, whose work and ideas have shaped my thinking about flexible production more than anyone; Haruo Shimada, who made me a full partner in a fascinating exploration of the cross-cultural experiments known as the Japanese transplants, and whose insights into the Japanese production system are central to this dissertation; Bob McKersie, whose wisdom I have often sought about the world of industrial relations and the tortuous path of research projects; Mike Cusamano, whose pioneering work on Toyota and Nissan helped pave the way for me and many others intrigued by Japanese manufacturing innovations; and Paul Osterman, Jim Rebitzer, and Lisa Lynch, who have helped me puzzle out how economists think about the issues that intrigue me.

Special gratitude goes as well to my advisors and colleagues in M.I.T.'s International Motor Vehicle Program (IMVP). I got to know Jim Womack through a series of brief but fascinating conversations about the auto industry in hallways and parking lots, discovering that he shared my "factory fascination". He got me hooked on the "industry of industries" and then supported me generously and creatively as my immersion became nearly total. John Krafcik, who initiated the International Assembly Plant Study that provides the primary data for this research, generously invited me to join his efforts as the scope of the project grew beyond anyone's imagination. His contributions to this research -- conceptually, methodologically, and in building strong relationships with participating plants and companies -- are visible throughout the dissertation. Beyond that, his vast experience in the world's assembly plants contributed enormously to my understanding of the intricacies of automotive manufacturing. Dan Roos has been a steadfast supporter, whose skillful piloting of IMVP through an often tempestuous five years made this research possible. Finally, Ann Rowbotham's ever-present cheer and energy, even more than her exceptionally capable administrative support, will remain one of my fondest memories of the IMVP years.

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I will also miss my traveling companions in the journey to an M.I.T. Ph.D., who provided the camaraderie and sympathetic support that make graduate school a not-so-unpleasant way to spend five years -- particularly Peter Cebon, Chip Hunter, Byeong-Cheol Lee, Yiorgos Mylonadis, Nitin Nohria, Brian Pentland, Kirsten Wever, and Elaine Yakura.

I am blessed with friends of many years standing who have provided moral support throughout my doctoral years, and with parents whose values are central to my work and whose caring nature continues to inspire. Last (but really first), my wife Jane has shared these long years with me, showing a generosity of spirit and commitment to our life together that have sustained me mightily. As our family has grown, she has somehow managed to hold the pieces together, keeping a "clean, well-lighted place" for all of us while nourishing a remarkable assortment of people in her roles as mother, friend, and social worker. I hope she will give me the chance to return the favor.

Most of the managers, engineers, and workers in automobile assembly plants who provided the data for this research will (fortunately for them) never read this document. So I will work to find other ways to express my gratitude for their assistance and my admiration for their efforts to master and transform an awesomely complex production system. Perhaps someday, when the time is right, I can give them a hand.

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CHAPTER 1

INTRODUCTION

The world of mass production is changing, but the nature of the world that will replace it remains unclear. This dissertation seeks to sketch the shape of the post-mass production world more clearly, through a systemic description of an alternative production paradigm -- flexible production. The dissertation then evaluates the consequences of the transition to flexible production for manufacturing performance -- both productivity and quality -- in automotive assembly, the quintessential mass production setting.

This chapter will introduce the argument of the dissertation, summarize its theoretical, methodological, and practical implications, and provide an historical perspective by reviewing changes in the automotive industry worldwide over the past two decades. The concluding chapter will summarize the empirical findings of the dissertation but will primarily address broader questions about the dynamics of flexible production over time, its effects on individuals, and the rate and extent of its diffusion, both in the auto industry and elsewhere.

Flexible production systems are diffusing in automotive assembly because their economic performance, as the dissertation will show, is superior to the mass production systems that have long been judged the best "fit" to this task. I argue that the source of flexibility in these production systems, and the reason for their superior performance, is their organizational characteristics, rather than their technological capabilities or the requirements of their product markets. These in turn provide a context in which technology is used more flexibly, regardless of its inherent programmability, and product variety can be high or low depending on market demand and product strategy.

Mass and flexible production, from this perspective, have a completely different "organizational logic", which affects everything from the structure of the production system (in such areas as work organization, human resource policies, and manufacturing practices) to its culture -- the assumptions, norms, values, and ways of thinking about problems that people in each production system manifest. To understand these production systems, I argue that a "configurational" approach is needed, that seeks, both theoretically and methodologically, to identify bundles of practices that capture their different logics.

The dissertation draws on data from two sources: quantitative data from a survey of seventy automotive assembly plants worldwide, carried out with John Krafcik through M.I.T.'s International Motor Vehicle Program, and qualitative data from a study of daily problem-solving processes at three assembly plants in North America. The former data address structural elements of the "organizational logic", while the latter address those cognitive aspects of production system culture that are revealed during problem-solving activities.

Understanding Flexible Production

I view flexible production as based on two sets of interdependent organizational innovations. The first expands human capabilities, so that people can deal effectively with contingencies (problem conditions) and achieve improvements in the production system, while the second reduces the technical system's ability to function in the face of contingencies, through the minimization of buffers of all kinds. The latter increases the visibility of problem conditions and the pressure to deal with them speedily, while the former creates the capability to do so effectively.

To expand human capabilities, flexible production relies on work organization and human resource policies that yield a motivated, multiskilled, and adaptable workforce.

Responsibilities for quality inspection, equipment maintenance, job specification, and statistical process control are systematically "pushed down" to lower organizational levels. Most communication occurs laterally rather than hierarchically, across functional groups whose boundaries are fuzzy or overlapping, rather than clearcut. Ongoing problem-solving processes -- on the shop floor, between manufacturing and design, and between assemblers and suppliers -- yield a continuous stream of incremental improvements, allowing the production system to cope effectively with change of all kinds.

To increase the sensitivity of the technical system to contingencies, flexible production systems increase the technical interdependence of the production process through the near-elimination of parts inventory, work-in-process inventory, separate inspection and repair areas, and utility workers. This both minimizes waste and, more importantly, provides immediate feedback that the workforce can use for system improvement.

The organizational innovations of flexible production, and its distinctive "logic", emerged from the experiments of Japanese companies in the 1950s and 1960s. (Cusamano, 1985) While these innovations are thereby grounded in a particular historical context, many of the underlying ideas came from U.S. and European sources and have been developed independently in those regions.

Furthermore, the full-fledged model of flexible production developed in Japan is now diffusing successfully to many different social and economic contexts. Thus, just as one can speak of the characteristics of mass production without necessary reference to its origin in the U.S., I will describe flexible production in terms of its generic organizational characteristics rather than its link to Japan.

My colleagues at the International Motor Vehicle Program (Krafcik, 1988b; 1989a; Womack, Jones, and Roos, 1990) have chosen the term "lean production" to capture many of the same characteristics I identify as flexible production.[1] "Lean production is 'lean' because it uses less of everything compared with mass production -- half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time." (Womack et al., 1990, p. 13)

I believe that the term "lean" successfully identifies the tremendous efficiency advantages of this approach to production, and those aspects of the technical system, such as the minimization of buffers, that underlie this superior economic performance. But "lean" fails to capture the organizational and human resource characteristics that create the ability to handle information, solve problems, cope with change, and achieve continuous improvement -- characteristics better described in terms of flexibility. In particular, it fails to capture the expansion of skill and conceptual knowledge under flexible production -- expansion to a degree that would be considered redundant and wasteful under mass production. The technical system may be "lean" but the human system is "enriched".

In choosing the term "flexible production", I also situate the dissertation amidst a growing literature on flexibility, much of which derives from Piore and Sabel's work on "flexible specialization" in The Second Industrial Divide (1984). I thereby differentiate my definition of flexible production from Piore and Sabel's model and from two other "post-mass production" models that I identify as "flexible mass production" and "neo-craft".

Contributions of the Dissertation

The dissertation seeks to make theoretical, methodological, and practical

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[1] Another difference is that I refer primarily to manufacturing, while Womack et al. (1990) include all aspects of the automotive industry -- product development, supplier relations, and distribution as well as manufacturing -- under the rubric of "production system".

contributions to the study of organizations, technology, and human resources. The broad conclusion of the dissertation, that flexible production achieves its economically superior results primarily through organizational innovations, contradicts the conventional wisdom of economics, which expects technology and economies of scale to be determinative of economic performance. It also contradicts much literature in organizational theory, industrial relations, and business strategy that predicts deterministic links between task/technology and organization.

Many of the organizational characteristics of flexible production have been described in these literatures for thirty years, e.g. Burns and Stalker's (1961) "organic" organizations, yet always in contexts like R&D labs or high-tech start-up firms that have vaguely-defined tasks involving the creation of something completely new. Automotive assembly, on the other hand, has always been a setting where the match of a standardized task with a mechanistic organization seems self-apparent. Much of the analytical leverage in this dissertation results from the unexpected appearance of flexible production in the place where most organizational scholars would least expect it.

The dissertation, by analyzing both structural characteristics and problem-solving processes of mass and flexible production systems, also allows for consideration of various ways of conceptualizing the dynamics between structure and process. This effort also begins to provide some understanding of the deep cognitive and cultural differences between these production systems.

Methodologically, the dissertation seeks to demonstrate the value of a "configurational" approach. From this perspective, organizations cannot be understood by decomposing them into independent elements but must be viewed as "bundles". This may be particularly true when addressing the causes of complex organizational outcomes, such as productivity and quality, since these are likely to be "overdetermined" phenomena.

Therefore, I attempt to capture the "organizational logic" of mass and flexible production by measuring bundles of practices of policies and analyzing them with appropriate statistical methods, i.e. cluster analysis.

The practical implications of the dissertation are consistent with a growing number of recent studies of U.S. competitiveness that locate the nation's economic problems is its failure to develop and utilize human capabilities, its difficulty in absorbing and achieving the benefits of advanced technologies, and its attachment to the philosophies and practices of mass production that were central in achieving economic dominance thirty to forty years ago. (Dertouzos et al., 1989; Cuomo Commission, 1988; Kochan and Useem, 1990) The advantage of the dissertation over these studies lies in its identification of the distinctive "logic" of flexible production, and in its lessons for the diffusion of this different approach -- particularly the importance of systemic change that focuses on changing underlying processes rather than implementing structural changes.

Description of the Dissertation

The dissertation is organized into eight chapters. Chapter 1 contains an overview of the dissertation and a discussion (below) of the research context that focuses on the changing competitive situation in the world auto industry over the past twenty-five years and changing explanations of competitive advantage.

Chapter 2 develops the argument that understanding the transition to flexible production requires organizationally-grounded models of production systems. I first describe the key elements of mass and flexible production in the auto industry. I then review various literatures that help (or don't help) in understanding these production systems. Next, ased on the descriptions and the literature, I define "ideal types" of mass and flexible production, identifying both structural and cultural aspects of their "organizational logic". Finally, I distinguish flexible production from other post-mass production models.

Chapter 3 outlines the research strategy for the dissertation; describes the International Assembly Plant Study, carried out with John Krafcik, that provides the quantitative data; and presents a model of the production system that identifies the variables to be measured and the operationalization of those variables.

Chapters 4 through 6 focus on analyses of the International Assembly Plant Study data. Chapter 4 presents a univariate analysis of the relationship between production organization and manufacturing performance. Chapter 5 examines the "integration hypothesis", which emphasizes the interaction of production organization and technology and its effect on manufacturing performance. Chapter 6 adds a set of control variables, including mix complexity, parts complexity, product design age, and scale, for a full multivariate analysis of manufacturing performance.

In all three chapters, there are two parallel data analyses -- the first involving the Production Organization measure, an additive index, together with other independent variables, and the second involving a cluster analysis that groups plants using the variables that make up the Production Organization index and the technology measures.

Chapter 7 reports on the qualitative data from the study of problem-solving processes in three assembly plants, considering the relationship between these processes and the structural aspects of production systems measured quantitatively, and emphasizing differences between mass production and flexible production plants in problem definition, problem analysis, the organization of problem-solving groups, and liaison roles.

Chapter 8 summarizes the conclusions of the dissertation and, as mentioned above, explores the broader implications of the transition to flexible production.

The Research Context: Upheaval in the World Auto Industry

The automotive industry has many advantages for studying the transition from mass production to flexible production. It continues to be the largest and most important manufacturing industry in the world, with nearly 50 million new vehicles produced per year, crucial to the economies of nearly all advanced industrial countries (and several newly industrialized countries) in its impact on GNP, employment, and trade balances.

It has also experienced tremendous competitive upheaval in recent years that exemplifies all of the broad economic and technological trends affecting mass production: the internationalization of economic activity, shorter product life cycles, the increasing differentiation of product markets (i.e. the diminishing appeal of "mass" products), the increasing demand for "quality" in both products and the services associated with them, and the increased use of microprocessor-based information processing and manufacturing technologies. (Piore and Sabel, 1984; Jaikumar, 1986; Powell, 1987; Kenney and Florida, 1988; Piore, 1989a; Dertouzos, Solow, and Lester, 1989)

I will here briefly review developments in the auto industry over the past twenty-five years, highlighting the competitive situation and competing explanations of competitive advantage.[2] This period has proven to be, on the whole, a time of decline for the American auto companies that pioneered mass production and a time of ascendancy for the Japanese companies that pioneered flexible production. But while this is broadly true, this regional distinction is increasingly irrelevant. The more accurate statement about the competitive situation in 1990 is that, irrespective of region, the ascendent companies have mastered (at least partially) the logic of flexible production, while declining companies hav

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[2] My understanding of the world auto industry, and this brief review, have been heavily influenced by the excellent work of my colleagues in the International Motor Vehicle Program, summarized in Womack et al. (1990). They are not, however, responsible for the emphasis and interpretation I have chosen.

not. Thus the transition from mass production to flexible production in automotive assembly is, in large part, a story of some Japanese and American companies that are thriving and some that are not.

The European situation is more complicated. European companies largely prospered during the past twenty-five years, but did so following strategies that leave them now further from the implementation of flexible production than any other region. During this time, the volume producers (VW, Fiat, Renault) mostly continued their move towards the high volume, standard product approach of mass production that proved elusive in earlier years, when production volumes were low and craft methods were more strongly entrenched. European luxury/specialist producers, on the other hand, continued to move their high quality niche products into higher and higher price categories, while keeping their craft-influenced production systems largely intact. Even such visible experiments as the Volvo plants at Kalmar and Uddevala are best understood as steps towards a neo-craft model rather than flexible production, as defined here.[3]

While competition within Europe has been intense, both volume and luxury/specialist producers have faced little challenge from Japanese companies, largely because of trade barriers. This will change as Japanese companies build production facilities in Europe, and as American companies such as Ford diffuse the lessons learned in their U.S. operations to their European plants. But for now, the transition to flexible production in automotive assembly largely excludes Europe. (Jones, 1989; 1990)

Plants in Australia and the New Entrant countries of Korea, Mexico, Brazil, and Taiwan (most of which are owned by foreign multinationals) generally have older technology, older products, and follow older management and production policies. Thus they have largely remained in the mass production world. But increasingly, some plants

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[3] See Chapter 2 for more discussion on this point.

in New Entrant companies are attempting to introduce flexible production systems, so they become part of the story of the transition away from mass production.

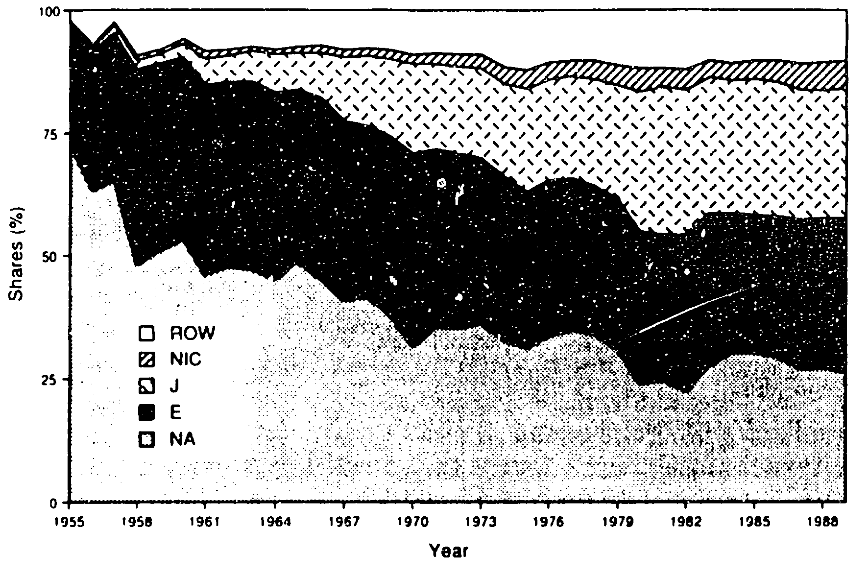
Figures 1-1 and 1-2 show the broad production and sales trends from 1955, the height of the dominance of U.S. mass producers, to 1989. The immediate postwar period, up until the mid-1960s, saw the recovery of European companies and the expansion of Ford and GM production in Europe. The world share of North American production dropped from nearly 75% to 49%, while the European share grew to 35%. But the U.S. market remained firmly in the grasp of the Big Three, who still held 94% of the market in 1965.

Much of the subsequent decline in the dominance of the U.S. Big Three was linked to the dramatic success of Japanese companies. From 1965 to 1989, the world share of North American vehicle production dropped by 23%, from 49% to 26%, while Japan's share grew by almost the same amount, from 7% to 26%; at the same time, the European share declined by 4% and the New Entrant share grew by 4%. During this same time, U.S.-owned companies saw their share of U.S. market sales drop by one-third, to 62%.

I will focus on developments in the U.S. market from this point on, since it has been the primary scene for these dramatic competitive shifts. Looking back over this period from a U.S. perspective, we can view the 1970s as a time when U.S. companies became painfully aware of their competitive woes, particularly with respect to Japanese competitors, and the 1980s as a time when those companies debated various explanations for those problems and attempted various remedies, with mixed results.

In the 1970s, two oil shocks drove U.S. consumers towards smaller cars, and U.S. companies were slow to respond to Japanese competitors who provided such products, together with better reliability and pricing. Meanwhile, European luxury/specialty products successfully cut into the most profitable part of the U.S. market. Also in the 1970s, U.S. products were acquiring a reputation for quality problems, in comparison with its

Figure 1-1: **Shares of World Motor Vehicle Production by Region, 1955–1989**

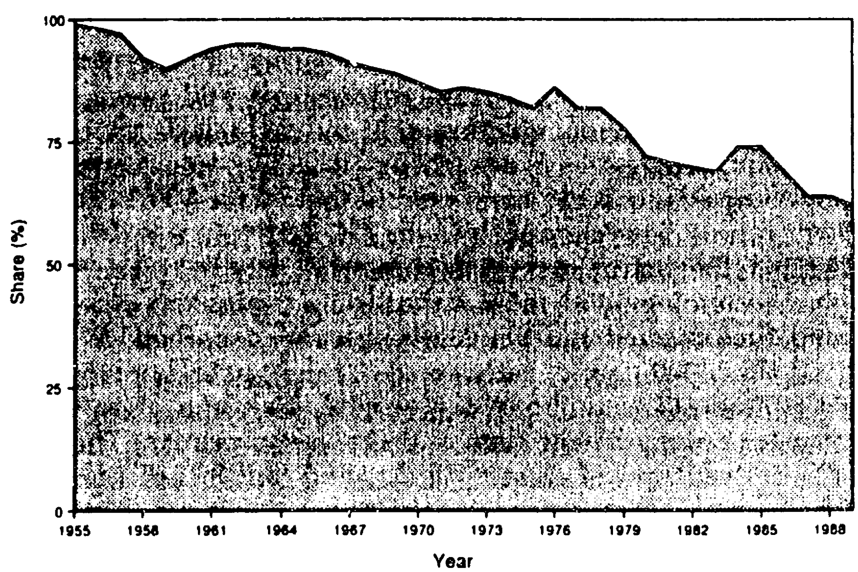


Note: This figure includes all vehicles produced within the three major regions, by all companies operating in those regions. In addition, it groups the production of the newly industrializing countries and of the rest of the world.

NA = North America: United States and Canada
E = Western Europe, including Scandinavia
J = Japan
NIC = Newly industrializing countries, principally Korea, Brazil, and Mexico
ROW = Rest of the world, including the Soviet Union, Eastern Europe, and China

Source: Calculated by the authors from *Automotive News Market Data Book*, 1990 edition, p. 3.

Figure 1-2: **Share of the American Car Market Held by the American-Owned Companies, 1955–1989**



Note: These shares include vehicles imported by the American-owned firms from their wholly owned and joint-venture factories abroad. They do not include "captive" imports purchased from independent foreign firms.

Source: 1955–1981 from *Automotive News Market Data Book*, based on vehicle registrations. 1982–1989 from *Ward's Automotive Reports*, based on vehicle sales.

Source: Womack, Jones, and Roos (1990).

competitors. By the end of the decade, Chrysler was near bankruptcy and seeking government loan guarantees, while Ford was kept from that precarious position only by European profits. General Motors was still relatively unscathed, apparently large enough and rich enough to ride out the storm.

By the end of the 1970s, the prevailing wisdom about the competitive woes of the U.S. industry focused on four things:

1) The impact of higher fuel prices on product demand;

2) The slowness of U.S. companies to respond to the demand for smaller, more fuel efficient cars;

3) The tendency for mature industries to move to locations with lower factor costs;

4) Inherent advantages of the Japanese companies.

During the 1980s, a series of developments challenged all four of these potential explanations.

First, fuel prices fell by the mid-80s and remained low until the Persian Gulf crisis in the summer of 1990. This prompted increased consumer demand for bigger, more powerful vehicles, thus helping U.S. companies, who had traditionally dominated this market segment.[4] But this also helped accelerate the movement of Japanese companies into making larger products. Their success in these new product segments, and particularly the luxury products of the Acura (Honda), Infiniti (Nissan), and Lexus (Toyota) lines, makes it clear that the Japanese competitive advantage goes well beyond small cars.

Second, U.S. companies did begin the switch to smaller, lighter front wheel drive designs in response both to Japanese competitors and government fuel economy regulations. But they also sought to buy time for this change in a variety of ways. With

[4] By 1990, this situation was once again reversed, with the Persian Gulf crisis, new federal taxes on fuel, and heightened concerns about air pollution once again favoring smaller, fuel efficient vehicles. This may once again give a boost to Japanese companies, who, despite their move to larger product segments, still have a more fuel-efficient fleet.

their production and sales slump continuing into the early 1980s, the U.S. companies lobbied the federal government for short-term protection from the surge of Japanese imports. The resulting Voluntary Restriction Agreements (VRA) avoided formal quotas but effectively capped Japanese exports at their 1980 level.

Ford and Chrysler responded to this breathing room with major initiatives in quality improvement and labor relations and with successful new products (Chrysler's K-car and minivan; Ford's Taurus/Sable) and saw a resurgence of sales. GM launched similar initiatives during this period, but had little success with its new products, which were slow to the market and criticized as "look-alikes". Instead, GM put its strategic emphasis on such high-visibility projects as Saturn, the separate subsidiary that sought to reestablish profitable small car production at GM; the acquisition of high-tech expertise, in the form of companies like EDS and Hughes; and a major push on advanced factory automation at such new plants as Hamtramck.

Despite some downsizing of products in all segments, the Big Three, for the most part, abandoned the small car segment of the market. To preserve a full range of products, all of the Big Three established linkages with Japanese partners to acquire small cars -- Ford with Mazda, Chrysler with Mitsubishi, and GM with Isuzu, Suzuki, and Toyota. By the mid-1980s, these linkages extended to joint ventures -- the NUMMI joint venture between GM and Toyota; Mazda's Flat Rock plant, producing a product for Ford; and the Chrysler-Mitsubishi Diamond-Star plant.

Japanese companies approached these linkages quite differently -- as a way to gain a production foothold in the U.S. market. Under the VRA, the only way for Japanese companies to increase their U.S. market share was to build cars in the U.S. Honda, with a small market share and limited distribution network in Japan, was the first to open a U.S. plant (in 1982), followed soon thereafter by Nissan (1983), Toyota (at NUMMI, in 1984), Mazda (1987), Mitsubishi (at Diamond-Star in 1989), and Subaru/Isuzu (1989).[5] By 1990, the announced capacity for these so-called "transplants" was over 2 million cars per year. The attempt to buy time for the U.S. industry to regroup only succeeded in accelerating the pace of transferring production from Japan to the U.S.

Third, the idea that the auto industry was inevitably moving "off-shore", to locations with lower factor costs, was challenged by a number of developments. In the late 70s and early 80s, many studies identified the Japanese advantage as one of lower wage rates (see below). But by the mid-80s, major exchange rate shifts, steady pay increases in Japan, and concession bargaining in the U.S. produced a situation in which U.S. real wages were less than those in Japan.

The successful debut of Korean products in the North American market, primarily from Hyundai, that quickly grabbed 10% of the Canadian market and 4% of the U.S. market from 1986-88, also appeared to support the "off-shore" argument. But from 1988 to 1990, sales of Korean products dropped by 50% as the quality problems of earlier model years became apparent. (Womack et al., 1990) The complete collapse during this time of the low-cost Yugo product, whose quality problems were even worse, was another sign that low factor costs, and the low prices they allowed, were not a ticket to success in a market that had come to expect high levels of quality and reliability.

Fourth, the arrival of Japanese transplants in the U.S. began to challenge the commonplace explanations of Japanese competitive advantage that had been advanced and debated in the late 1970s and early 1980s. Among these explanations were:

1. Lower Japanese wage rates. Several studies of the "landed cost differential" between comparable U.S. and Japanese products found a gap of between $750 and $1,500. (Abernathy, 1982). Most early studies attributed this difference to lower wages and benefits in Japan, and these figures were used to press the UAW

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[5] Honda and Toyota have since opened additional new plants in Canada and the U.S. -- in 1987 and 1989 for Honda, respectively, and in 1988 for both Toyota plants.

for concessions in the 1982 national bargaining. Two later studies found a similar gap but attributed it to different causes: the Harbour study pointed to appreciable productivity advantages based on Japanese production methods, while the UAW-commissioned Telesis study pointed to much lower levels of management and staff employees in Japanese plants.

2. Unique cultural attributes. From this perspective, the Japanese advantage was due to the strong work ethic and longer working hours of Japanese employees; a group orientation more supportive of teamwork than the individualistic Western orientation; cooperative enterprise unions; and internal labor market policies (notably recruitment from school, firm-specific training, low job mobility, and lifetime employment) that increased individual commitment to the firm.

3. Automation. Amid a wave of concern about the potential effects of relatively low-cost and sophisticated robotic technology, many media reports concluded that Japan had a substantial advantage due to its more rapid implementation of this technology. This in turn led to explanations about the lower cost of capital in Japan (based in part on a higher savings rate) as the source of a higher level of capital investment, particularly in new technologies.

All of these explanations were undermined by the experience of the Japanese plants in the United States. Within a few years after opening, the "transplants", using American workers, engineers, managers and (at NUMMI and Mazda) union officials, achieved performance results, in terms of both productivity and quality, that matched or surpassed most American plants. Their wages and benefits were essentially equivalent to U.S. plants (although, with a new young workforce, their pension costs were, and continue to be, much lower). Their level of technology ranged from moderate (at NUMMI and Honda's first plant) to high (at Mazda, Nissan, and Diamond-Star), but was often less in amount and sophistication that the most advanced U.S. plants. Finally, these plants implemented a production system and set of human resource practices nearly identical to that used by their companies in Japan, despite the very different social and economic context.

The NUMMI case was particularly intriguing, because unlike the "greenfield" plants opened by Honda and Nissan in Ohio and Tennessee, it occupied a former GM plant in California and hired its employees from the ranks of the former GM workforce. Union officials from what had been regarded as one of the most militant local unions at GM were brought back as well. Yet within a year of opening, NUMMI had the best quality and productivity of any GM-affiliated plant, and the lowest absenteeism and grievance rates as well. (Krafcik, 1986; Brown and Reich, 1989)

NUMMI thus served as a kind of natural experiment -- with the physical plant, workforce, union, cultural context, and level of technology[6] held constant -- for testing hypotheses about the sources of manufacturing performance. Its success highlighted the fact that what had changed from the old GM plant, essentially, was the approach to organizing the production system, which in turn reflected a very different approach to managing human resources and managing technology. In the terms of this dissertation, NUMMI had succeeded by effectively implementing a flexible production system.

Thus the experience of the transplants highlighted the role of the production system as the source of superior manufacturing performance, rather than factor costs, cultural attributes, or technological superiority. Furthermore, the success of the transplants established that the Japanese approach to production could be successfully transferred to a very different cultural context. (Shimada and MacDuffie, 1987)

Also revealed during the 1980s were significant Japanese advantages in other parts of the auto industry besides manufacturing: product development, supplier networks, and distribution. (These are described in Womack et al., 1990) In these areas, as in the factory, the primary advantages appear to be organizational -- shorter product development cycles and better design manufacturability through simultaneous engineering (Clark, Chew, and Fujimoto, 1987); better coordination of deliveries, inventory management, quality, and

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[6] NUMMI did make a substantial investment in technology for the Fremont plant, installing a stamping plant (GM had received stampings from an internal supplier), and renovating the weld and paint departments. (Krafcik, 1986) But the resulting level of technology was still moderate, and not appreciably different from the former GM plant, particularly in comparison to new plants opened in the U.S. during the 1980s by both American and Japanese companies. Since that time, after thoroughly establishing its production system, NUMMI has added considerably more advanced technology.

component design through effective supplier relations (Nishiguchi, 1989; Lamming, 1989); and a closer link between market requirements (both consumer product preferences and delivery time) and production capabilities (Shimokawa, 1989).

At the end of the 80s, the situation of the U.S. auto companies can be assessed, in part, by how well they have absorbed the message that a very different production system -- flexible production -- is the source of Japanese competitive advantage. In the U.S., two of the Big Three are again in trouble. Chrysler failed to capitalize on its dramatic recovery from bankruptcy, keeping its older product designs in production too long while failing to develop new designs, and maintaining a largely traditional mass production system. Efforts to introduce the team-based work organization of flexible production have been largely unsuccessful, due in part to the failure to make other fundamental changes in the production system. Furthermore, Chrysler appears to have learned little from its joint venture with Mitsubishi. As a result, Chrysler is once again facing a financial crisis.

GM, which still looked strong at the end of the 1970s, suffered a dramatic loss of market share during the 1980s - from 46% to 35%. In part, this reflected the fact that GM went through the restructuring process caused by the 1970s import surge a few years later than Ford and Chrysler. But it also reflects the fate of the major strategic initiatives launched by GM in the early 80s. Some were remarkably slow to be implemented -- the GM-10 product development effort took seven years, and Saturn has just begun production in the fall of 1990). Others were problem-laden -- the absorption of companies like EDS proved extremely difficult, and the Hamtramck plant, a showcase for GM's most advanced technology, became a symbol of the failure of a high tech-only strategy.

Finally, GM was slow to learn from the experience of NUMMI, despite having the opportunity to observe it first-hand. While many GM plants attempted to introduce the "team concept", these efforts were largely motivated by the goal of increasing participation and remained isolated from changes in the production process, which were focused almost exclusively on implementing advanced automation. At the very end of the 80s, an integrated effort to change the production system (the Quality Network) was beginning to be implemented, and the Saturn plant, GM's laboratory for flexible production, was just opening. While some plants are already achieving considerable success with this new approach, it remains to be seen whether GM will be able to diffuse the principles of flexible production through its immense system.

Of the Big Three, Ford has accomplished the most in mastering the principles of flexible production. Ford faced financial difficulties much earlier than GM and more precipitously. The strong sense of crisis that resulted focused attention on fundamental changes in Ford's ways of doing business, from product development to manufacturing to labor relations. Because of the crisis, Ford was also quite receptive to what it could learn from outside the company, particularly from Japan, and with its purchase in 1979 of 25% of Mazda, it had close-up exposure to a valuable "learning example".[7] One result has been a commitment to quality improvement that has brought about a substantial shift towards the principles of flexible production.

But another result has been a cautious strategy of taking the time for a new quality philosophy to sink in before attempting major changes in work organization (e.g. teams), human resource policies, inventory practices, or product development processes. While perhaps a wise choice in the mid-1980s, this caution has persisted, with the result that

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[7] Mazda was in the midst of its own transition at the time, based on its own crisis in the mid-1970s. At the manufacturing level, Mazda chose to adopt, as completely as possible, the Toyota Production System. At the time Ford purchased its share of Mazda, this process of learning from Toyota was still fully in place, so that Ford had the chance to learn not only the principles of Toyota's production system but also to see how to implement it.

Ford appears to be stuck at a transitional state between mass and flexible production.[8] Without moving ahead to a more fundamental embrace of flexible production, Ford will feel the pull back to familiar ways learned during decades of mass production experience. Thus one important question for the 1990s is whether Ford will fully join the ranks of the companies who have mastered flexible production.

The performance of Japanese automotive companies has also varied during the 1980s. The principles of flexible production have diffused quite thoroughly in Japan, so that the variance in production systems among these companies is much less significant than their differences from most U.S. and European companies. In addition, many Western observers (including myself) have tended to treat the Japanese companies as a whole, so that less is known about differences among these companies. However, just as mass production systems can be managed more and less capably, so too can distinctions be made among flexible production companies.

Toyota is the acknowledged pioneer of flexible production, followed closely by Honda, which has developed its own unique variant. Nissan, Mazda, and Mitsubishi come to flexible production much more recently -- Nissan because of its long history of borrowing technology and production methods from Western partners (Cusamano, 1985), Mazda because of its predominantly engineering focus and its near-bankruptcy in the mid-1980s, and Mitsubishi because of its relatively recent emphasis on the automotive sector in relation to its many other industrial activities. Smaller Japanese companies -- Isuzu, Suzuki, Subaru, and Daihatsu -- have adopted flexible production principles in large part, but do not appear to have mastered this approach as thoroughly as their larger competitors. It is likely that the gap among the Japanese companies will widen in the

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[8] The Ford case in the problem-solving study, described in Chapter 7 provides much of the basis for this assessment.

1990s, and that this will be due, in part, to their relative success with flexible production.

In summary, the experiences of the 1980s have steadily pushed aside the prevailing wisdom about the competitive situation that existed at the beginning of the decade. Thrust to the center is a very different explanation -- that the dramatic competitive shifts have resulted from fundamental, systemic differences between mass production and flexible production, and the inherent economic performance advantages that accrue to those companies that master the latter approach. (Krafcik, 1988a, 1988b, 1989a; Krafcik and MacDuffie, 1989; MacDuffie and Krafcik, 1989b, 1990).

In Chapter 2, I examine mass production and flexible production systems in greater detail, and describes the research framework that will guide the subsequent investigation of their "organizational logic" and their link to manufacturing performance and problem-solving processes.

CHAPTER 2

BEYOND MASS PRODUCTION? EXAMINING MODELS OF PRODUCTION ORGANIZATION

Chapter 1 describes a time of upheaval and innovation for the global automotive industry, and the rise of an alternative model -- flexible production -- based on organizational innovations that yield significant performance advantages. In this chapter, I explore the key elements of flexible production in more detail and discuss how this approach to production challenges many long-established theories -- theories that were developed based on observations of the mass production world.

I then draw out, inductively, the key organizational characteristics -- the "organizational logic" -- of mass production and flexible production, viewed as "ideal types". I further distinguish two dimensions of this "logic" -- a "structural logic", related to patterns of work roles and administrative mechanisms, and a "cultural logic", related to how individuals think about the production system and their role in its operation. These polar types provide the parameters for a discussion of different models of production organization, aimed at identifying the precise model of flexible production for the empirical work in later chapters.

A. KEY ELEMENTS OF FLEXIBLE PRODUCTION

Introduction

My research on flexible production has been a process of discovery -- first, the discovery of its distinctive logic (and the transferability of that logic) from my study of Japanese-owned assembly plants in North America with Haruo Shimada (Shimada and

MacDuffie, 1987), and second, the discovery of the many ways in which this logic challenged theories and concepts from the organization studies and industrial relations literature.

Mass production provides the reference point for most alternative models of production. The hallmarks of this dominant model of production, and their historical origins in the U.S., are well-known (Hounshell, 1984; Hughes, 1988; Womack et al., 1990):

1. Interchangeable parts, resulting from technical advances in steelmaking, machine tool design, gauging, and parts design during the latter half of the 19th century, in a variety of American industries (e.g. guns; sewing machines);

2. Product standardization and the principle of continuous flow, embodied in the moving assembly line, brought together by Henry Ford at the Highland Park Model T factory (c. 1913-15);

3. Task specialization through a highly rationalized division of labor and the separation of conceptual (managerial) work from production work, both aspects of Frederick Taylor's "scientific management" philosophy (c. 1911-13);

4. Large-scale organizational bureaucracy, with a centralized hierarchy of managers and staff, specialized by function, to handle the unprecedented coordination requirements of producing and distributing "mass" products for ever-larger "mass" markets, diffusing broadly in the late 1800s and early 1900s.

Most efforts to establish a "post-mass production" model, such as the Volvo experiments at its Kalmar and Uddevala assembly plants, have taken aim at three central characteristics of mass production: 1) the machine pacing of the assembly line, which constrains the autonomy of individual employees; 2) narrowly-defined, repetitive, and low skill tasks; and 3) a strong supervisory presence, directed towards controlling and monitoring worker behavior.

Accordingly, the alternative model used at Volvo stresses the elimination of the assembly line, to provide workers with more control over work pace; broadly-defined tasks and rotation among tasks, to make work more challenging; and self-managing teams that absorb supervisory responsibilities, and thereby require little monitoring.

These were the organizational characteristics I expected to find in the Japanese transplants. To my surprise, I found none of them.[1] These plants all continued to use a moving assembly line, and process technology that differed little from a mass production plant. Jobs were defined around similarly narrow production tasks, although job requirements were expanded in other ways and the relationship between workers and jobs was approached quite differently. Work teams were being used, but they were not self-managing, and supervisors still held significant authority.

Yet as I talked to American workers and managers in the transplants, I learned that these plants followed very different principles from a mass production plant. Only a few of these differences were readily visible. The transplants were clean, relatively quiet, and more compact, in terms of space utilization, than most traditional assembly plants. They had stamping presses on-site, rather than receiving stampings from a supplier. Many graphs, charts, and lists of job specifications were posted near most work stations. It was difficult to tell managers and engineers from production workers, for noone wore ties and most wore a company uniform and hat.

Over the course of a day in these plants, other differences became apparent. The physical environment of the plant -- the low noise, lack of visual obstructions, and close proximity of different sections -- made it relatively easy for people to talk with each other. There were no big piles of inventory next to the assembly line, or filling whole bays of the plant.

When the body shop encountered dents on a stamped body part, it could send someone immediately to tell the stamping department. Inventories of stamped parts were

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[1] I now view these characteristics as part of a "neo-craft" model, which is discussed in greater detail below.

also low, with only 500-600 of each part (compared with thousands in a typical stamping plant) being made at a time, so very few dented parts would be "in the pipeline". When switching to make another part, a team of workers, working as quickly and smoothly as a pit crew at the Indy 500, changed the stamping die in under 10 minutes -- a far cry from the five or six hours needed in a traditional plant.

The charts, graphs, and lists next to the assembly line included statistical information about quality problems, detailed job specifications, and information about department cost and quality performance. The quality charts were filled out by production workers themselves, since, upon further investigation, it became clear that the plant had no separate quality inspectors. Production workers also modified job specifications when necessary, in consultation with their team leader -- once again, because the plant had no industrial engineers to do the job.

Many of the uniformed people on the shop floor turned out to be managers, engineers, and trainers, who seemed to spend most of their time in the plant. A visit to the administrative offices of the plant revealed a mostly empty room with rows of desks facing each other, unseparated by dividers. Only after a shift did the managers, engineers, and trainers return to their desks, to talk over the day's production activities.

Sometimes, when a problem would occur on the shop floor -- a machine breakdown, a defective part -- a worker would pull a cord to stop the assembly line. Signs near that work station would light up, and groups of people, including managers and engineers, would gather quickly around the problem and work at a furious pace to get the line moving again. With inventory levels so low, any lengthy stopping of the assembly line could close down all downstream operations. The work team for that operation would meet after the shift to work on a permanent remedy for that problem.

As our investigations at the transplants continued, it became clear that these observations were just a sample of broad and comprehensive differences from traditional mass production -- a different "logic" that encompassed the goals of the production system and the way technical and human capabilities were organized.

Since these plants were operating quite successfully in the U.S. context, with American managers, engineers, workers, and, in some cases, unions, it seemed inappropriate to identify this logic as "Japanese", although it was clearly being transferred from Japan. Far preferable, I decided, was an approach that would identify the generic organizational characteristics of the production system in these plants.

This would sharpen the contrast both with traditional mass production and with the "post-mass production" expectations I had brought to these plants. It could also provide the basis for an empirical investigation of differences in production organization for plants in many different settings. In the rest of this section, I describe these organizational characteristics.

Overview

Flexible production is oriented towards different goals than mass production. As a result, it organizes both technical capabilities and human capabilities in different ways.

As mentioned in Chapter 1, the technical system becomes more "lean" through the minimizing of buffers, and therefore more sensitive to problem conditions (i.e. less able to function when problems are unresolved). At the same time, human capabilities are "enriched", as employees develop the capacity to deal with problem conditions when they occur, and thus make it possible to operate a "low buffers" production system. This requires a workforce that is skilled, able to adapt quickly to changing circumstances, and motivated to respond to problem conditions. Haruo Shimada and I (1987) have described this relationship between technical and human capabilities as "humanware".

<u>Production Goals</u>

Under flexible production, productivity and quality are regarded as complementary goals, with no necessary tradeoff. Thus the production system is organized both to eliminate quality defects and to reduce costs, unlike mass production, where it is generally assumed that achieving high productivity would hurt quality (and vice-versa).

While both productivity and quality are accorded equal importance under flexible production, quality is the goal that shapes how people think about the production system. Quality is understood as the process of eliminating waste, where "waste" includes defective parts, unneeded space (in equipment layout), unnecessary motion (in how jobs are performed), repair activities (not required if you "get it right the first time"), poorly-designed (in ergonomic terms) work processes that drain energy or lead to accidents, and disposable packaging for supplies (e.g. cardboard boxes that can't be reused), among many other things.

The expectation, under flexible production, is that if you worry about quality and the minimization of waste, cost savings will follow as a natural consequence. This encourages a longer time frame for thinking about costs, in which incurring short-term costs for quality improvement that yield the long-term elimination of waste is not only tolerated but encouraged.

This "first among equals" treatment of quality as a goal has several consequences. First, while productivity and efficiency are goals that often divide managers and workers, especially in the absence of norms of employment continuity, quality is a unifying, mutually beneficial goal, in terms of better sales and more "pride in work". (Cole, 1990a) Second, while productivity has a primarily internal referent -- company profitability -- quality has an external referent -- the customer. Flexible production plants tend to rely much more heavily on customer-based measures of quality than mass production plants, which rely more on internal quality audits (cf. Chapter 7); this reinforces the unifying purpose of providing better quality to the customer.

Finally, Dore (1983) suggests that exchange relations shift fundamentally when quality is the primary criterion for a successful transaction. This may be, he suggests, a function of affluence, when consumers shift their attention from the "what" of price to the "which" of identifying desirable product characteristics. When quality is the goal, Dore argues, exchange norms shift in the direction of trust and reciprocal obligation, since quality depends on (and promotes) repeated, reliable actions by both parties to a transaction -- manufacturer and customer, assembler and supplier, or manager and employee.

Thus the primacy of quality as a goal favors a particular approach to business relationships, both inter- and intra-organizationally. This is turn affects the configuration of technical and human capabilities.

Technical Capabilities

In order to achieve the complementary goals of productivity and quality, the technical system under flexible production takes a very different approach to buffers and production lot size.

Minimization of buffers. Under mass production, disruptions to the production process (sales fluctuations, supply interruptions, equipment breakdowns) prevent the realization of economies of scale. Accordingly, buffers such as extra inventories, repair space, or utility workers, are added to the production system. These buffers essentially create organizational slack that minimizes the impact of unforeseen contingencies.

But under flexible production, such buffers are seen as costly, for several reasons.

The buffers represent a commitment of resources not directly devoted to production. Inventory buffers in particular are costly to store and handle, and can hinder the move from one product design to another.

Most importantly, buffers can hide production problems. So buffers are minimized under flexible production, so that problems become visible immediately, creating pressure to resolve them. If a quality problem with a part is found and inventory stocks are high, it is easy to throw out the bad part and draw another from inventory. But if inventories are very low, as with a Just-in-Time inventory system, a bad part draws immediate attention, and must be dealt with, to prevent the production system from grinding to a halt. Similarly, a large repair area is a buffer that catches production problems after-the-fact. When the repair area is very small, defective products have nowhere to go, thus reinforcing the need to "build in" rather than "inspect in" quality.

Small lot production. Production is also carried out in small lots under flexible production, not the very large lots of mass production. While this requires more frequent equipment set-up, flexible production plants reduce setup times dramatically, by automating as much of the process as possible, doing preparation for the changeover while machines are still running, and training teams to specialize in setup. For example, most flexible production plants are able to change the die on a stamping press in less than 10 minutes, in comparison with the several hours required in a mass production plant.

Cusamano (1986; 1988) argues that Japanese auto companies developed many of the innovations of flexible production because of a market context in the postwar years with low consumer demand and high competition, requiring small lot production. The advantages of mastering small lot production were, he writes:

> ... higher worker output and utilization rates for machinery, faster inventory turnover, and even higher quality -- since "just-in-time" systems did not tolerate defectives or equipment breakdowns, and Japanese workers producing in smaller

> lots found they were able to pay greater attention to what they were doing. (1986, p.26)

But these advantages of small lot production far outlasted the market conditions that gave rise to them. Even as exports grew and volumes per product increased to mass production levels, Japanese companies maintained their practice of producing in small lots.

This is because both small lot production and the minimization of buffers not only help to reduce costs and increase flexibility with respect to product changes, but also serve a cybernetic or feedback function, providing valuable information about production problems that can be used to improve the production system. This is similar to the "informating" concept of Zuboff (1988), although it is based less on intrinsic characteristics of the technology than on choices about how the technical system is organized. Thus the technical system provides information about problem conditions in the production process, while also becoming more susceptible to interruption when problems occur.

Human Capabilities

While the technical system becomes "lean" under flexible production, human capabilities are enriched, providing the "buffer" that allows the technical system to function. Instead of attempting to deal with problem conditions by making the technical system more adaptable, flexible production operates under the assumption that people are more capable of responding effectively to contingencies.

Continuous improvement. Central to the relationship between technical and human capabilities under flexible production is the philosophy of continuous improvement, known in Japan as "kaizen". The basis for this philosophy, pioneered by Taiichi Ono at Toyota, that problems are opportunities for learning. Here is an excerpt from Ono's book

Workplace Management:

> I tell workers to turn the machine off if they discover a problem because once it is off they can look for a solution.... Since considerable losses are incurred when a machine stops, figuring out how to continue production without stopping is clearly linked to quality improvement.
>
> When we were first starting out, I used to tell people in the Motomachi plant to turn off machines if they grew tired. If they did, I would ask the group leader or foreman why the workers had been given such tiring tasks. They would say that workers turned off machines because they were attaching defective parts. "Well then," I would ask, "how can you prevent them from attaching defective parts?" (1988, p. 91)

This philosophy has become institutionalized in a problem-solving procedure known as the "five whys". As illustrated in Ono's quote, the idea is to identify the "root cause" of a problem by repeatedly asking what may underlie its most obvious manifestations. Kaizen, therefore, requires a careful and extensive understanding of the current situation so that the appropriate remedy can be found.

A Multiskilled Workforce. A multiskilled and committed workforce is critical to the implementation of this continuous improvement philosophy, together with a "lean" technical system. With the reduction of buffers, workers must be able to identify and resolve quality problems as they appear on the line. To do so, they must have both a conceptual grasp of the production process and the analytical skills to identify the root cause of problems. This in turn requires a decentralization of production responsibilities from specialized inspectors and engineers to production workers and a variety of multiskilling practices, including extensive off- and on-the-job training, work teams, quality circles and job rotation within a few broad job classifications. These practices provide the basis, in large part, for the measurement of work organization and human resource management policies in the empirical work below, and, as such, they are described in more detail in Chapter 3.

Reciprocal Obligation. These multiple skills and conceptual knowledge are of little use unless workers are motivated to contribute mental as well as physical effort. The attentiveness, analytical perspective, and creativity needed for incremental problem-solving can not be attained through close supervision or the elaborate control systems used to insure compliance in a mass production system.

Workers will bring those qualities to their jobs only if they believe there is a real alignment between their individual interests and those of the company, and will only commit themselves to advancing company goals if they believe there is a reciprocal commitment from the company to invest in their future wellbeing. As a result, flexible production is characterized by such "high commitment" human resource policies as employment security[2]; compensation that is partially contingent on corporate, plant, and/or individual performance; and a reduction of status barriers between managers and workers. The company investment in building worker skills also contributes to this "psychological contract" of reciprocal commitment.

"Giving Wisdom to the Machine". Under flexible production, workers and engineers apply their problem-solving abilities to the task of improving equipment performance over time -- a process identified by Monden (1983) as "giving wisdom to the machine". This means that production technology need not be automatically subject to decay and

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[2] Japan's policy of employment security for male employees in large firms is not a function of long-standing Japanese cultural tradition, as some believe, but rather the outcome of bitter labor-management struggles in the 1940s and 50s. Left-wing unions, established on a company or enterprise basis, had tremendous organizing successes in the immediate post-war years, reaching over 50% representation by 1949. (Gordon, 1985) Alarmed, the management of several large companies crushed radical unions in a series of strikes in 1949-50, promoting more conservative enterprise unions in their stead. These new unions, both to gain legitimacy and to preserve their membership, pressed for long-term employment security. Management, concerned about high turnover, shortages of skilled workers, and company-specific work stoppages, agreed. Kenney and Florida write, "By the unwritten terms of this accord, layoffs can occur only after the implementation of alterative measures such as wage freezes, progressively indexed wage cuts, and early retirement, and then only if the economic health of the company is truly in jeopardy." (p. 129) This policy, while highly specific to Japan, may well be a critical foundation for flexible production. The fact that Japanese plants in the U.S. follow this policy assiduously suggests that this may be the case.

depreciation but can actually appreciate in value over time. For example, the installation and "debugging" of a new technology is carried out by workers rather than staff specialists or vendors. (Cole, 1990a; Krafcik, 1989a) This important learning is thereby retained among those who will operate (and seek further improvement in) the equipment over time rather than being taken along to the next plant or customer.

Workers as Industrial Engineers. The same principle of continual process improvement applies to all job specifications under flexible production, whether directly related to technology or not. While production levels and the basic framework for the production process are determined by engineering requirements, teams of production workers have responsibility for developing, recording and modifying job specifications. These specifications are extremely detailed, as much as any industrial engineering time study, but with the crucial difference that workers, rather than managers or engineers, take charge of their revision (Monden, 1983; Krafcik, 1989a; Cole, 1990a).

A "Fragile" System

Shimada and MacDuffie (1987) characterize flexible production as "fragile", because of its distinctive relationship between technical and human capabilities. It is "fragile" because, when buffers are minimized, any minor disruption, such as the failure of a supply delivery to arrive on time, can force the entire plant to shut down. But it is also "fragile" with respect to human capabilities. It will deteriorate or even cease to function if the workforce loses the ability to move among different jobs, or is no longer willing to spot quality problems or engage in process improvement, or is sufficiently disgruntled to take advantage of the vulnerability inherent in minimal buffers. Paradoxically, the awareness of this vulnerability appears to strengthen the production system by providing an ongoing incentive to maintain effective communication and a problem-solving orientation, both with employees in the plant and in relationships with suppliers. (Nishiguchi, 1989)

Summary

Thus the key elements of flexible production are small lot production and minimal buffers, both of which provide rapid feedback about problems to the production system; a philosophy of continuous improvement which takes those problems as opportunities for learning; work organization and human resource policies that develop a multiskilled, adaptable, and motivated workforce and a "psychological contract" of reciprocal obligation between the company and individual employees; an approach to technology in which workers take responsibility for incremental innovations that lead to revisions in job specifications and "give wisdom to the machine", so that any technology is used more flexibly; and "fragility" from the high interdependence between technical and human capabilities.

B. THE IMPLICATIONS OF FLEXIBLE PRODUCTION -- THEORY AND METHOD

For someone trying to understand flexible production, much of the literature from organization theory, industrial relations, business strategy, and political science raises more questions than it answers. For, with a few exceptions, theories that apply to manufacturing settings have been built upon observations of the mass production world, and, conversely, theories of "flexible" organizations have developed from the study of settings associated with innovation -- generally considered the antithesis of manufacturing.

Furthermore, most empirical studies of production systems identify and measure only a few organizational characteristics, and from the analyses of these data, draw broad conclusions about the system as a whole. This can be very misleading if it misses the crucial interdependencies among a "bundle" of related organizational characteristics.

In this section, I will examine the ways in which prevailing theoretical and methodological approaches to the study of production systems both do and don't help in understanding flexible production. This will provide the backdrop for my own research efforts.

First, I review three literatures -- on contingency views of the "fit" between technology and organizational structure, socio-technical systems, and the link between industrial relations practices and economic performance -- and analyze why they are not particularly useful for the study of flexible production. Then, I review two literatures -- from political economy, on changes in production system paradigms, and from business strategy, on a configurational approach to organizational research -- that prove to have greater value.

Organization/Technology "Fit": Technology-based Contingency Theory

The development of contingency theories of organization in the 1960s represented an attempt to move beyond the normative assertions of much early management theory that there was "one best way" to structure an organization -- whether the task specialization and span of control emphasis of the "classical" management theorists (Fayol, Gulick, Taylor) or the focus on informal social norms and cooperation of the "human relations" theorists (Mayo, Roethlisberger).

Early contingency theory took an intra-organizational focus, attempting to explain differences in structure and goals across different types of organizations in terms of the organization's primary task or technology. Perrow (1967) linked organizational structure to the number of exceptions and analyzability of tasks, putting mass production settings in the low exception - high analyzability category, for which a bureaucratic structure is most appropriate. For Burns and Stalker (1961), mass production, with the stable conditions provided by its standardized products and large markets, is a "mechanistic" system with specialized tasks performed by isolated individuals, knowledge retained at the top levels of a hierarchy, and vertical interaction patterns. Joan Woodward (1965) found the greatest amount of functional specialization and the greatest separation of conception and execution in the "large batch and mass production" category of her sample of firms.

From this perspective, the organizational characteristics of mass production (centralized hierarchy; vertical interaction; functional specialization; low-skill, low-discretion jobs; etc.) are determined by the nature of its task (the large-scale production of a single product) and its technology (a machine-paced continuous line flow, e.g. the assembly line). Indeed, the mass production assembly line became an organizational archetype, the quintessential rigid, technically-constrained bureaucracy.

Thompson's influential work (1967) further identified the link between the assembly line and its operating environment. Thompson described mass production in terms of its long-linked technology, characterized by "serial interdependence, in the sense that act Z can be performed only after successful completion of act Y." He writes that the assembly line:

> approaches instrumental perfection when it produces a single kind of standard product, repetitively and at a constant rate.... The constant rate of production mean that, once adjusted, the proportions of resources involved can be standardized to the point where each contributes to its capacity; none need be underemployed. (p. 16)

Achieving this instrumental perfection requires a closed system of technical logic that controls relevant variables as completely as possible. This in turn requires protection from environmental uncertainties such as fluctuations in volume, shortages of parts, and equipment breakdowns. This protection is provided by buffers such as inventories of materials and supplies on the input end and finished goods at the output end, vertical integration to bring sources of critical supplies within the firm, and a smoothed-out flow of input and output transactions. Furthermore, with buffers to keep uncertainty low, information processing demands in the technical core can be minimized. (Galbraith, 1973)

This literature provides an insightful analysis of mass production, but offers little understanding of the emergence of flexible production in automotive assembly -- a setting that, in terms of both task and technology, would still appear to require the organizational characteristics of mass production. Because it posits a deterministic effect of technology on organizational structure, it neglects the possibility that auto assembly could, in a different organizational context, be conceptualized as a nonroutine task, with ambiguously-defined problems and high information-processing requirements.

This literature also correctly identifies the importance of buffers to mass production, but suggests that these are a technological requirement, thus foreclosing the possibility of other technology/organization combinations. From this perspective, the elimination of buffers would be an example of a bad "fit" that would result in a loss of production efficiency.

Finally, this literature dichotomizes production and innovation tasks, with "mechanistic" organizations for the former and "organic" organizations for the latter. This misses a central feature of flexible production (described below) -- that it integrates innovation and production.

Socio-technical Systems

The most substantial literature addressing the relationship between technical capabilities and human capabilities is that developed by Eric Trist and his colleagues at the Tavistock Institute. (Trist and Bamforth, 1951; Emery, 1959) Their theory of socio-technical theory, or STS, underlies some of the most ambitious and successful examples of "high commitment work systems" in the United States and Europe, especially Scandinavia. (Davis and Cherns, 1975; Emery and Thorsrud, 1976; Goodman, 1979; Trist, 1981). Yet STS, in both theory and application, proves to be of limited usefulness in understanding flexible production.

The Tavistock researchers were students and advocates of the "leaderless groups" (Bion, 1950) and discovered through their coal-mining studies that such groups could function as an innovative and effective alternative to the dominant Taylorist approach to work organization. After a number of field studies in England, they became convinced that there was no inherent technical constraint preventing the deployment of "semi-autonomous work groups" in any context. (Trist, 1981) This emphasis was reinforced through the involvement of STS researchers in the 10-year Industrial Democracy Project in Norway, since work groups were seen as the structure that could most increase participation in the workplace. (Emery and Thorsrud, 1976). The orientation of STS became increasingly anti-hierarchical, emphasizing the ability of the work group to be "self-regulating" -- free from interference from either management or the technical system -- above all else.

At the same time, STS viewed the technical system as an "internal environment" providing a "boundary condition" for the social system. As a result, STS designs tended to focus on modifying the social system to fit its environment, i.e. the technical system, and to neglect the possibilities for changing the technical system itself.[3] (Pasmore, 1988; Mumford, 1983)

These two features of STS theory -- its emphasis on work group autonomy and its predominant focus on changing the social system rather than the technical system --

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[3] The Volvo plants at Kalmar and Uddevala, described in greater detail below, are exceptions, for they have premised their STS designs on eliminating (partially at Kalmar and totally at Uddevala) the assembly line.

account for its limitations in analyzing flexible production. From the STS perspective, work groups are only "semi-autonomous" because they cannot escape certain economic and technical exigencies. (Emery and Thorsrud, 1976) In order to maximize work group autonomy, STS designs add buffers of inventory -- especially work-in-process inventory -- that free each team from dependence on the pace or output quality of the previous group. From this perspective, the attempt to minimize inventories under flexible production imposes an undesirable constraint on the work group. (Klein, 1988; Sjostedt, 1987)

The attempt to buffer groups from one another also impedes intergroup communication and involvement in problem-solving activities. Two STS theorists noted the risks of overemphasizing group autonomy, because a group whose social identity and task identity are closely aligned "is all too likely to become committed to that particular arrangement so that, although efficiency and satisfaction may be greater in the short run, in the long run it is likely to inhibit technical change." (Miller and Rice, 1969) Highly independent work groups tend to resist the lateral interactions and cross-functional problem-solving that are so critical to flexible production -- and, perhaps, group effectiveness in general. (Gladstein, 1985). The addition of buffers to the technical system just accelerates this dynamic of internally cohesive but externally closed groups.

Furthermore, the anti-hierarchy flavor of STS poses what Hackman (1981) calls an "expertise dilemma - the tension between leaving all decision-making about the design and management of the work system to group members vs. telling them what to do or doing it for them". On the one hand, middle managers and supervisors often resist a work system design that is premised on the complete transfer of their responsibilities to the team. On the other hand, some managers respond to autonomous groups by completely abandoning any exercise of authority, with the result being chaos. Hirschorn (1985) describes the tendency for "utopianism" in STS plants -- hopes among managers that work groups will solve difficult personnel and technical problems on their own, and expectations among workers that everyone will be promoted or that their recommendations will always be adopted.

Thus, despite many apparent similarities between STS and flexible production, there are fundamental differences between them. STS is far more valuable for its insights into the "participative management" culture[4] that has been implemented in "high commitment" companies in the U.S., and what I call the "neo-craft" production model in Sweden (discussed below) than as a way to understand flexible production.

Industrial Relations and Economic Performance

This literature is relevant to the understanding of flexible production for two reasons. First, it is concerned with explaining differences in manufacturing performance at the plant level, based on variation in organizational practices. Second, it demonstrates a methodological approach -- measuring a few indicators of industrial relations (e.g. grievances) in isolation from other aspects of the production system -- that I believe is inadequate. I will argue instead that research on production systems should examine configurations or "bundles" of inter-related policies and practices.

One group of studies on the automobile assembly plants carried out by researchers at M.I.T. over the past five years is particularly relevant. Two early studies explored the link between plant-level industrial relations measures (e.g. grievances, turnover, absenteeism), economic performance, and quality-of-work-life (QWL) efforts at plants in one company over several years (Katz, Kochan, and Gobeille, 1983; Katz, Kochan, and Weber, 1985). Both found a strong link between industrial relations indicators and

[4] I also discuss the differences between the "participative management" and "flexible production" culture in Chapter 8.

economic performance, but only limited evidence that QWL efforts affected either performance or labor-management relations. This latter finding, it was argued, indicated the degree to which these QWL efforts were isolated from the production system, with little effect on work organization, process improvement, or skill development.

A more recent study (Katz, Kochan, and Keefe, 1988), carried out within the same company as the two earlier studies, expands the analysis to include such variables as the existence of work teams, the presence of certain work rules, the number of job classifications, and work group participation in decision-making. This study found that those work practices which reduce relief and idle time and decrease contractual regulation over the allocation of overtime, layoffs, and job transfers had a strong positive association with economic performance (fewer labor hours, fewer supervisors per production worker, and higher quality scores). Measures of work participation were also positively associated with performance, albeit weakly.

However, the number of job classifications had virtually no independent effect on economic performance and the use of work teams was negatively associated with performance, when controlling for the effects of the variables noted above. This finding runs counter to the earlier studies that would have expected these changes in work organization (that typically did not result from QWL efforts) to lead to better economic performance. It is also surprising in light of the prevailing views of the advantages of teams for motivation and skill development, views which had prompted serious efforts by management and the union to diffuse team systems throughout the company.

There are several possible interpretations of these most recent findings. At the company where these three studies were carried out, the effort to introduce work teams came at a time when QWL efforts had stalled and were somewhat discredited. Furthermore, teams were often introduced as a quid pro quo from the union for management investments to keep the plant operating. Thus there was considerable variation in what was meant by a "team plant". At some plants, teams were little more than a formal structure for grouping workers, while at other plants, they were part of a broader initiative to increase participation.

Furthermore, the Katz, Kochan, and Keefe study used regression analysis to examine each variable independently. Thus plants that installed teams under duress and made no further changes were treated identically to those that had undertaken more comprehensive organizational changes. The implication is that research of this kind will benefit from considering clusters of interdependent organizational practices. Cutcher-Gershenfeld (1988) conducted such a study at Xerox and found that clustered measures of human resource innovations were positively related to economic performance.

Finally, this finding raises a caveat about relying on measures of organizational structure to explain performance outcomes, when these outcomes may in fact be most closely related to intervening organizational processes, such as the ability to solve production problems effectively. While structural changes such as the adoption of work teams may be intended to foster effective problem-solving, there is no reason to expect that they will always do so. This relationship between structure and process is explored at length in the problem-solving study reported in Chapter 7.

Production Systems and the Political Economy

More useful than the three literatures reviewed above are works that consider production systems from a political economy perspective. This literature generally begins with a broad analysis of economic and social forces that are creating difficulties for mass production. (cf. Chapter 1). It then builds inductively from the observation of certain cases (e.g. corporate restructuring in the U.S.; industrial districts in Italy; the Japanese economy) to a broad characterization of a new economic/organizational paradigm.

Particularly valuable as a reference point for this dissertation is Piore and Sabel's "flexible specialization" model, as described in The Second Industrial Divide and later papers. The authors see flexible specialization, both historically and at present, as a response to market diversification. When demand for niche or customized products is high (either because of pre-existing markets or because the firm has helped create new markets), the firm has an incentive to utilize more generalized resources -- both workers and equipment -- that can efficiently switch among products.

While this approach to production organization has always been peripheral in an economy dominated by mass production, Piore and Sabel see new microprocessor-based, programmable automation speeding the diffusion of flexible specialization, because these powerful general-purpose tools can shorten set-up times and reduce economies of scale, thus enhancing the system's variety-generating capability. So Piore and Sabel see flexible specialization as resulting from both a market "pull" and a technology "push", with high product variety as its primary output.

Much of The Second Industrial Divide is devoted to an extensive formulation of the inter-organizational, institutional, and macro-economic context that would support that broad diffusion of "flexible specialization". There is less detail on the internal workings of such a production system, although later work by Piore and Sabel fills in the picture to some extent. They tend to emphasize three things: 1) product over production; 2) technology over organization; and 3) craft-based ideas of work organization and skill development.

Because market-driven product variety is the defining characteristic of flexible specialization, Piore and Sabel emphasize the role of the production system in generating that variety. In a later paper, Piore (1989a) develops a typology of product designs intended to mark points on a continuum between mass production and flexible specialization. The degree of flexibility in the design, in this view, determines the extent of flexibility in the production system. This view neglects the possibility of changes in the process of making things -- production -- irrespective of changes in the product.

Second, because they emphasize the "push" of new, programmable technologies, Piore and Sabel's argument has the flavor of technological determinism. While they emphasize that strategic choice exists at those "divides" when new technologies create new possibilities, it is still technological capabilities that provide the choice -- not changes in production organization that might bring about flexibility in their own right.

Third, Piore and Sabel describe flexible specialization in terms of a return to craft principles, facilitated by the capabilities of programmable automation. In this view, the division of labor broadens to encompass both conception and execution, so that skilled workers can apply their craft expertise to developing new designs and production processes.

Piore and Sabel present a strong case for why craft principles may once again be applicable to current market and technological conditions. But they neglect the possibility that other forms of work organization and skill development may support the requirements of a flexible production system. The model of flexible production I will present below breaks with craft principles in fundamental ways and, accordingly, I will advance a different view of the division of labor than Piore and Sabel.

While Piore and Sabel draw primarily on developments in Europe and the U.S. for their flexible specialization model, Kenney and Florida (1988) focus on Japan. They describe the social organization of production in Japan as a "post-fordist" system that overcomes the institutional rigidities of mass production. "Self-managing teams, just-in-time production complexes, and learning-by-doing have replaced the functional specialization, deskilling, and linear production lines of fordist mass production." (p.145)

Kenney and Florida acknowledge overlap between their description of post-fordist production and Piore and Sabel's flexible specialization; both models "consist of tightly networked groups of institutions that reproduce highly skilled labor, continuously mobilize information, and establish a stable structure within which enterprises mutually adjust to one another." But they argue that flexibility with respect to market and technological conditions, on its own, provides an insufficient basis for an alternative economic/organizational paradigm. Rather, "flexibility must be enmeshed within relatively stable social institutions that bind production and innovation together, giving rise to structured flexibility." (my emphasis)

Kenney and Florida emphasize the cross-functional and strategic aspects of integrating production and innovation utilized by Japanese companies: the multidisciplinary project teams, the overlapping product development process, the tendency to spin off new innovations to separate subsidiaries, and the collaboration among competitors to develop new core technologies. But their point applies, I believe, more generally to the internal workings of flexible production. Furthermore, as I will argue below, the primary significance of integrating production and innovation is not its impact on structural arrangements but that it fundamentally changes the "cultural logic", which in turn affects how production activity of all kinds is perceived and understood.

Thus this literature offers valuable "post-mass production" models that provide reference points for my organizationally-based definition of flexible production. Following this lead, I will present below a more detailed analysis of the differences between flexible production and flexible specialization, and also provide two other production system models -- flexible mass production and neo-craft production -- for comparison purposes. This literature also provides the premise, explored below, that the integration of production and innovation can be seen as a defining characteristic of flexible production.

A Configurational Perspective

The "clustering" approach that this dissertation research requires can be found in the business strategy literature, where it is described as a "configurational" perspective on organizations. Mintzberg (1981) summarizes the argument, "Like all phenomena, from atoms to stars, the characteristics of organizations fall into natural clusters, or configurations... Effective organizations achieve a coherence among their component parts." Miller and Friesen (1980) describe these as "gestalts" -- "integrated, self-perpetuating alignments among a complex of variables" that result from "multivariate interdependencies".

Van de Ven and Drazin (1985) contrast this "systems" approach that identifies patterns of interdependencies with approaches that "treat the anatomy of an organization as being decomposable into elements that can be examined independently." Most statistical techniques, particularly multiple regression and its variants, are dedicated to isolating such independent effects.

This approach can yield misleading conclusions, particularly when addressing the causes of organizational outcomes. Hackman (1986) writes:

> Influences on productivity do not come in separate, easily distinguishable packages. ...Indeed, to try to partial out and assess the causal effects of each piece of a multi-faceted organizational change may lead to the conclusion that nothing is responsible for an observed improvement in productivity. ...If our attempt to understand productivity focuses on single causes, we are unlikely to generate a coherent understanding of the phenomenon. There are simply too many ways to get there from here, and the different routes do not necessarily have the same causes.

Systems theorists call this characteristic of organized activity "equifinality" (Katz and Kahn, 1978). By this principle, a social system can reach the same final state from a variety of initial conditions and by a variety of methods.

The configurational approach argues that any given variable can only be understood through reference to the entire configuration, since its effect is either amplified or attenuated through its interdependencies with other variables in the configuration. Hackman makes this point about productivity, suggesting that we think about it as "an overdetermined phenomenon, the product of multiple non-independent factors whose influence depends in part on the fact that they are redundant."

I have used the configurational approach in this dissertation, with two consequences: 1) At the theoretical level, I identify bundles of interdependent variables linked by what I will call an "organizational logic"; 2) During data analysis, I use various methods -- including a multivariate scale and cluster analysis -- to allow this "bundled" effect to be tested.

C. THE "ORGANIZATIONAL LOGIC" OF MASS AND FLEXIBLE PRODUCTION

In this section, I will draw out the general organizational characteristics of each production system -- the "organizational logic" -- as an "ideal type" that can be used to guide the empirical work that follows. This "logic" is a systemic property that provides a powerful pull towards internal consistency -- towards the configurations I identify as mass and flexible production.[6] I will argue that this logic has two components: a "structural" logic and a "cultural" logic. These components are reviewed in turn.

[6] The degree to which this internal consistency exists is, of course, a matter for empirical investigation.

Structural Logic

I will describe the "structural logic" of mass production and flexible production in terms of four interdependent organizational dimensions: the deployment of resources; the link between core production activity and the market; the structure of authority relations; and the link between conception and execution (see Figure 1).

Mass Production. The core premise of mass production, still best exemplified by Adam Smith's discussion of the pin factory, states that the efficiency of production increases as the division of labor becomes more extensive. More generally, this is a statement about the link between efficiency and the specialization of resources, including both people (trained in specific skills) and machinery (designed especially for particular tasks). As the task of drawing out wire to make pins is separated from the task of putting heads on the pins, efficiencies result because a specialized task takes less time to learn and no time is spent in switching between tasks (and tools).

A corollary of this maxim is that there are limits to specialization. In Smith's words, the division of labor is limited by the extent of the market. Sufficient volumes of a product must be made to keep specialized resources fully utilized, or else the inefficiencies of underutilized resources will outweigh the efficiencies of specialization.

The second dimension encompasses factors that mediate the link between the market and the production system -- product diversity, lot size and organizational buffers. It is axiomatic that, for mass production, the greatest efficiencies result from standardized product designs, since this allows for the most extensive specialization of resources. This requires large and stable markets with predictable demand, and a mass production firm must either find or create such markets to remain efficient. These standardized products must be produced in very large batches, for two reasons. The first is economies of scale -

- the reduction in per unit cost from distributing the high costs of specialized equipment and labor over a large number of units. The second is the setup costs involved for any one production run; the more specialized the resources, the more extensive the time and money needed to reconfigure the production system for another product.

Finally, to insure that these economies can be achieved, the production process must be protected from disruptions (such as sales fluctuations, supply interruptions, equipment breakdowns) by large buffers -- of inventory, of space, of people. These buffers moderate the tight coupling among interdependent steps in a highly specialized production process.

The third dimension deals with the structure of authority. While the division of labor brings efficiencies to production, it also increases the coordination required to reintegrate the many sub-divided tasks into a whole. Those involved in specialized tasks lose the ability to maintain a unified view of the whole process, and thus must be directed by some higher authority that has the knowledge to reintegrate the production process. For mass production, a centralized hierarchy is the organizational form that exerts this reintegrative control. Within such an organization, vertical interactions within each specialized function predominate, with cross-functional coordination occurring only at the top of the hierarchy.

Finally, the specialization of resources applies not only to different stages of the production process but also to the task of coordination. Thus the efficiency of the system is further enhanced not only by establishing separate specialists for different job tasks, such as pin drawing and pin heading, but also by establishing one set of specialists to think about pin heading (how to specify the job, how to automate) and another set of (relatively low-skilled) specialists to do it. Thus the separation of conception from execution is the fourth dimension of mass production.

Flexible Production. The logic of flexible production can be described in precise counterpoint to the mass production model. It involves a fundamentally different perspective on the relationship between the production system and the market, which in turn leads to a different approach to the division of labor and the coordination process.

As noted above, mass production depends on large and stable markets to achieve efficiency through the highly specialized use of resources devoted to long runs of standardized products. A flexible production system results from the premise that there are substantial economic or competitive advantages in being able to respond to more differentiated or fluctuating markets.

The high costs under mass production of coordinating a highly specialized division of labor and changing among product designs provide a barrier to this different market orientation. Centralized hierarchy further inhibits this market strategy through the barriers to information flow across segmented tasks and the costs of insuring compliance that accompany hierarchical authority. Finally, the separation of conception and execution limits product and process innovation through the underutilization of knowledge developed during task execution.

We can characterize a flexible production system, therefore, by inverting the four dimensions of mass production described above. First, more general resources (multiskilled workers, general purpose machines, fewer functional specialists) are used. Second, small buffers and lot sizes support the greater variety of product designs that result from a different orientation to the market. Third, coordination depends on decentralized authority marked by lateral communication in a "network" that spans functional boundaries. Fourth, there is a greater integration of conceptual activity with the execution of production tasks.

Cultural Logic

The above discussion describes the structural logic -- the way in which production activity is organized. But each of these ways of organizing is also characterized by a distinctive way of thinking about, or framing, production activity. (Piore, 1989b) These frames, viewed as cognitions, are obviously held at the individual level. But they will also be manifest at a collective level, in the culture of the production system.

My discussion of "cultural logic" will focus on one aspect of the culture of flexible production that I believe marks its fundamental difference from mass production -- that production activities are understood by organizational members to be integrally bound to innovation.[6] In this section, I offer some analytical distinctions for understanding how this "cultural logic" affects the way of thinking about information processing, the division of labor, and the coordination process under these two production systems. In Chapter 7, I present fieldwork observations that support these distinctions.

I draw the idea that flexible production integrates production and innovation from Kenney and Florida (1988), although many others have also emphasized the critical role of ongoing, incremental innovation in flexible production. (Womack et al, 1990; Cole, 1990a; MacDuffie and Krafcik, 1989a; 1990; Imai, 1986) This integration can be understood as structural, comprising the links between parts of the organization that traditionally handle production and innovation -- for example, the nature of coordination mechanisms between design and manufacturing departments. (Clark, Chew, and Fujimoto, 1987; Dean and Susman, 1989; Adler, 1990).

But I emphasize instead the integration of production and innovation as a way that individuals in the production system think about their daily experience. The culture of a

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[6] Much more can be said (and much more needs to be learned) about the cultural underpinnings of flexible production. I offer some speculative observations in Chapter 8.

flexible production system shapes the interpretation its members give to their role in the organization, their skills and experience, and their interaction with others, so that they view daily production work as not only a destination for externally-developed innovations, but as an actual locus of innovative activity, directed (potentially) towards both the product and the production system itself. In contrast, the culture of mass production orients individuals towards standardization, specialization, continuity, and replicability in a realm that is understood to be quite distinct from innovation.

Differences in "cultural logic" between mass production and flexible production, again portrayed as "ideal types", can be found in the orientation towards three common organizational activities: 1) information processing; 2) the division of labor; and 3) coordination processes.

Information Processing. With respect to information processing, problems (a gap between actual and desired conditions) can be viewed as obstacles or opportunities; correspondingly, information about problems (or solutions) can be guarded or made transparent

Where problems are viewed as discontinuity-causing obstacles, organizations will avoid or protect against problems in the interests of preserving the continuity of organizational routines. Information about problems will be carefully guarded, managed, controlled in the interests of minimizing disruptions to established procedures, hierarchies, structures. Information is "guarded" in the sense that barriers of access and understanding operate to limit the circle of those able to appropriate it.

Conversely, where a problem is viewed as an opportunity, it will be sought out, and the resulting discontinuity valued for its ability to shed light on possible improvements in organizational routines. If this value is to be realized, information about problems must be transparent to all those with knowledge relevant to its solution. (Womack et al., 1990)

"Transparency", therefore, refers not only to the accessibility of information but its comprehensibility to all those who take advantage of that access -- something which requires a common conceptual base and a common language.

In these terms, under mass production, production problems are obstacles because they threaten the standardization and impede the high volume necessary for the maximal specialization of resources. Information is handled in a way that limits the impact of problem disruptions on the broader imperatives of the production system. Flexible production, on the other hand, welcomes problems as sources of insight. With conception and execution activities closely integrated, a discontinuity in execution can be quickly coupled to a conceptual advance. The reliance on generalized rather than specialized resources, in turn, requires information that is broadly available and comprehensible.

Division of Labor. With respect to the division of labor, it can be understood as holistic or fractional in its intent.[7] The term "holism", as defined in Webster's New Collegiate, refers to a theory that nature is best understood in terms of interacting wholes that are more than the mere sum of their parts. The term "fractional", on the other hand, refers to a fragment, a part broken off from the whole.

Here, the terms "holistic" and "fractional" apply to the relationship between a subdivided task and the body of conceptual knowledge that applies to that task. Piore, using Adam Smith's pin factory as an example, argues that the difference between them is captured in the contrast between the pin craftsman and the pin header. The separation of pin-making from other economic activity (e.g. cloth-making or soap-making) represents the holistic division of labor, while the further breaking down of pin-making into pin-heading

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[7] Piore (1989b) makes a similar distinction, drawing on Marx, and using the terms "social" and "detailed" division of labor. The former term is valuable primarily as a way of understanding the division of labor at a more societal level. The latter term does not convey the difference between parts and wholes that I attempt to capture with my terms.

and pin-drawing represents the fractional division of labor.

> The [former] separation contributes to productivity because it isolates an activity with a distinct conceptual core, and by focussing on that core and understanding it better, one will produce better pins, possibly in a more effective way. The isolation of pin-heading yields no such advantages, because pin-heading is not a conceptually distinct operation; it has no meaning independent of pin-making. (1989b, p. 14)

In these terms, mass production is characterized by the fractional division of labor, which creates subtasks that are not conceptually distinct but also allows for increased specialization of resources, and flexible production is characterized by the holistic division of labor, which reintegrates conception and execution to the point where subtasks have conceptual coherence.[8]

Coordination. There must also reside within the production system the knowledge necessary to coordinate the division of labor, so that the output of divided subtasks comes together into a final product. This coordination process can be framed in one of two ways: as primarily oriented towards replication or as primarily oriented towards reformation.[9]

An orientation towards replication reflects a relatively static view of the coordination process. To take a replicative approach to coordination is to bring various subtasks back together according to exactly the same rules used to divide them. This coordination can be accomplished more or less efficiently, but always relies on fixity in the rules specifying the relationship of subtasks.

For example, the use of work standards developed by industrial engineers to insure compliance with process specifications is replicative, not because of the rationalization of

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[8] There is, potentially, more than one "conceptually coherent" way to divide tasks, i.e. more than one possible holistic division of labor. For example, the making of pins to hold together pieces of cloth may require quite different conceptual knowledge from the making of pins to hold together pieces of metal.

[9] Further definition may be in order. To say that something replicates is to say that it duplicates or produces a copy (replica) of itself. It is reproduction without variation. Reformation, on the other hand, implies change into an improved form or condition. To be reformative is to intend such change.

the process but because the standards are intended to be a fixed and lasting reference point. Mass production is primarily oriented towards replicative coordination, since it emphasizes a stable process where the uniform reintegration of subdivided tasks can yield high volumes of a standardized product.[10]

In contrast, an orientation towards reformation reflects a dynamic view of the coordination process. Bringing the subdivided parts of the production process back together is framed as an opportunity to create new knowledge that can lead to product or process improvements. While this reformative orientation can improve efficiency, it is just as likely to enhance quality or lead to design innovation.

Work standards play a different role in such a system. The careful rationalization of process steps serves as a starting point for process change rather than an endpoint, a baseline against which an attempted change can be assessed. Flexible production is primarily oriented towards reformative coordination, since it relies on the novel combination of general resources to generate design diversity and serve niche markets.

Summary. Flexible production, then, is oriented towards the integration of production and innovation activity, because production problems are viewed as opportunities for innovation and information is made transparent to all potential participants in the innovation effort; the division of labor organizes tasks (and the related skill development and task assignment processes) around a coherent conceptual core; and the coordination process involves the ongoing search for opportunities to reform the production system.

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[10] This is not to imply that there is never change in mass production settings, but rather that the orientation of mass production is to avoid such change wherever possible. Abernathy (1978) describes this as the "productivity dilemma" -- that the investment in special-purpose equipment and standardized processes under mass production becomes so great that there is a tremendous cost involved in any change. Chew's work on "confusion" (1985) and Tyre's work on the implementation of new process technologies (1989) both point to the difficulties mass production settings have accommodating change.

In contrast, mass production keeps production and innovation strictly separate, through a emphasis on production continuity that makes problems appear as obstacles, providing an incentive for problem avoidance and the careful guarding of information; through a division of labor that fragments tasks to the point where conceptual coherence is lost; and through a coordination process whose aim is fixity and replication.

D. CONTRASTING PRODUCTION SYSTEM MODELS

As noted in the literature review, many analyses of mass and flexible production use either technology (e.g. contingency theorists) or product market (e.g. Piore and Sabel) as defining characteristics. I instead see these production system types as having different organizational characteristics that cohere into a "logic", and do not assume any necessary correspondence between a particular organizational logic and technology or product market.

In this section, I will contrast my definitions of mass and flexible production with those based on technology or product market. This is particularly necessary for flexible production, which, as an emergent alternative to mass production, is still not well understood. In the process, I will elaborate on the "structural logic" and "cultural logic" distinctions made in the previous sections.

First, I contrast the "ideal type" of mass production with its actual operation as a production system for most of this century -- what I will call "traditional mass production". Second, I contrast flexible production with production systems that implement programmable, flexible automation without otherwise moving away from the "mass" organizational logic, which I characterize as "flexible mass production". Third, I elaborate on the differences between flexible production and Piore and Sabel's flexible specialization.

Fourth, I examine Scandinavian experiments with production systems, based on socio-technical theory, which I characterize as "neo-craft", and contrast with flexible production.

Traditional Mass Production

The logic of mass production implies that it will be most efficient to make a single, standardized product, thus allowing for the maximum specialization of resources. This model has never precisely fit actual practice -- with the possible exception of the early days of Ford's Model T production. Instead, the common practice of traditional mass production reflects an early innovation of General Motors under Alfred Sloan: making products that were essentially the same in design, yet varied in some exterior styling details and could be marketed under a different nameplate. Sloan called this approach "flexible mass production" -- a term I will reserve for a different (albeit consistent) usage. I use the label "traditional" since, for all intents and purposes, this is the way mass production has been organized in this century. Piore (1989) calls this "mass production with cosmetic variation". The design features that vary in such a production system (e.g. fenders, trim, upholstery, optional equipment such as air conditioners, whitewall tires, power locks) are independent of the core design of the body, chassis, and drive train of the vehicle. While this cosmetic variation has important implications for such logistical matters as materials flow, it has essentially no impact on the basic organizational and cognitive aspects of mass production. Thus any use of the term "mass production" in the empirical work that follows should be understood to refer to this "traditional" production system that makes a few products rather than the pure, single product model.

Flexible Mass Production

I define "flexible mass production" as the use of flexible, programmable technology within an organizational context still based on mass production principles. As noted above, Alfred Sloan first used this term to describe GM's ability to accommodate annual model changes through cosmetic variation to core designs. My usage is consistent, in that the term is used to characterize a marginal increase in flexibility within an otherwise unchanged production system.

At a time when microprocessor-based manufacturing and information technologies are diffusing widely, many technology-focused managers and researchers are quick to label any production system that uses this programmable automation as a "flexible manufacturing system." Programmable automation does, of course, have the potential to increase production flexibility, by reducing the specialization (and hence the rigidity) of the tool stock, and providing the ability to produce several distinct designs on the same equipment, with minimal set-up time. (Gerwin, 1986; Suarez, 1990)

But in the engineering and operations research literature on flexible automation, there is often a rather limited vision of how this flexibility can be used. What is often emphasized is the ability to change quickly among a small number of designs, or the efficiency with which a sequence of design changes can be replicated, rather than the potential for more fundamental changes in manufacturing processes or design-to-manufacturing coordination.

Furthermore, this literature does not link technological flexibility with any change in "organizational logic". Indeed many sociologists of technology (Braverman, Noble, Edwards, Shaiken) have found ample evidence, both in technocentric literature and in practice, that programmable automation can (and often does) reinforce mass production organizational principles, leading to a more fractional division of labor (for any jobs not eliminated outright by automation), more separation of conception from execution, and more technical control of the workforce. At best, the most organizationally sophisticated accounts of flexible manufacturing systems (FMS) imply that flexible organizational capabilities will result deterministically from the implementation of the technology.

But recent studies suggest the reverse causation -- that organizational context tends to determine how new technologies are utilized. (Attewell and Rule, 1984; Zuboff, 1988; Adler, 1988; Henderson and Venkatramen, 1990; Scott Morton, 1990; Kochan et al., 1990; Walton, 1990) One particularly relevant study, by Jaikumar (1986), provides evidence of the consequences of combining flexible automation with a mass production organization.

In his cross-national investigation of the use of the manufacturing technology known as Flexible Manufacturing Systems (FMS), comparing similar equipment making similar parts, Jaikumar found that in a U.S. sample of 35 plants, a typical FMS only produces about 10 parts, while in a sample of 60 Japanese plants, a comparable FMS produces 30 parts. Annual volume per part in the U.S. was 1,727 vs. only 288 in Japan. At the U.S. plants, he observes:

> Management treated the FMS as if it were just another set of machines for high-volume, standardized production -- which is precisely what it is not. Captive to old-fashioned Taylorism, these executives separated the establishment of procedures from their execution, replaced skilled machinists with trained operators, and emphasized machine uptime and productivity. In short, they mastered narrow-purpose production on expensive FMS technology designed for flexible usage. (p. 71)

At the Japanese plants, on the other hand, "managers view the challenge of flexible manufacturing as automating a job shop, not simply making a transfer line flexible." This observation captures the difference between the replicative perspective characteristic of mass production with the more reformative approach of flexible production.

What Jaikumar finds in U.S. plants using FMS captures the essential features of flexible mass production: its emphasis on new technology as a source of limited flexibility within an organization that is still fundamentally oriented towards mass production; a primary emphasis on replicative coordination of the complex logistics of manufacturing as the chief application of this flexibility; and a continued emphasis on the fractional division of labor.

Flexible Specialization

Upon first impression, there is little difference between flexible production as I have described it and the "flexible specialization" model of Piore and Sabel, particularly in terms of the above discussion of "organizational logic".

Flexible specialization uses general-purpose resources -- both programmable technology and broadly skilled workers -- to produce high product variety in response to demand from niche markets. The need for rapid change among designs and for the continual development of new designs (and, consequently, new processes) requires that workers take on both conception and execution tasks. This in turn requires an abandonment of centralized hierarchy as an coordinating mechanism and its replacement by lateral, "network" forms of coordination.

In terms of cultural logic, flexible specialization can be said to integrate production and innovation, with an orientation towards problems as opportunities for design or process improvements; a holistic view of the division of labor, in which tasks are defined around conceptually coherent bodies of knowledge; and a reformative view of the coordination process, in which the possibility of innovation or improvement is actively sought.

There are differences, however, that are at once subtle and critical, in five areas:

1) Volume per Product. Piore and Sabel equate flexible specialization with lower production volume, i.e. lower economies of scale, and high product diversity. By comparison, flexible production's reliance on small lot production and minimal buffers is

independant from volume and product diversity. The advantages of these production practices in terms of quality improvement and cost reduction through rapid feedback and the stimulation of problem-solving activities hold whether one or many products are being produced. Thus flexible production is flexible because it can be directed either towards high volume per product or low volume per product; in either case, it produces that volume in small lots.

2) Buffers. Piore and Sabel don't address the issue of buffers, which I describe as a critical differentiator of mass and flexible production. By implication, if flexible specialization marks a return to craft principles, it would still have buffers to guard against bottlenecks and parts shortages and to preserve the autonomy of individual workers. In keeping with a lower scale of production, these buffers would be smaller than mass production. But a production system that maintains buffers proportionate to production volume is quite different from one that seeks to eliminate buffers.

3) Product Variety. By emphasizing product variety, Piore and Sabel draw attention to the production system's role in generating product innovation, with the implication that process innovation will follow suit. They provide no sense of how flexible production might occur in the absence of flexible products. My view of flexible production reverses this causality, seeing process innovation as independent from product variety. In this view, incremental process innovation occurs even when product variety is low, yielding increased quality, efficiency, safety and product innovation within a given product design.

Furthermore, I would argue that the capacity for process innovation may be a necessary (but not sufficient) condition for achieving high product variety. To the degree this is true (and I have no direct evidence), Piore and Sabel's claim that production system flexibility is attained through product innovations that, in turn, yield process innovations, is called into question.

Finally, their focus on product variety suggests a vision of the innovation process centered on new designs (major innovations) rather than the minor process improvements (incremental innovations) that are so key to my view of flexible production.

4) Technological vs. Organizational Flexibility. Because of their emphasis on a technology "push" for flexible specialization, Piore and Sabel do not explore the possibility that flexible organization can exist in lieu of flexible technology. Thus they fail to identify the prospect of "flexible mass production" -- flexible technology with inflexible organization. In addition, they neglect a key element of flexible production, as discussed above: the ways in which any technology, whether programmable or fixed, general-purpose or single-purpose, can be utilized more "flexibly" under a flexible production organization.

5) Adherence to Craft Principles. Piore and Sabel's view of the division of labor under flexible specialization is closely wedded to craft principles.[11] While certainly holistic in orientation, the division of labor under flexible specialization is seen as corresponding to the delineation of individual jobs, i.e. a conceptually coherent set of tasks is assigned to a single individual, who gains mastery (and the potential for innovation) through the integration of conceptual understanding and direct execution.

There are several ways in which this view diverges from mine. It implies that conceptual coherence exists only when jobs are organized around craft expertise -- what Sabel (1989) calls "mastery of the secrets of working with certain materials and processes". But this is too narrow. While all traditional crafts fit within a holistic division of labor, there are many production tasks that could be described as conceptually whole that would not fit with our notions of craft autonomy, complexity, and socialization

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[11] While Piore and Sabel do refer to flexible specialization in craft terms, they do not fully specify all aspects of how such a production system would function. Thus the points that follow are as much in response to the craft production principles implied in The Second Industrial Divide as they are to specific points made by the authors.

processes. In other words, some simple tasks, with no resemblance to a craft as we generally think of it, can be structured to allow a worker to develop a broad conceptual understanding and therefore create the possibility for improvement or innovation.

In addition, Piore and Sabel assume a correspondence between work organization (the actual allocation of tasks) and the way the division of labor is framed. Thus the more holistic the orientation towards the division of labor, the more broadly defined individual jobs will be. Flexible production, in contrast, decouples the development of conceptual knowledge from individual jobs.[12] It utilizes the fractional division of labor in its allocation of subtasks, yet seeks to develop broad conceptual knowledge -- consistent with the holistic orientation -- through training, job rotation, and other multiskilling strategies. Production tasks are therefore not conceptually distinct, as they might be in a craft model, but are carried out by a worker whose process understanding applies to a broader, conceptually distinct entity.

To return to the pin factory example, a worker may still be assigned to the job of pin-drawing at a given point in time, but over time will also learn the jobs of pin-heading and pin-polishing through rotation within and across work teams and thereby develop a conceptual mastery of pin-making overall.[13] Like flexible specialization, the emphasis on incremental problem-solving reflects a reformative orientation towards coordination in the production process, yet the implications for work organization (and thus, potentially, for

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[12] Similarly, flexible production, which combines broad job classifications with narrowly-defined jobs, decouples compensation (linked to classification) and task (which will vary over time). In Japan (but not in Japanese plants in the U.S.), seniority is similarly decoupled from task (i.e. seniority does not govern movement among jobs) while remaining coupled to compensation (i.e. a substantial portion of pay is based on seniority). The result of these policies is that multiskilling through job rotation within and across work teams occurs much more readily that in settings where narrow job classifications and seniority transfer rights exist.

[13] I have discussed this point in another context in contrasting the Japanese and Scandinavian approaches to work teams (MacDuffie and Krafcik, 1989a).

work experience and identity) are quite different.

Finally, Piore and Sabel implicitly locate the source of innovation in flexible specialization within the jobs that result from a broader division of labor. In contrast, the narrow task specifications under flexible production, combined with multiskilling practices to build conceptual knowledge, provide two sources of innovations. First, narrow task specification lends itself more readily to advances in automation than broad, craft-based tasks.[14]

Second, narrow task specification creates many opportunities for innovation in the interstices between tasks, rather than solely within tasks. Interaction among the individuals in these different jobs, each of whom possesses a broader conceptual knowledge about the production system, is critical if these opportunities are to be captured; small group problem-solving activities are particularly appropriate for this between-task innovation.[15] This contrasts with the craft principles underlying flexible specialization, which are primarily concerned with individuals who develop their expertise autonomously and only secondarily with how they interact.

Summary. Despite the apparent overlap between flexible specialization and flexible production, there are in fact considerable differences between these post-mass production models. The two models diverge primarily because they take a different view of the causal links between technological and market factors on the one hand and organizational factors on the other, and because flexible specialization is implicitly based on craft production

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[14] Frederick Taylor recognized this as one of the primary advantages of task specialization, as did Marx, for whom the narrowly-specialized worker is merely a transitory step prior to automation. (Piore, 1989b; Zuboff, 1988)

[15] Abegglen and Stalk, in their book on Japanese corporations (1985), note that Japanese competitive advantage has emerged most strongly in industries where production processes are composed of many decomposable tasks, because of the potential for incremental improvement in each subtask, and much less in such industries as chemicals and oil refining, where the process cannot be so easily broken down into component parts.

principles that flexible production does not follow.

"Neo-craft" Production

The difference between craft production and flexible production is particularly clear when examining one persistent effort to move beyond mass production -- what I call the "neo-craft" efforts of such Swedish companies as Volvo and Saab, inspired by the principles of socio-technical theory. Since Volvo's efforts in particular are often heralded as a move to flexible production, it is important to distinguish these two post-mass production models.

I will use the most advanced of Volvo's experimental plants as the case example of "neo-craft" production -- the new plant at Uddevala that opened in mid-1989. Uddevala does have many of the features associated with flexible production -- general-purpose tools, broadly-skilled workers, decentralized authority, and lateral rather than vertical interaction patterns. (MacDuffie and Krafcik, 1989a)

The plant's most notable feature, however, is that it does away with the assembly line, in favor of six separate workshops in which work teams assemble entire cars at a single work station. Unlike flexible production plants, therefore, this plant breaks from the continuous flow and machine pacing of mass production to return to the craft model of autonomous work stations and stand-alone tools. (Like any modern manufacturing operation, it uses interchangeable parts.)

The lot size in the plant is extremely small (1 vehicle), providing ample opportunity for the feedback so valued under flexible production. However, this is a distinctly low volume production system; capacity is not expected to exceed 10,000 a year (compared with an average of 250,000 vehicles per year for most "volume" mass production plants). There are modest buffers for each workshop, proportionate to the production rate of 4 cars per day, so each team can control their work pace and prevent production bottlenecks -- a craft approach to buffers.

There are vestiges of mass production at Uddevala as well. Most notable is that the plant makes only a single product. While this is a relatively new plant and more products may be added in the future, the previous experimental Volvo plant at Kalmar has made only one product at a time throughout its 17 years of production. Despite the flexibility that general-purpose tools and multiskilled workers should provide, the complicated logistics of material handling that result from the elimination of continuous flow appear to preclude any move to greater product variety. Instead, these general-purpose resources are used to accommodate a wide range of option combinations for Volvo's top-of-the-line product while maintaining high quality -- an advantage, perhaps, over Volvo's conventional mass production plants but hardly a significant move towards flexible (or craft) production levels of product variety.

Furthermore, Volvo remains a highly functionally specialized organization, so that conception is kept largely separated from execution (i.e. engineers still develop and specify work processes) and innovation is kept largely separated from production (i.e. production concerns have relatively little impact on design activities). This is quite clear in the functioning of the work teams, which are highly autonomous in terms of administrative activities (with no supervisors in the plant, teams assign work tasks, schedule overtime, handle absenteeism and discipline, and keep quality and material handling records) but carry out very little independent problem-solving activity related to either product or process.

The neo-craft model, based on this Volvo example, is based on socio-technical theory, which emphasizes the centrality of autonomous work groups as the building block for less hierarchical, non-Tayloristic organizations. From this perspective, the neo-craft model represents an effort to regain, for the autonomous work team, the autonomy of the craftsman and the chance for identification with a "whole product", by moving away from centralized authority and the technical interdependence of the assembly line.

Both the craft and neo-craft models view the integration of conception and execution narrowly; for the former, this occurs within the job of an individual craftsman, while for the latter, it occurs within the responsibilities of the team. By comparison, flexible production attempts to develop conceptual knowledge at the level of the entire production system. Because the combination of continuous flow, small lot production, and minimal buffers raises the degree of interdependence in the system as a whole, this knowledge is essential if production problems are to be solved. But the neo-craft model, in attempting to break away from the undesirable interdependencies of mass production, eschews this systemic perspective in favor of self-contained autonomy.

Finally, unless it can eliminate the functional specialization that divides conception from execution and design from manufacturing, Volvo's neo-craft experiment faces continued constraints in terms of product variety (like mass production) and product/process innovation (like both craft and mass production). Furthermore, there are likely to be substantial efficiency costs from the abandonment of production flow as a central coordination mechanism. While Uddevala is likely to have very good quality, high production costs might force Volvo to increase the prices of products built there -- potentially beyond what the market will bear, given the increasing number of lower-priced Japanese products in the same product niche.

Summary: A Working Definition of Flexible Production

Studies of flexible production have tended to emphasize the market "pull" (a demand for high product variety) and technology "push" (from programmable automation) leading to such a system. I have argued above that an organizationally-based definition is needed instead.

I argue that innovations of flexible production have great significance as a break from mass production principles, even where product variety or technology is not greatly changed, and may in fact constitute a necessary (but not sufficient) precondition for the attainment of high product variety or the effective utilization of new technology. Furthermore, flexible production utilizes very different principles of work organization and skill acquisition than craft (and neo-craft) models that emphasize the autonomous individual expert.

Thus the key characteristics of flexible production are the emphasis on the integration of technical and human capabilities, leading to continuous, incremental process innovation (and a reformative orientation to coordination); the elimination of buffers to force problem conditions to the surface, to be used as a source of dynamism and innovation; and a fractional division of labor, combined with a multiskilling strategy to give workers an understanding of broader, conceptually distinct activities (corresponding to the holistic division of labor).

Chapter 3 will consider the issues involved in operationalizing the organizational dimensions of mass and flexible production, and will also describe other variables that potentially affect manufacturing performance and the sample for the International Assembly Plant Study.

CHAPTER 3

METHODOLOGICAL CONSIDERATIONS IN ASSESSING PRODUCTION SYSTEMS

Thus far, I have focused on theoretically differentiating mass production and flexible production. Now I turn to methodological considerations. This chapter will: 1) Outline the research strategy for the dissertation; 2) Describe the International Assembly Plant Study, carried out by John Krafcik and myself, that provides the primary empirical data for this dissertation; and 3) Present a model of the production system that will guide the variables to be measured, the operationalization of these variables, and the data analysis.

A. RESEARCH STRATEGY

I have sought to investigate the differences between mass and flexible production organization in two ways. Through the International Assembly Plant Study, I have gathered data on the structural elements of production organization, corresponding to the "structural logic" of the production system; these data are analyzed in Chapters 4-6. In addition, my fieldwork on daily problem-solving processes in three assembly plants provides data that I will use to draw out differences in "cultural logic" between mass and flexible production; this is described in Chapter 7. This section lays out the research strategy for analyzing the former set of data. Methodological details on the fieldwork can be found in Chapter 7.

Research Questions

Research Questions

The empirical work based on the International Assembly Plant Study will address five research questions:

1. To what extent do the variables measuring structural elements of production organization cluster together empirically around the two "ideal types"?

2. What is the resulting distribution of mass production and flexible production plants in the sample?

3. What is the relationship between production organization and manufacturing performance?

4. To what extent does the "integration hypothesis" -- that high levels of automation within the context of flexible production organization yields the best manufacturing performance -- hold?

5. To what extent do the findings for questions 3 and 4 hold in the presence of various control variables? Do the control variables contribute substantially to manufacturing performance, independent of production organization and technology?

The first three questions will be addressed in Chapter 4. Question 4 is addressed in Chapter 5, and Question 5 is addressed in Chapter 6.

Operationalizing Production Organization

A central dilemma for this research strategy is how to operationalize the conceptually interdependent "bundles" that make up the "organizational logic" of a production system. An example will suffice. One frequently noted structure associated with a flexible production system is the organization of the workforce into teams. Thus it makes sense to have a measurement of the extent of work teams in the survey of assembly plants. But which theoretical dimension does the variable "work teams" reflect?

Teams are, in part, a structure that helps organize the acquisition of multiple skills by the workforce, through job rotation, team meetings and problem-solving activities, etc. As such, they contribute to a move from highly specialized to more general resources in the area of worker skills. At the same time, teams take on many responsibilities that are vested in functional groups in a traditional mass production system and thus contribute to the decentralization of authority. Finally, inasmuch as teams can combine the learning of multiple tasks with the decentralization of some conceptual activity, they contribute to the greater integration of conception and execution.

The same complex interrelationships between an empirically-observable organizational form or practice and the theoretical dimensions exist for nearly all the production organization variables. Thus the goal of cleanly and orthogonally matching measurable variables to the specific theoretical dimensions seems futile, or at least foolish.

I will follow a different strategy instead. I will combine the variables that measure production organization into "clusters" or "bundles" that are both statistically reliable and "make sense" in the assembly plant context (i.e. they are variables that people in assembly plants regard as similar and inter-related). I will then argue that these bundles adequately encompass all of the theoretical dimensions that are part of the organizational logic of a production system. Thus, I will not have a single variable that captures the "use of resources" in different plants, but rather a group of variables that cover "use of resources" as well as all other dimensions (e.g. authority structure, link between conception and execution).

B. THE INTERNATIONAL ASSEMBLY PLANT STUDY

John Krafcik and I have carried out the International Assembly Plant Study under the auspices of the International Motor Vehicle Program (IMVP) at M.I.T. This five-year research project is sponsored by practically every automotive manufacturer in the world (with the exception of Soviet, Eastern Europe, and Chinese producers), as well as some governments and trade unions. The close working relationship between the IMVP and its sponsors has provided the opportunity to gather the extensive data needed for this study.

The assembly plant study has had three stages. In the first stage (Sept. 1986 - May 1987), John Krafcik developed the productivity and quality methodology and collected data on these outcomes from a sample of 13 North American plants. (Krafcik and Womack, 1987) In the second stage (June 1987 - April 1988), John expanded the sample to 38 plants in the U.S., Europe, and Japan, refined the productivity and quality methodology, and developed a short survey to collect data on some independent variables; this was John's M.S. thesis at the Sloan School. (Krafcik, 1988a)

In the third stage (May 1988 to present), I worked with John to develop the current assembly plant survey (see Appendix A), which includes the full set of variables discussed in this dissertation, and to expand the sample to its current size of 90 plants. The broad goal of the study throughout these three stages has been to identify performance differences among a worldwide sample of assembly plants, and test a variety of possible explanations for these differences.

The sampling strategy was opportunistic. Plants were added to the sample as companies showed a willingness to participate in the survey. But a balanced mix of companies and countries and product classes was the goal at all times, and specific companies were approached at certain times with this in mind.

Each plant received a plant visit from either John Krafcik or myself, as well as the survey form; John visited practically every plant, while I visited 16 plants, and spent a week or more at 4 of them. Both John and I were in frequent contact with all participating plants by telephone and fax to insure that the data were as complete and accurate as possible. We guaranteed confidentiality to the plants, promising not to identify either company or plant name.

In return for their participation, plants received a report from us showing their score for over 100 variables in comparison with average scores for different regions. We often provided a briefing on the study during plant visits as well. Finally, intermediate results for the study were presented at IMVP conferences to industry representatives and academics -- by John Krafcik in Canada and Italy, and by both of us in Mexico and Japan.

The 90 plants in the sample represent 24 producers in 16 countries. To date, we have relatively complete responses from 70 of these plants, for a response rate of 77%.

We have divided the data into certain categories for parts of the data analysis. First, plants fit into either a "volume" or a "luxury/specialist" category, based on the selling price of their product in the U.S. market, with $22,000 marking the dividing line between categories. Three plants whose products fall on the line are included in both categories for analysis purposes. This dissertation only analyzes data from the 62 volume plants[1]; missing data for some key variables reduces the sample for most multivariate analyses to 56 plants.

Second, we divide plants into six regional groupings in order to report performance differences among regions: Japanese plants in Japan; Japanese plants in North America; U.S.-owned plants in North America; all European plants; all Australian plants; and all plants in New Entrant countries (Taiwan, Korea, Brazil, and Mexico). The distribution of the 62 volume plants by region, together with the abbreviation we will use in referring to each region (parent company location/plant location) is in Table 3-1.

We use these regional groupings to maintain the confidentiality of plants and because of the interest in these comparisons expressed by IMVP sponsors. However, all multivariate data analyses below are based on the entire sample, to preserve a sample size large enough for statistical tests; regional effects are tested with dummy variables.

[1] For analysis of the luxury plant data, see Krafcik (1989b).

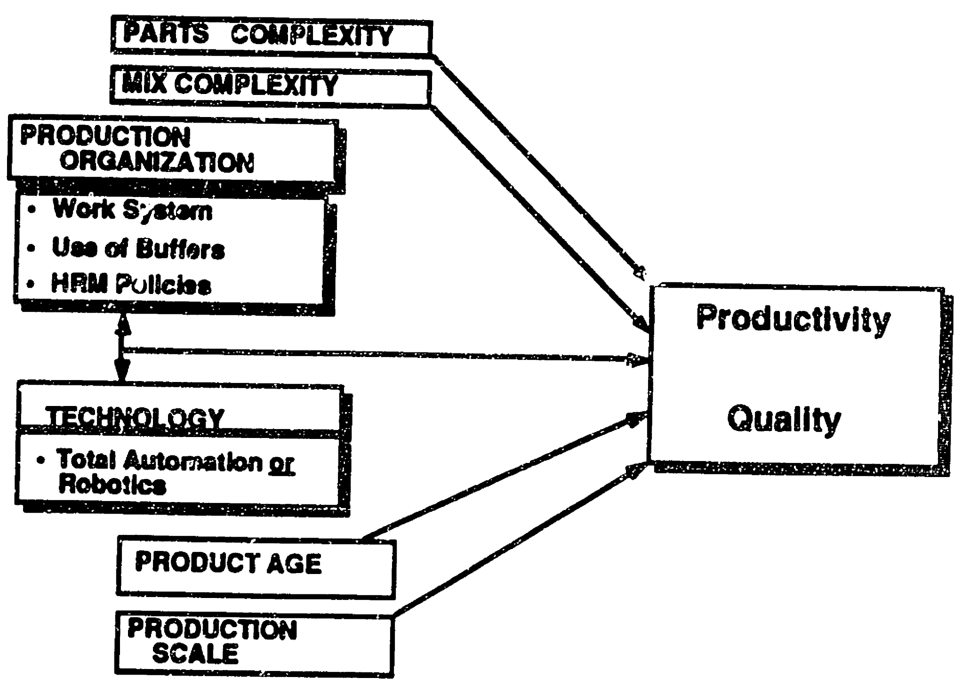
Table 3-1

Regional Distribution of Assembly Plant Sample

Regional Group	N of plants
Japanese-owned plants in Japan (J/J)	8
Japanese-owned plants in N. America (J/NA)	4
U.S.-owned plants in N. America (US/NA)	14
All European plants (All/E)	19
All Australian plants (All/Aust)	6
All New Entrant plants (All/NE) (Korea, Mexico, Brazil, and Taiwan)	11
Total	62

Figure 3-1

General Model of the Production System



C. A MODEL FOR THE MEASUREMENT TASK

The overall model for measurement is portrayed in Figure 3-1. The primary independent variable, actually an index made up of many variables and intended to capture the "organizational logic" of the production system, is labeled "Production Organization". The "Technology" category includes two independent variables whose relationship with manufacturing performance is expected to interact with production organization. The dependent variables, labeled "System Outcomes", include productivity and quality. Other independent variables that potentially affect system outcomes will be treated as control variables. Each of these categories of variables will be described in a separate section.

Virtually all of the variables included in the International Assembly Plant Study were first included by John Krafcik in earlier stages of the work. (Krafcik and Womack, 1987; Krafcik, 1986; 1988a; 1988b; 1989a) When we reached the third stage, which generated the data described here, John and I worked together to improve and expand the measures of all the independent variables. I also expanded the production organization variables considerably, while John refined his methodology for productivity and quality measurement. Feedback from participating plants, IMVP company sponsors, and fellow IMVP researchers also guided our revision and expansion of the survey.

PRODUCTION ORGANIZATION

As discussed above, there is no simple correspondence between the theoretical dimensions that differentiate mass production and flexible production and the empirically-observable features of production organization. Rather, many overlapping features of production organization comprise these dimensions. The measurement model, therefore, will group variables according to empirically-observable features of production organization.

The Production Organization measure is an index made up of three broad "bundles" of variables, here labeled Use of Buffers, Work Systems, and Human Resource Management (HRM) Policies. Each bundle, and the variables it includes, will be described in terms of the rationale for its inclusion, its link to the theoretical dimensions, and the manner in which it was operationalized. (See also Krafcik, 1988a; Krafcik and MacDuffie, 1989; MacDuffie, 1989; MacDuffie and Krafcik, 1990) Details on coding of variables and construction of this index are in Appendix B.

Use of Buffers

The Use of Buffers index measures the degree to which production operations are buffered against various potential disruptions, which affects the speed with which problem conditions emerge and the degree of pressure to resolve them.

Mass production utilizes large buffers to limit disruptions to the high volume production essential to its efficiency. Flexible production minimizes buffers. This assures that problem conditions will emerge quickly. It also raises the likelihood of a costly disruption to production and thus creates an incentive to maintain strong problem-solving capabilities.

There are three variables in this bundle; theoretically, all affect the way the production system organizes its input/output functions and thus mediates its link with the market.

Inventory Buffers. When there are large inventories of parts and a defective part is found, it is easy to draw a new part from inventory and not deal with the defect. But where inventory levels are very low, there is immediate pressure to fix defective parts or to work with the supplier to replace them. If the problem is not dealt with quickly, the production process will have to stop.

In-process Buffers. Buffers of in-process space can have the same effect. When there is a large area for work-in-process inventory, an equipment breakdown in an "upstream" area of the production process won't affect "downstream" processes for some time. When this space is minimized, there is immediate pressure to get the equipment functioning as soon as possible -- and a strong incentive to carry out the preventive maintenance or equipment improvement that will help avoid such crises.

Repair Buffers. The same principle applies to the post-process repair area. When this has a large capacity, quality problems that occur in the production process tend to be passed on to this area for later rectification. When repair capacity is small, the pressure is strong to introduce procedures that achieve "first time through" quality, e.g. worker inspection and statistical process control, attention to supplier quality, etc.

Work Systems

The Work Systems index encompasses those work structures and policies that govern production activity on the shop floor and influence the skill acquisition and development of production workers. There are six variables in this bundle:

Work Teams. A striking structural feature that differentiates flexible from mass production systems is the presence of work teams -- formally designated groups of workers that meet regularly for administrative and problem-solving purposes, rotate jobs and otherwise substitute for each other in production tasks, are overseen by a team leader whose employment status (e.g. nonmanagerial, hourly pay) is the same as that of the group, and form a social unit. Teams (to summarize the discussion above) contribute to a move from highly specialized to more general resources in the area of worker skills; they contribute to the decentralization of authority by taking on many functional responsibilities, such as quality control and industrial engineering; and they contribute to the integration of conception and execution by helping build a broad understanding of the production system.

Problem-Solving Groups. Another group structure that may or may not accompany formal team structures in a flexible production system is a problem-solving group, often identified as an Employee Involvement or Quality Circle group. Unlike work teams, which are ongoing groups whose membership is formally defined (often mandated) and identified with a particular physical location and set of operations, problem-solving groups are often short-term in nature, voluntary, with membership drawn from many different work areas (depending on the problem focus), and with no location-specific ties. In theoretical terms, they contribute in much the same ways as work teams to the despecializing of resources, the decentralization of authority, and the integration of conception and execution, but do so in a way that accentuates and develops inter-group rather than intra-group relationships.

Suggestions Made. Problem-solving activity is manifested in many ways, only a few of which are amenable to survey measurement. Here, the number of production-related suggestions, from either individuals or groups, submitted through a formal suggestion program and for which an administrative record is kept, will be measured. While this does not capture more informal problem-solving activities, it does provide one indication of how extensive the commitment is to continuous improvement through incremental problem-solving as an operating philosophy. As such, it is primarily an indicator of the relationship of conception and execution in the production system; the more suggestions per worker, the more likely it is that workers are developing a conceptual understanding of the production process.

Suggestions Implemented. The degree to which suggestions that are received are actually implemented is an important check on the impact of the formal suggestion system. It reflects the receptiveness of plant management to employee participation in production matters -- a key factor in whether or not the suggestion system actually contributes to ongoing problem-solving and reflects real employee influence. Thus, it provides another way to evaluate the integration of conception and execution.

Job Rotation. Job rotation within and across work areas and departments is an important means of achieving a multiskilled workforce. It may or may not be associated with the use of formal work teams. Theoretically, it contributes primarily to the despecializing of resources and, particularly when it involves considerable inter-group rotation, the integration of conception and execution. Whether or not it contributes to the decentralization of authority depends on the exact nature of the tasks included in a job rotation scheme.

The Decentralization of Quality-Related Tasks. One hallmark of flexible production systems is the priority given to quality (see below). When the quality philosophy emphasizes building in rather than inspecting in quality ("getting it right the first time"), the most visible organizational manifestation is that quality responsibilities are moved out of the domain of staff specialists (quality control inspectors, engineers, production staff) and are integrated into the jobs of production workers. Theoretically, this "vertical integration" of functional responsibilities into production jobs contributes to the despecializing of resources, the decentralization of authority, and the integration of conception and execution. With quality responsibilities, there is also likely to be a direct link to the use of repair area buffers, since effective in-process quality control reduces the need for post-process repair.

Human Resource Management Policies (HRM Policies)

The HRM Policies index encompasses the broad, organization-wide policies that govern the relationship or "psychological contract" between the organization and its employees and thus affect employee commitment and motivation. There are four variables in this bundle:

Recruitment practices and hiring criteria. Under mass production, where jobs are narrowly defined and highly specialized, recruitment and hiring practices tend to emphasize individual expertise and past work experience, as these provide the best clues as to whether an applicant will fit a precisely delimited slot. Under flexible production, recruitment and hiring practices emphasize employee attitudes and general skills -- e.g. a willingness to learn new skills, necessary to support the despecializing of resources; interpersonal skills, necessary when authority is decentralized and lateral (rather than hierarchical) communication flows are dominant; and, at the production worker level, math and reading skills, necessary for problem-solving activities that help to integrate conception and execution.

Contingent Compensation. Compensation policies play an important role in aligning employee rewards with the overall goals of the organization. Under flexible production, compensation is often contingent on performance, so that employees are likely to be more committed to the organization and more motivated to help improve organizational effectiveness.

This effect should be more pronounced the more closely the performance measure relates to actual employee activities, i.e. contingent compensation based on plant-level performance will be a more effective motivator than that based on corporate performance. By giving both managers and workers a common stake in organizational performance, contingent compensation helps to break down hierarchical authority. By giving workers an incentive to participate in problem-solving, it helps integrate conception and execution.

Contingent compensation, as defined in the survey, consists of bonus payments to individuals based on one of several criteria: corporate or plant performance; department or team performance; or individual performance (including "pay-for-knowledge" plans in which hourly pay is boosted as more skills are learned, as well as lump-sum bonuses based on, for example, participation in problem-solving activities). It does not include piecework, where pay is based on the volume of individual output -- a practice currently not found in the assembly plants in our sample.

Status Differentiation. Status barriers between managers and workers and across functional groups are common in mass production organizations, where they reinforce hierarchical and specialization boundaries. In flexible production systems, these status barriers are minimized (e.g. common parking and cafeteria areas for all employees) in order to increase identification with the organization (a sense of a "common fate") and to facilitate communication across group and functional boundaries. This primarily contributes to the decentralization of authority.

Training. There is little employee training in a mass production organization, since the recruitment and hiring process is organized to produce the appropriate match between relatively static task requirements and applicant skills. In contrast, employee training for both new and experienced employees is extensive in a flexible production system. This training contributes to the development of more generalized skills, many of which facilitate the decentralization of authority and the integration of conception and execution.

SYSTEM OUTCOMES

The two system outcomes measured in the model are productivity and product quality.

Productivity

While one advantage of comparing assembly plants around the world is a high degree of commonality in the tasks they perform, many adjustments are necessary to make a true "apples to apples" comparison possible. Krafcik's productivity methodology is reviewed here; full details can be found in Krafcik (1988c).

Productivity is a measure of efficiency, the ratio of inputs to outputs. We look at labor productivity. While it is advantageous to use a broader measure of productivity (Hayes and Clark, 1985) -- e.g. Total Factor Productivity, that encompasses the full range of inputs to the production process (capital, labor, materials, energy) -- it can be very difficult to get these data and to insure their comparability across countries. Labor productivity is both easier to measure and the most relevant productivity measure for a study that examines how human and technical capabilities are organized.

Furthermore, recent studies of company-level productivity differences in the automotive industry, comparing U.S. and Japanese companies using annual report data, have found tremendous variation in labor productivity but nearly equivalent levels of capital productivity.[2] (Cusamano, 1985; Lieberman et al., 1989) This suggests there is greater potential for finding significant results, and greater value, in investigating labor productivity rather than capital productivity.

We define labor productivity as the hours of actual working effort required to build a vehicle at a given assembly plant, with adjustments for vertical integration and product differences. Focusing on effort rather than cost has two significant advantages. First, there is no need to worry about the impact of exchange rates, wage differentials, or

[2] These studies use conventional measures of capital stock that include all plant and equipment expenditures in depreciated, inflation-adjusted dollars. The International Assembly Plant Study examines capital inputs with measures of assembly plant technology (described below), the subset of "plant and equipment" that is most relevant to understanding assembly plant performance. See Chapter 6 for further discussion.

differences in national employment policies that might influence a labor cost comparison.

Second, when only actual effort is considered, the costs associated with absenteeism buffers, i.e. keeping enough people on the payroll to cover for absent employees, can be set aside. This is an advantage since absenteeism may well be influenced by the type and availability of social benefits covering various absences, and because working hours will vary based on union contract and national norms.

Therefore, the methodology adjusts total labor input by the amount of overall absenteeism and adjusts to a standard amount of daily relief time for employees. By not penalizing a plant located in a high absenteeism country (and not rewarding a plant in a low absenteeism country), the impact of these cultural and societal factors is minimized.

One adjustment of critical importance relates to vertical integration. Since there are different levels of vertical integration at plants, the productivity methodology considers only a set of "standard activities" that are common to virtually every plant in the world. Some plants make their own body stampings, while many more receive stampings from a supplier plant; therefore, stamping is not included as a Standard Activity. The questionnaire, in Appendix A, lists the Standard Activities (p. 2).

Adjustments for product differences include size, option content, and product manufacturability. Since a large vehicle will presumably require more effort to assemble than will a small vehicle (and many options more effort than few options), adjustments are made to a standard vehicle size and option content.

The design of a product can certainly affect how efficiently it can be built. The methodology does adjust for the manufacturability of the design in the welding and paint departments but not in the assembly department, where no adequate measure has been found (although the age of the product design, as described below, may be a proxy).

Other factors not adjusted for in the productivity methodology include the level of automation, the scale of production, and the complexity of the product mix. These will all be measured separately, as independent variables.

Quality

Product quality is a manufacturing measure that has become increasingly important to consumers. As such, we use a measure based on customer perceptions rather than internal company measures. The quality measure (defects per 100 vehicles) is drawn from a 1989 survey of new car buyers in the U.S. carried out by J.D. Power a market research firm that is also a sponsor of the International Motor Vehicle Program. The written survey, conducted four to six months after the new car purchase, contains an exhaustive list of possible problems for consumers to check. One advantage of this survey is that it tracks quality back to the specific plant where a vehicle was built, rather than aggregating data at the product nameplate or company level.

Krafcik's methodology adjusts these data to develop a more specific measure that only includes those defects that an assembly plant can affect, such as the fit and finish of body panels, paint quality, the integrity of electrical connections, and water leaks, while omitting problems with the engine or transmission.

In the case of a plant that does not sell its products in the U.S., we examine the relationship between internal company quality data and J.D. Power figures for plants that do sell in the U.S. to estimate the equivalent Power score.

TECHNOLOGY

Two complementary technology measures, the Robotic Index and Total Automation, capture capital inputs to the production system. (Krafcik, 1989c)

Robotic Index

The Robotic Index is the number of robots (defined as programmable and having three or more axes of movement) in the welding, paint, and assembly areas, adjusted for the scale of the plant. Since robots are often new investment and are by definition flexible automation, this index captures these aspects of a plant's technological intent or strategy. However, it misses the often substantial investments plants make in fixed or "hard" automation and thus only partially reflects how automated a plant is.

Total Automation

The Total Automation measure, in contrast, captures the level of both flexible and fixed automation. Total Automation measures the percentage of direct production steps in the welding, painting, and assembly areas that are automated. As such, it is an indicator of the overall automation stock in the plant, while giving no indication of the age or capabilities of the automation. The data analysis will test both measures of technology.

CONTROL VARIABLES

This group of variables includes Model Mix Complexity, Parts Complexity, Production Scale, and Product Design Age. (Krafcik, 1988c) While all potentially affect manufacturing performance directly, in this dissertation, they will be treated primarily as control variables. The one exception will be Model Mix Complexity, which will be regarded as a control variable with respect to productivity and quality outcomes, but will also be considered as a proxy for Product Variety -- a third outcome of the production system that will only be briefly discussed in this dissertation.

Model Mix Complexity

Model Mix Complexity refers to the mix of different products and product variants that the production system produces. This is not intended to capture every minor variation in products (e.g. all different options available for a given automobile model) but rather the major variants (e.g. number of distinct automobile models and body styles -- two-door, four-door, five-door). This measure also varies depending on the configuration of the production system. For example, a plant with two different assembly lines that builds two different models will have the same product variety score as a plant with one assembly line that builds one model.

Parts Complexity

Unlike Model Mix Complexity (which refers to the number of distinct product designs that are produced) and option content (which refers to cosmetic variations that are independent of the core design), Parts Complexity refers to an intermediate category of variation that affects the sequencing of vehicles, materials flow, the variety of required subassemblies, and the administrative requirements for dealing with suppliers. This index is based on the number of: wire harnesses, exterior paint colors, engine\transmission combinations, the number of assembly area part numbers, the percentage of parts used in the assembly area that can be used in all vehicles built in the plant, and the number of suppliers to the assembly area.

Production Scale

Production Scale is central to the definition of mass production, and all models of flexible production posit a reduction in economies of scale. We would therefore expect this variable to be an important differentiator between mass and flexible production systems.

It is defined as the average number of vehicles built during a standard, non-overtime day. For most plants, this is based on a high level of capacity utilization. If a plant is operating at a low capacity utilization rate due to poor short-term market conditions, this measure will be adjusted to reflect their long-term level of operation.

Product Design Age

Product Design Age is defined as the weighted average number of years since a major model introduction for each of the products currently built at a given plant. This measure is a partial proxy for manufacturability, on the assumption that products designed more recently are more likely to have been conceived with ease of assembly in mind than older products.

CHAPTER 4

PRODUCTION ORGANIZATION AND MANUFACTURING PERFORMANCE

This chapter will present data analyses related to the construction of the Production Organization index for the sample of assembly plants and the relationship of this index (and its components) to manufacturing performance, independent of other explanatory variables. It will also report the results of a cluster analysis that groups plants using the same variables that make up the Production Organization index.

The use of cluster analysis is consistent with the configurational perspective on production systems outlined in Chapter 2. It provides more detail than the ProdOrg index about the internal structure of production organization for groups of homogeneous plants, and lays the groundwork for examining the integration of production organization and technology -- the focus of Chapter 5.

First, I summarize the distribution of manufacturing performance data for the 62 volume assembly plants, for both the sample as a whole and for regional groupings.

A. ASSEMBLY PLANT PERFORMANCE

Sample-wide Performance

The data reveal large differentials in productivity and quality. The best productivity level is found in a plant in Japan, at 13.2 hours per vehicle; the worst productivity level is nearly six times more -- 78.6 hours per vehicle for a New Entrant plant. Mean productivity for the volume sample (n=62) is 33.1 hours per vehicle, with a standard deviation of 12.4 and a moderate positive skew of .975. All plants fall within two standard deviations from the mean, except the New Entrant plant mentioned above, which is a clear outlier (nearly 4 S.D.'s from the mean.) Without this outlier, the mean productivity level is 32.2 hours per vehicle.

For quality, the range of performance is even greater. The best quality level, at 27.6 defects per 100 vehicles, is found at a New Entrant plant, while the worst quality level is more than six times higher -- 168.6 defects, found at a U.S.-owned plant in North America. The mean for quality in the volume sample is 78.4 defects per 100 vehicles, with a standard deviation of 31.2 and a moderate positive skew. For quality, there are two outlier plants -- the plant mentioned above and another plant with 158 defects per 100 vehicles in Australia; both are nearly 3 S.D.'s from the mean. The average quality for the sample without the outliers is 74.2 defects per 100 vehicles.

Regional Performance[1]

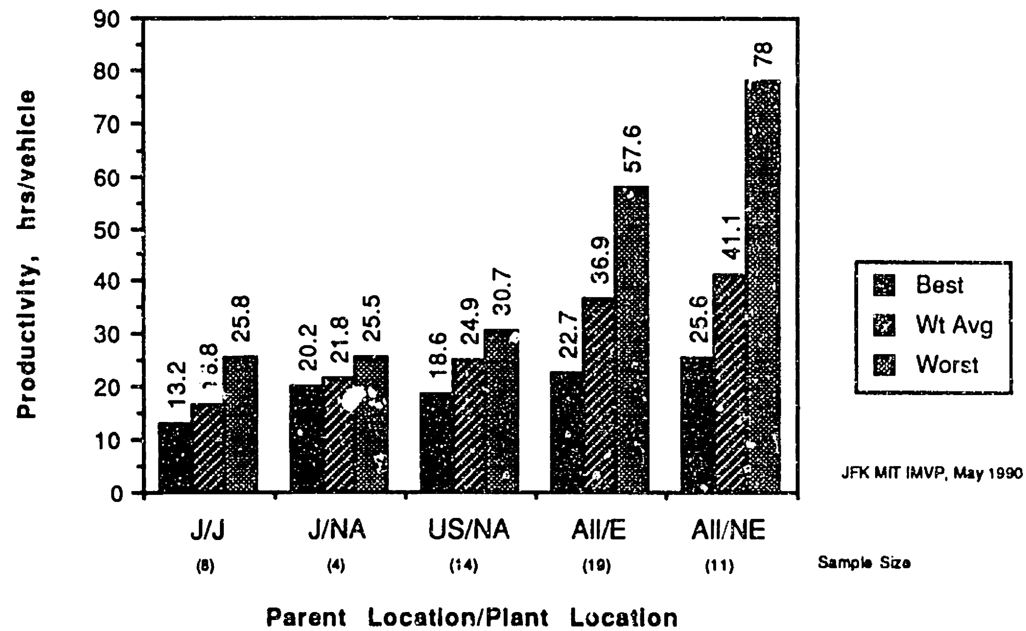
Figure 4-1 shows productivity performance for five regional groupings, identifying best, worst, and weighted average (by plant scale) productivity levels.

There is a wide range of productivity performance across and within regions, replicating earlier results. (Krafcik and Womack, 1987; Krafcik, 1988a; Krafcik and MacDuffie, 1989) Compared to the average plant in Japan, U.S.-owned plants require 48% more effort, and European plants 119% more effort, to complete the same set of manufacturing activities. The Japanese transplants in North America outperform U.S. plants on average, but do not yet match the performance of plants in Japan. But there is overlap in performance results across regions as well, e.g. some American plants are more productive than some Japanese plants. Also, the range of performance among plants in

[1] The analysis and presentation in this section are based on Krafcik and MacDuffie (1989), updated to include plants that have joined the sample since that time. Australian data are not shown here due to graphical constraints, but are used in all other analyses.

Japan (nearly 2 to 1) belies the notion that these plants are all equally productive.

Figure 4-1: Regional Productivity Performance



The range of world-wide quality is shown in Figure 4-2.[2] Here again, there are significant differentials across and within regional categories. While Japanese plants in Japan have the best quality average, the transplants in the U.S. have very nearly equalled their performance. U.S.-owned plants in North America and European plants both have approximately 50% more defects, on average, than Japanese plants in Japan and the U.S.

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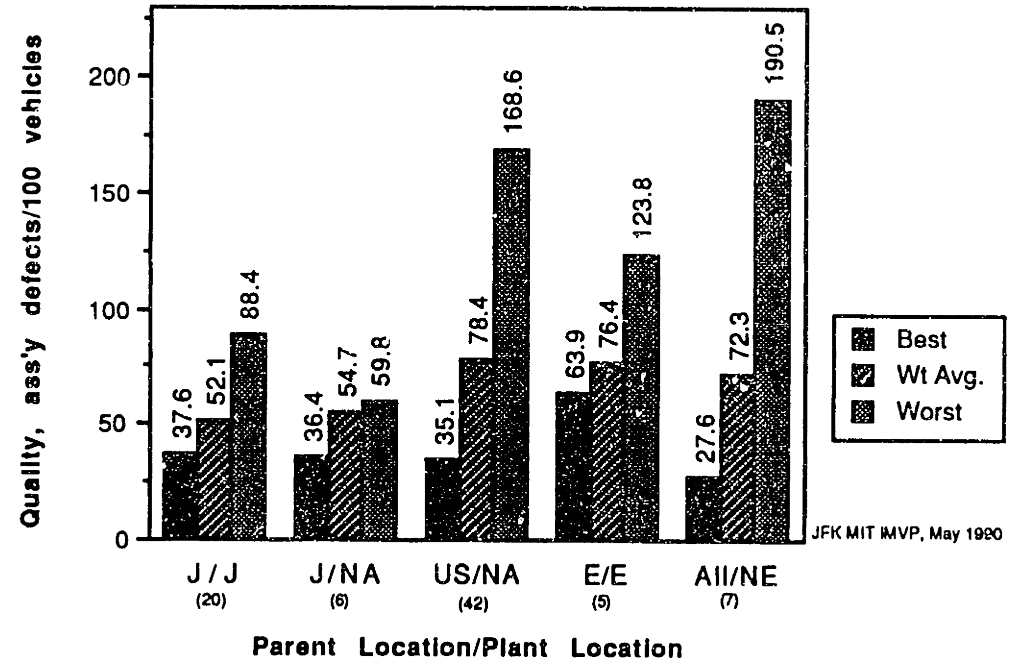
[2] The International Assembly Plant Study (IAPS) sample draws data from the 1989 J.D. Power Initial Quality Survey and, for plants not selling products in the U.S. market, corporate quality records adjusted to produce an equivalent score. We have quality scores for 46 plants in this sample. Figure 4-2 is more comprehensive, presenting the same data for a larger group -- all plants (n=80) that sell products in the U.S. (but with no extrapolated corporate data). Regional averages for the IAPS sample are similar to those in Figure 4-2, with some exceptions: J/J - 47.7 defects/100 vehicles; J/NA - 48.7; US/NA - 91.8; E/E - 77.7; NE - 71.5; and Australia (not shown in Fig. 4-2) - 118.5. Thus the IAPS sample used in the data analyses includes better-than-average Japanese plants and worse-than-average American plants, in terms of quality.

Figure 4-2: Regional Quality Performance

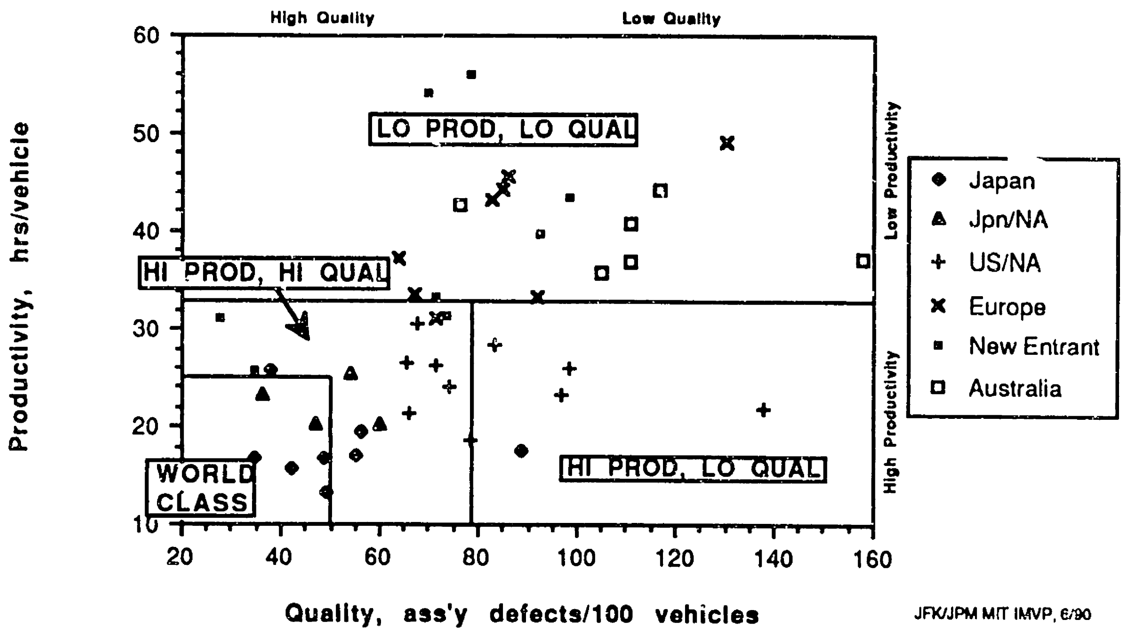


The Link between Quality and Productivity

Although traditional manufacturing doctrine propounds that high levels of quality and high levels of productivity are incompatible, our data show otherwise. We divide the sample into four performance zones (Figure 4-3) and find a surprising number of plants that achieve better than average productivity and quality performance, with an overall correlation between these outcomes of .36 (p=.007). Further, we have identified a small group of "world-class" plants that simultaneously achieve very high levels of productivity and quality.[3]

[3] The high and low productivity and quality zones are divided at the sample average for the 46 plants for which we have both kinds of data -- 33.1 hours per vehicle and 78.4 defects per 100 vehicles. The plants in the Low Productivity - Low Quality zone whose quality level is slightly better than the sample average were judged too few to constitute a separate category and virtually indistinguishable on most variables from those with worse-than-average quality. The "world-class" zone includes plants with productivity better than 25 hours/vehicle and quality better than 50 defects/100 vehicles.

Figure 4-3: Productivity/Quality Performance Zones



Note that the simultaneous achievement of better-than-average quality and productivity is not limited to plants in Japan -- six American plants, one European, and three New Entrant plants join five Japanese-parent plants in this high-performing zone. On the other hand, the world-class performance zone contains only Japanese plants -- four in Japan and two in North America. One striking manifestation of the relationship between productivity and quality is the small number of plants with above-average quality and below-average productivity, or below-average quality and above-average productivity. For the majority of plants in our sample, quality levels and productivity levels are closely linked.

B. THE PRODUCTION ORGANIZATION INDEX

Constructing the Index

The theoretical rationale for choice of variables for the Production Organization (ProdOrg) Index is found in Chapter 3. Here I focus on the statistical relationships among these variables supporting their inclusion in the index.

The organizational variables measured on the assembly plant survey are grouped into three component categories: Use of Buffers, Work Systems, and Human Resource Management Policies. All the variables in these three component groupings are recoded to a scale from 0 to 4 (where 0 is the mass production endpoint and 4 is the flexible production endpoint), thereby effectively standardizing them. Table 4-1 lists the variables (both coded and uncoded) in each category, together with descriptive statistics.

The component indices are formed by adding the variables together, with an equal weight for each variable since there is no clear theoretical basis for unequal weights. Each component index is then standardized by creating a scale from 0 to 100, where 0 is the plant with the lowest index score and 100 is the plant with the highest index score. Finally, the overall ProdOrg index is created by taking the simple average of the three component indices. A high score on the ProdOrg index then indicates the "organizational logic" of a flexible production (FlexProd) system and a low score indicates the same for a mass production (MassProd) system.

Distribution of MassProd and FlexProd Organizational Practices

There is no reason to expect that plants in the sample will be normally distributed along the ProdOrg Index or any of its components. Indeed, as Chapter 2 suggests, the flexible production practices under investigation were developed initially in Japan and have subsequently diffused to other countries, both as Japanese transplants have opened in various regions and as Japanese-influenced manufacturing philosophies about quality control, inventory policies, and continuous improvement have been adopted by U.S. and European firms. This diffusion is still a relatively recent phenomenon, so we can expect that mass production plants will still predominate.

Table 4-1

Production Organization Variables:
Descriptive Statistics

Component	Mean	S.D.
Use of Buffers		
Size of Repair Area (as % of assembly dept. square footage)	2.4	1.1
Inventory Policy (days of parts and frequency of delivery)	2.3	1.0
Size of Paint-Assembly Buffer (as % of one-shift production volume)	2.5	1.3
Work Systems		
Percent of Workforce in Work Teams	1.1	1.6
Percent of Workforce in Employee Involvement Groups	1.6	1.4
Suggestions per Employee	1.4	1.2
Percent of Suggestions Implemented	1.8	1.4
Decentralized Responsibility for Quality	1.5	1.3
Job Rotation	1.8	1.1
Human Resource Management Policies		
Recruitment Selectivity	1.5	1.6
Training for Experienced Employees	1.5	1.2
Contingent Compensation	1.6	1.5
Status Differentiation	1.9	1.5
Statistics for Selected Uncoded Variables		
Size of Repair Area (as % of assembly dept. square footage)	11%	8%
Inventory Level (in days for 8 parts)	2.2	1.5
Size of Paint-Assembly Buffer (as % of one-shift production volume)	34%	30%
Percent of Workforce in Work Teams	18%	30%
Percent of Workforce in Employee Involvement Groups	31%	46%
Suggestions per Employee	9.2	26.1
Percent of Suggestions Implemented	52%	47%
Training of New Production Workers (hours)	170	259
Training of Experienced Production Workers (hours per year)	44	63

All variables are recoded to a scale from 0 to 4, where 0 is the "mass production" and 4 is the "flexible production endpoint.

An examination of the frequencies for the variables making up the Work System and HRM components of the ProdOrg index shows that nearly all of them are slightly positively skewed, meaning that more plants fall on the MassProd side of the mean. The skew is greatest for variables indicating participation in work teams, employee involvement groups, and suggestion programs, and for job rotation, training of experienced employees, and the decentralization of quality responsibilities.

This distribution suggests that these practices are, for the most part, adopted either extensively or not at all. If so, this may be because it is very difficult to achieve a stable transitional state in these areas. Considerable previous research (e.g. Lawler, 1985; Cutcher-Gershenfeld, 1988) finds that workplace reforms (e.g. teams, quality circles, or job rotation), undertaken as a "quick fix" without any accompanying change in business or technology strategy often become stagnant or isolated and are then abandoned.

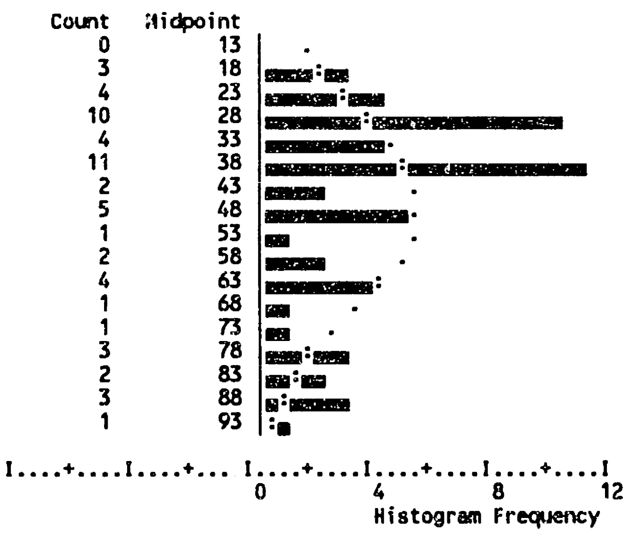
In contrast, variables related to the Use of Buffers component are slightly negatively skewed. This may indicate that the idea of buffer reduction as a way to reduce waste and improve quality is diffusing more readily than the work organization changes discussed above.

When these three groups of variables are combined into the three component indices, the Work System component is most strongly positively skewed; 74% of plants have scores below 50, the midpoint of the scale. For the HRM component, 61% have scores below 50, while for the Use of Buffers component, which is slightly negatively skewed, only 40% have scores below 50. When the components are combined into the overall ProdOrg index, there is also a positive skew, with 68% having scores below 50. On the basis of this index, therefore, we can characterize about two-thirds of the plants as "mass production" and one-third as "flexible production".

This rough categorization is not meant to suggest a strictly bipolar distribution between these two types. Some plants clearly fall into a "transitional" category. As the histogram in Figure 4 (with an imposed normal distribution curve) shows, there are higher-than-normal concentrations of plants not only at the high and low ends of the distribution, but also at some points closer to the middle (e.g. scores between 35 and 39 and 43 and 47). There are at least a few plants scattered continuously throughout the distribution, with the exception that there are no plants with scores below 16 or above 91.

Figure 4-4

Histogram for Production Organization Index



Valid Cases 56

Below, when using these same variables in a cluster analysis, the resulting 2-cluster solution corresponds to the broad divide described above -- two-thirds MassProd and one-third FlexProd. But the 4-cluster solution, which allows a finer-grained analysis, does identify plants in a transitional phase, between the two polar types.

To make the ProdOrg index score more comprehensible, Table 4-2 shows the relationship between a plant's ProdOrg score and its scores on specific variables. It focuses on four pairs of plants across the ProdOrg distribution, where each pair has similar scores; there is a pair of plants close to both the MassProd and FlexProd endpoints and two pairs of plants with intermediate scores.

The trends for these variables are clear as one moves from the MassProd scores to the FlexProd scores, with more use of teams and problem-solving groups, more suggestions per employee and higher implementation rates, more job rotation, less status differentiation, more training, and small buffers. But examination of the individual plants does show some variation in the policies and practices underlying a given ProdOrg score.

This supports the value of the configurational perspective over one that focuses on individual variables, for two reasons. First, isolated FlexProd practices in predominantly MassProd plants (such as the high amount of training at the New Entrant and European plants with the lowest ProdOrg scores in the sample) could be misleading if chosen as the sole indicator of production organization. Second, different plants may manifest the organizational characteristics of mass or flexible production in different ways, involving different combinations of policies and practices. Thus this approach, designed to encompass those differences, is less structurally determinist than one that only examines individual variables.

Reliability Tests

Reliability tests for the three component indices reveal a significant intercorrelation among the included variables. The Cronbach's standardized alpha score for the Use of Buffers index is .62, for the HRM index is also .62, and for the Work Systems index is .80. Furthermore, the three component indices are highly intercorrelated -- for the Use of Buffers and Work Systems, $r=.55$; for Use of Buffers and HRM Policy, $r=.53$; and for Work Systems and HRM Policy, $r=.51$. This supports the combination of these three components into the ProdOrg index, whose Cronbach's standardized alpha score is .77.

Table 4-2
Individual Plant Scores for Production Organization Variables

Variable Region*	P1 NE	P2 E/E	P3 US/NA	P4 E/E	P5 US/NA	P6 J/NA	P7 J/J	P8 J/J
ProdOrg index (0=MassProd; 100=FlexProd)	16	19	40	40	64	64	89	91
Use of Buffers								
Repair Area as % of Assembly Department	10	25	11	4	7	7	1	3
Size of Buffer between Paint & Assembly as % One-shift Volume	62	145	16	21	14	17	6	8
Inventory Levels (in days, weighted average for 8 parts)	7.6	2.3	3.3	1.9	2.1	2.9	0.1	0.4
Work Systems								
% Employees in Work Teams	0	0	0	0	62	80	90	61
% Employees in Problem-solving Groups	8	0	10	23	100	80	100	86
Suggestions/Employee	0.1	0	0	0.3	0.4	2.4	26.7	55.4
% of Suggestions Implemented	17	0	0	16	15	95	94	96
Job Rotation (0=none;4=high)	0	2	1	2	1	2	4	2
Human Resource Policies								
Status Differentials (how many, from a set of four policies)	2	3	4	3	1	0	2	0
Training of New Production Workers	120	120	70	40	36	260	100	100
Training of Experienced Production Workers	NA	40	40	80	20	48	NA	70

* Regional Codes: J/J - Japanese plants in Japan; J/NA - Japanese plants in N. America; US/NA - U.S. plants in N. America; E/E - European plants in Europe; NE - Plants in New Entrant countries (Brazil, Mexico, Korea, Taiwan).

Correlation with Other Key Variables

Here I examine the relationship between the ProdOrg index (and its component indices) and other independent and dependent variables. Table 4-3 shows the correlation matrix for the ProdOrg index, the two technology measures, the two complexity measures, scale, product design age, and the two performance measures.

Table 4-3

Correlations between ProdOrg Index and Other Key Variables

Variable	Correlation with ProdOrg
Productivity (hours per vehicle)	-.61
Quality (defects per 100 vehicles)	-.63
- -	
Total Automation (% of production steps)	.47
Robotic Index	.44
Product Design Age	-.46
Model Mix Complexity	.06
Parts Complexity	.03
Scale (daily production volume)	.24

ProdOrg is very highly correlated with both performance measures, with a simple correlation of $r=-0.61$ ($n=57$, $p=.000$) with productivity (hours per vehicle) and of $r=-0.63$ ($n=45$, $p=.000$) with quality (defects per 100 vehicles). This indicates that over 36% of the variation in both productivity and quality for this sample of plants can be explained by this organizational measure alone.

ProdOrg is also quite highly correlated with both technology measures and product design. Thus flexible production plants are highly automated (with a high level of robotics) and build products that have relatively new designs -- all of which fits general expectations for such plants.

But flexible production plants do not build a more complex model mix or handle more parts complexity, on the whole, than mass production plants -- contrary to what we commonly think of as "flexibility". This apparent contradiction will be discussed in further detail in Chapter 6. Furthermore, the correlation between ProdOrg and scale is positive but low (r = .24). This suggests that there is no simple correspondence of MassProd plants with high scale and FlexProd plants with low scale, as arguments that link flexible production to lower economies of scale claim.

These relationships change very little when the component indices of ProdOrg are examined. On the whole, the correlations are higher when the full index is used than when individual indices are considered separately -- supporting the idea that these organizational practices are highly interdependent and reinforce each other. Generally, the Work Systems index has a lower correlation with other variables than Use of Buffers and HRM Policies.

Component Analysis for Production Organization and Performance

As a test of the separate effects of the three ProdOrg components on performance, I examined the correlation between the ProdOrg index and the outcome variables, controlling successively for each of the components.

As Table 4-4 shows, the greater the drop in the correlation between ProdOrg and productivity when controlling for one component, the greater the role of that component in accounting for the overall relationship. Thus Use of Buffers contributes most and Work Systems least to the strong relationship between ProdOrg and productivity, while HRM Policy contributes most and Work Systems least to the ProdOrg - quality relationship.

Table 4-4

Component Analysis of Production Organization and Key Outcomes

Correlation of ProdOrg w/:	Productivity	Quality
No controls	-.61	-.63
Controlling for Use of Buffers	-.26	-.40
Controlling for Work Systems	-.46	-.56
Controlling for HRM Policy	-.36	-.23

One interpretation of these findings is that there is no structurally determinant effect of "flexible production" organizational practices on performance. For example, we know from other research that it is quite possible to implement the structural changes that underlie the Work System index -- work teams, Employee Involvement groups, suggestion systems -- without necessarily changing organizational processes. As cited above, Katz et al. (1988) in fact found a slightly negative relationship between work teams and productivity, holding all other factors constant in their sample of automotive plants from a single U.S. company. In that company (as in others), teams had often been forced into place as a quid pro quo for investments in plant technology or the placement of a new model and were never accepted as legitimate by the workforce. The same point can be made about the use of buffers. It may be quite possible to minimize buffers for purely cost reduction purposes (i.e. the elimination of inventory holding costs) without changing the organizational processes that lead to high quality.

In both cases, it may be true that the reduction of buffers or the introduction of new work structures only contributes to manufacturing performance if they improve a plant's capability for ongoing problem-solving, or "continuous improvement", as suggested in Chapter 2. If this is the case, the significant contribution of the HRM index to both productivity and quality suggests that these policies, which help create a "psychological contract" that aligns individual and organizational goals, may be an important precondition to achieving this capability for incremental innovation.

The ProdOrg index and its component indices provide one way of examining bundles of interdependent organizational practices and their effect on manufacturing performance. Next, I will discuss another way of using the variables in the ProdOrg index -- as the basis for grouping plants into clusters that organize their production systems similarly.

C. CLUSTER ANALYSIS OF PRODUCTION ORGANIZATION

Why Cluster Analysis?[4]

If, as I have argued in Chapter 2, production systems consist of bundles of interdependent features and must be analyzed as such, one should be able to distinguish among plants by examining the degree to which such bundles of practices can be found. All mass production plants should evidence a particular bundle of organizational practices;

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[4] One common approach to this analysis would be to use factor analysis to reduce a large number of variables to a few underlying factors. The configurational perspective would suggest that any such factors would not be independent, as orthogonal rotation would require them to be, but correlated. However, oblimin rotation could be used instead, which allows for factor intercorrelation. I did try factor analysis, using various extraction algorithms and oblimin rotation. Strong factors did emerge, but generally each factor combined a variable involving use of buffers with some work system and human resource variables, in ways that were not readily interpretable. Ultimately, I chose not to rely on factor analysis because the high degree of intercorrelation (both conceptually and statistically) among the component variables makes the selection of factors relatively arbitrary, given the large number of variables and the small sample size.

flexible production plants should be characterized by a contrasting bundle. Between these polar types should be some transitional states at which, we might expect, groups of plants with similar practices could also be found. Identifying these groupings of plants is an important step in developing a classification of production systems, which in turn is important for advancing our theories of production systems.

A statistical procedure especially well-suited to this classification task is cluster analysis. Aldenderfer and Blashfield (1984) describe cluster analysis as a method "that starts with a data set containing information about a sample of entities and attempts to reorganize these entities into relatively homogeneous groups." While there is no precise definition of what constitutes a cluster, the ideas of similarity within a group and differentiation from other groups of homogenous entities are central to the concept.

Another definition, from Wallace and Boulton (1969), is also germane to our purposes here; they define a cluster as "a subset of entities which may usefully be treated as equivalent in some discussion." The goal of this dissertation, which is to understand the implications of the emergence and diffusion of a new type of production system, is well-served by a statistical technique that helps identify such groupings.

Methodological Choices

There are several decision points in a cluster analysis. (Everitt, 1980; Aldenderfer and Blashfield, 1984; Norusis, 1988; Ulrich and McKelvey, 1990) First, a method for computing the similarity (or dissimilarity) among cases must be selected. Then, the method through which similar cases will be joined together into clusters must be selected. The proper number of clusters can not entirely be determined statistically and so is affected by the researcher's judgment about their simplicity and interpretability.

Finally, since the choice of clusters is somewhat subjective and since different algorithms can produce different clusters (and will always identify some kind of cluster structure), the identified clusters must be validated, both statistically distinct and conceptually meaningful.

Similarity Measures. The most commonly used similarity measures are based on the distance between cases in some n-dimensional space, where n is the number of variables used to evaluate similarity. Most of these distance measures are true metrics, meaning they satisfy several desirable mathematical properties, including symmetry (the distance between A and B equals the distance between B and A) and ability to distinguish nonidentical cases.

This makes distance measures preferable to the Pearson correlation coefficient, which is not a true metric, since it can report a correlation of 1.0 (identity) for two cases that have an identical shape of variation but different values for the variables in question.

The only disadvantage to distance measures is that they are very sensitive to differences in the range and scaling of variables. Therefore, it is routine in the use of distance measures to standardize data first, most commonly by using a z transformation to achieve a mean of zero and a standard deviation of 1 for all variables. While this is not strictly necessary for the ProdOrg variables, given that all are recoded to the same 0-4 scale, it will be necessary for later analyses where the technology variables will be added to the set of clustering variables. Therefore, all variables used in all cluster analyses below are first standardized.

The most commonly used distance measure is Euclidean distance -- the square root of the sum of squared differences in values between two cases for all clustering variables. I use this measure -- the default in SPSSX; other measures produced similar results.

Clustering Methods. There is an assortment of clustering methods that can be used, but again there are some heuristic guides to selecting a method. The most commonly used approach for continuous data in the social sciences is a group of hierarchical agglomerative clustering methods. (Blashfield and Aldenderfer, 1978) The predominance of these methods is partially revealed by the fact that these are the only clustering methods offered through the general statistical packages SPSSX and SAS.

These methods initially treat each case as a separate cluster. They then search a similarity matrix for all cases and merge the two most similar cases to form a larger cluster. Then at each stage, two more clusters are merged, so that clusters "agglomerate" -- in contrast with "divisive" methods which start with all cases in one giant cluster and then remove dissimilar cases sequentially.

The resulting clusters are hierarchical in the sense that they are nested, and can be graphically represented by a tree diagram. For any particular cluster solution, e.g. four clusters, there is no overlap among clusters; each branch is independent. But when the agglomeration process continues, the three cluster solution is reached by combining two of the previous four clusters together. Thus a solution with more clusters always reveals a more finely differentiated view of the structure defined by a solution with fewer clusters.

Hierarchical agglomerative methods are distinguished by the different rules or sorting strategies they use to form clusters; the most commonly used methods are known as Single Linkage ("nearest neighbor"), Complete Linkage ("farthest neighbor"), Ward's method, and Group Average. For example, with Single Linkage, the first two cases combined are those that have the smallest distance between them. The distance between the new cluster and individual cases is then computed as the minimum distance between an individual case and a case in the cluster. In contrast, Complete Linkage calculates the distance between two clusters as the distance between their two furthest points.

The other two methods strike a middle ground: Ward's method calculates the distance from each case to the cluster mean for all variables and merges clusters to minimize within-cluster distances, and the Group Average method combines clusters so that the average distance between all cases in the resulting cluster is as small as possible.

Each method tends to produce clusters with certain characteristics. The Single Linkage method has the liability of "chaining" clusters; the algorithm makes it more likely that a new case will join an existing cluster rather than starting a new one. The result is often one or two very large clusters and a string of single case clusters. The Complete Linkage method, on the other hand, tends to produce many small clusters by favoring the start of new clusters. Ward's method tends to produce clusters of more nearly equal size but also excels at distinguishing clusters that are relatively close together, while the Group Average method is often favored as a compromise method with no consistent biases.

While at times, the structure of the data may provide a clear preference for one clustering method over another, most statisticians believe that choice of method must ultimately emerge from a process of comparison and validation. Everitt (1980) writes:

> "... no one technique can be judged 'best' in all circumstances. In general, a number of techniques should be used; if all produce very similar solutions, then one would be justified in concluding that this solution is worth further investigation, while widely different solutions might be evidence against any clear-cut cluster structure."

Following such a process (described below), I ultimately chose the Group Average method for these data -- what in SPSSX is called the "average linkage within groups" method.

Number of clusters. There is also widespread agreement among statisticians that the problem of selecting the proper number of clusters remains unresolved. Everitt writes:

> The main difficulties with deriving formal significance tests appear to be the specification of a suitable null hypothesis, the determination of the sampling distribution of the distance measure used, and the development of a flexible test procedure. Perhaps the problem is in fact incapable of any formal solution since there is no universally acceptable definition of the term cluster.

One common heuristic is to examine the "fusion coefficient" at each clustering stage. These values indicate the distance threshold at which two clusters were merged;

small coefficients indicate that fairly similar clusters are being merged, while large coefficients indicate the joining of two dissimilar clusters.

Evaluation of the proper number of clusters can then be based on the size of the increase between two adjacent steps, since it is best to stop agglomerating before very dissimilar clusters are forced to join. Other factors also influence this choice, especially with a small sample, since with many clusters, the number of cases per cluster may be so small as to be impossible to validate and/or interpretively useless. I chose to examine both two and four cluster solutions. The only major discontinuity in the fusion coefficients comes after the two cluster solution is reached. Also, the two cluster solution matches the broad distribution of plants along the MassProd to FlexProd continuum, while the four cluster solution allows for the examination of transitional groups between the MassProd and FlexProd polar types.

Statistical Validation of Clusters

Aldenderfer and Blashfield (1984), Everitt (1980) and Ulrich and McKelvey (1990) all argue that it is the use of validation procedures once a cluster structure is determined that can best settle the issue of whether the choice of clusters is appropriate and useful. Everitt (1980) provides a useful summary of validation steps:

> 1) Trying different clustering methods and different clustering solutions (e.g. different numbers of clusters) to see they produce similar results. If results are very different, there is probably no clear structure in the data.
>
> 2) Attempting to replicate the cluster solution with a subset of the sample and/or a subset of the clustering variables, again to test whether the same structure emerges even when there is less information for classification.
>
> 3) Comparing clusters on variables not used in the clustering analysis but conceptually relevant as differentiating criteria.

Ulrich and McKelvey (1990) argue that the comparison of clustering methods should not merely check for similar results but should provide statistical guidance for selecting a preferred method. In their derivation of a classification of the population of electronics firms in the U.S. and Japan, they use various tests to choose which of two similarity measures (distance and correlation) and which of three clustering methods (single, complete, and Group Average) produce the statistically most distinct clusters of firms.

First, they examine the cophenetic correlation, a measure that tests how well the similarity matrix implicit in the structure of a cluster solution matches the similarity matrix used for clustering. Then they test for significant differences across clusters for the variables used in the clustering process, in three ways: 1) discriminant analysis (checking whether cases are correctly assigned to the chosen clusters); 2) t-tests (seeing what percentage of cluster means differed significantly from sample means); and 3) F-tests (with a one-way ANOVA to compare between-group and within-group variance).

It is, of course, no surprise that the means of variables used for clustering should be significantly different across clusters. This fact alone provides absolutely no validation of clusters, as Aldenderfer and Blashfield (1984) point out:

> Cluster analysis, by definition, will separate entities into clusters that have virtually no overlap along the variables being used to create the clusters. Significance tests for differences among the clusters along these variables should always be positive. Since these tests are positive, regardless of whether clusters exist in the data or not, the performance of these tests is useless at best and misleading at worst.

But Ulrich and McKelvey use these comparisons to show that the Group Average clustering method with a distance measure yields the clusters that are <u>most statistically distinct</u>, i.e. have the largest difference in means of the clustering variables. Using the same tests they did, I also found that the Group Average method produced the most distinct clusters for these data.

Table 4-5

Comparison of Clustering Methods for the 4-cluster solution:
Discriminant Analysis, T-tests, F-tests

	Single Linkage	Complete Linkage	Group Average	Ward's Method
Discriminant Analysis				
Total eigenvalue in discriminant function	1.39	10.63	13.22	10.39
Number of significant functions ($p < .05$)	0	3	3	3
% of cases accurately grouped	---	98.2%	100%	98.2%
T-test				
% of significant differences of each variable across all clusters	---	55.1%	64%	64%
F-Test				
Between group variance (average for variables across all clusters)	1.3	7.2	7.5	7.4
Within group variance	0.97	0.64	0.62	0.63
F-test	1.4	13.5	15.6	13.6

* * * * * * * * * * * * * *

Table 4-6

Comparison of Cluster Methods:
Correlation between Cluster Membership for 4-Cluster Solution

Cluster Method	Correlation w/ Group Average Clusters
Single Linkage	.24
Complete Linkage	.82
Ward's	.92

Table 4-5 summarizes the discriminant analysis, F-test and t-test results for the four clustering methods described above. For the discriminant analysis, the sum of the eigenvalues measures the total between-group variance existing in the clustering variables. Examining the 4-cluster solution, Group Average method has the highest sum, at 13.22, following closely by Complete Linkage and Ward's method at 10.63 and 10.39 respectively, and with Simple Linkage at a very low 1.39.

All methods, save Simple Linkage, identify three statistically significant functions, but Group Average is marginally better at grouping plants in assigned clusters, with an accuracy of 100% compared with 98.2% accuracy (i.e. one misclassified case) for the Complete Linkage and Ward's methods.

For t-tests, I compare means for all possible pairs of clusters for each of the ProdOrg variables, unlike Ulrich and McKelvey, who compare a cluster mean with the mean for all cases outside the cluster because of their much larger number of clusters and variables. Thus there are six comparisons among the four clusters for 13 variables, for a total of 78 t-tests. I then count the number of these tests that are significant (at $p < .05$, using two-tailed tests, since the direction of the relationship is not always predicted). Group Average method and Ward's method both yield 64% significant t-tests, compared with 55% for Complete Linkage. (T-tests could not be computed for the Single Linkage clusters, since three of the four clusters consisted of a single case.)

Finally, I average the between-group and within-group variance for all 13 variables across the 4-cluster solutions for each method. Again, Group Average has marginally the highest between-group variance (at 15.6), the lowest within-group variance (at .62), and the highest F-score (15.6), with Complete Linkage and Ward's Method showing nearly equivalent results. Single Linkage has the only F-score that is not statistically significant at the $p < .05$ level.

These results show that the Group Average method is only slightly preferable to the Complete Linkage and Ward's methods; all three of these are, in turn, much preferable to the Single Linkage method. In this sense, the choice of method here is not so crucial since all methods but Single Linkage identify a similar cluster structure. Table 4-6 shows the correlation between a cluster membership variable for the Group Average method (4-cluster solution) and the same variable for the other three methods. The very high correlation, especially between the Group Average and Ward's methods, is reassuring.

To further validate the Group Average 4-cluster solution, I compared it with the 4-cluster solution resulting from a subset of cases (the random selection of 50% of the cases in the sample), and from a subset of variables (using every other variable, once starting with the first variable in the variable list and once starting with the second variable).

As above, I created a variable identifying the cluster membership for each case; the correlations between cluster membership for these different subsets is in Table 4-7. The high correlations show that the cluster structure is clear and quite stable even with half the classificatory information.

Finally, as a check on whether the continuous ProdOrg index and this cluster analysis are identifying the same basic structure in the data, I correlate Group Average cluster membership for the 2,3,4, and 5 cluster solutions with the index and its components. Table 4-8 shows that there correlations are quite high, especially for the two and four-cluster solutions that will be the focus below. This suggests that there is a convergence of results from these two very different methods of identifying a plant's overall production organization.

Table 4-7

Validation of Group Average 4-Cluster Solution:
Clustering with Subsets of Cases and Variables

Subset	Correlation with Original 4-Clusters
Using 50% of cases (random selection)	.87
Using every other variable (starting with first one)	.82
Using every other variable (starting with second one)	.70

* * * * * * * * * * * * * *

Table 4-8

Validation of Group Average Cluster Solutions:
Correlation with Production Organization Index and its Components

Index	Correlation with Group Average Clusters			
	2-clus	3-clus	4-clus	5-clus
ProdOrg	.87	.79	.85	.69
Use of Buffers	.63	.66	.68	.42
Work System	.82	.53	.67	.86
HRM Policies	.68	.75	.84	.64

Understanding the Clusters - Validating for Usefulness

Having arrived at a cluster solution, we can consider the value of these clusters to our understanding of these data. The questions are twofold: 1) Do the clusters shed light on the internal structure of the clustering variables (the same ones used to create the ProdOrg index)? and 2) Do the clusters also tell us something of importance about other variables not used to form the cluster?

To summarize, the final two and four cluster solutions to be examined here resulted from the use of the 13 ProdOrg variables with a Euclidean distance measure and the Group Average clustering method for 56 assembly plants. The two cluster solution has 41 plants with "mass production" characteristics and 15 plants with "flexible production" characteristics.

The four cluster solution divides the 41 MassProd plants into two groups, one of which emphasizes participation and employee involvement activities (n=17) and the other of which emphasizes careful recruitment, extensive training, job rotation, and uses buffers more sparingly (n=24).

It also divides the 15 FlexProd plants into two groups, one of which (n=7) is made up of Japanese plants in Japan that utilize FlexProd practices most extensively, and the other of which (n=8) includes the Japanese transplants in North America and other plants scattered around the world that follow the human resource policies of flexible production but have (to date) implemented less of the associated work structures and policies about buffers.

The ProdOrg index and its three component indices provide a useful way to examine these clusters for meaningful differences. While we would expect to find that such differences do exist (as mentioned above), both for the individual variables and the indices, here the focus is understanding how the variables relate to each other within each cluster.

Table 4-9

Validation of Group Average Cluster Solutions:
Mean Differences for ProdOrg Indices Across Clusters

Index	C1	C2	C1a	C1b	C2a	C2b
ProdOrg	34.8	74.9	31.4 *	37.2	68.2	82.6
Use of Buffers	47.6	80.0	40.3	52.8	74.6 *	86.1
Work System	24.4	71.4	33.6	17.9	57.4	87.3
HRM Policies	32.4	73.3	20.4	40.8	72.5 +	74.3
n of cases	41	15	17	24	8	7

All mean differences for adjacent clusters (comparing C1 and C2 or comparing C1a, C1b, C2a, C2b) are significant at $p < .05$, unless marked:

* = $p < .10$ or + = not significant

Table 4-9 therefore shows mean differences for the key indices for the two and four cluster solutions. The two-cluster solution is presented in the columns marked 1 and 2, and the four-cluster solution is presented in columns 1A, 1B, 2A, and 2B. (Because the clusters are hierarchical, the three-cluster solution can also be seen by comparing columns 1A and 1B with column 2.) All means are significantly different at the $p = .001$ level, with the exception of the Use of Buffers means between 1A and 1B ($p = .05$) and between 2A and 2B ($p = .10$), the ProdOrg means between 1A and 1B ($p = .10$), and the HRM Policy means between 2A and 2B (n.s.)

This table reveals the striking difference between the major clusters 1 and 2, corresponding to the broad distinction between MassProd and FlexProd plants. The proportion of MassProd to FlexProd plants is, in this grouping, about 75%-25% -- a somewhat higher proportion of MassProd plants than was suggested by the histogram in Table 4-1.

These data suggest that, while clusters 1A and 1B are similar in their ProdOrg index mean score, the internal structure of those organizational practices is quite different. The 1A plants emphasize modest Work System changes -- not teams but limited employee involvement activities (affecting a third of the workforce, on average) and suggestion programs (less than one suggestion per employee per year, on average). These plants also report a more extensive decentralization of quality inspection tasks to production workers than the 1B plants.

In contrast, the 1B plants emphasize "high commitment" human resource policies --selective recruitment, focused on attitudes towards learning new skills; extensive training for new and experienced employees; and reduced status barriers between managers and workers. These plants also report a more extensive use of job rotation than 1A plants - consistent with the "multiskilling" approach. Finally, the 1B plants report having smaller parts inventories and in-process buffers than 1A plants.

The 2A and 2B clusters differ substantially in their mean ProdOrg score, but the component indices show that this difference is accounted for by a much lower mean Work System score and, to a lesser extent, by a more extensive use of buffers for the 2A plants.

Given that the 2A cluster consists of Japanese transplants in North America and other plants in transition to flexible production, this difference is not surprising. These transitional plants are in the midst of establishing Just-in-Time relationships with their suppliers (as well as coping with much greater geographical distance from suppliers than most plants in Japan). Also, the fact that employee involvement groups and other problem-solving activities are less fully implemented for these transitional plants matches

Table 4-10

Validation of Group Average Cluster Solutions:
Mean Differences for Other Key Variables Across Clusters

Variable	C1	C2	C1a	C1b	C2a	C2b
Productivity	35.8	22.3	40.8	32.3 *	26.2	17.9
Quality	89.7	56.3	100.3 +	82.6 *	58.6 +	53.9
Total Auto	22.2%	32.6%	18.5% +	24.7% +	27.3%	38.7%
Robotic Index	1.8	3.4	1.4 +	2.0 +	2.6 +	4.3
Product Age	5.7	2.8	7.2	4.6 +	3.3 +	2.1
Model Mix	29.7 +	35.1	32.4 +	27.7 +	25.2 *	46.4
Parts Complexity	55.6 +	57.3	63.7 *	49.9 +	45.0 *	71.3
Scale	885 +	1055	912 +	865 +	749 *	1403
n of cases	41	15	17	24	8	7

All mean differences for adjacent clusters (comparing C1 and C2 or comparing C1a, C1b, C2a, C2b) are significant at $p < .05$ unless marked:

* = $p < .10$ or + = not significant.

an earlier observation (MacDuffie, 1988) that, for the Japanese transplants, these practices tend to follow a period of extensive training and skill development rather than being part of the initial structure.

Finally, the fact that there is no statistically significant difference in HRM policies between these clusters supports the argument that these policies are readily transferable and are implemented at an early stage of the transition to flexible production to help establish the "psychological contract" that is the foundation for later changes.

Perhaps the more important validation of differences among these clusters comes through comparing the means of variables not used to form them, as mentioned above. Table 4-10 shows means for the two and four cluster solutions for the key dependent and independent variables used in the overall analysis of manufacturing performance.

There are statistically significant ($p < .05$) differences between the two major clusters on three independent variables -- both technology measures and product design age -- and even greater differences ($p < .001$) for both productivity and quality. Differences in model mix complexity, parts complexity, and scale across these two clusters are not statistically significant.

The four-cluster solution reveals that clusters 1B and 2A differ significantly for the two dependent variables (at $p < .10$) but not for any of the independent variables (with the exception of the ProdOrg index and its components, since those were the variables used for clustering.) Clusters 2A and 2B are much more differentiated for these variables, with significant differences in productivity (but not quality), Total Automation (but not Robotics), Model Mix and Parts Complexity, and Scale (but not Product Design Age).

In summary, the plants in cluster 2B, closest to the pure "flexible production" type, are more productive, have more overall automation, handle more of both types of complexity, and produce at higher volumes than the transitional plants in cluster 2A.

Discussion

Clearly, there are significant differences among these clusters, whether the two or four cluster solution is examined. The use of cluster analysis helps identify plants that are highly homogeneous in their organizational strategy, in terms of the production organization variables considered here. The resulting clusters also differ in level of technology and product design age -- all variables important for our later analyses.

Although such differences do not exist for all the independent variables, this does not pose a challenge to the validity of these clusters, since, as seen above, model mix complexity, parts complexity, and scale have a very low correlation with all of the organizational indices. In other words, there is no reason to believe that there is an alternative grouping of plants, using the ProdOrg variables for clustering, that would show significant differences for these three control variables.

Finally, the highly significant productivity and quality differences among these clusters support their value in understanding performance differences -- and also support the strategy of using cluster membership as a key independent variable in the multivariate analyses of Chapter 6.

To make the clusters more comprehensible, Figure 4-5 shows the regional grouping of plants in each cluster. Cluster 1a includes about half of the plants in three regions -- Europe, Australia, and New Entrant -- as well as a few North American plants. Cluster 1b, on the other hand, is dominated by 10 North American plants, and also includes most of the remaining European, Australian, and New Entrant plants. Half of Cluster 2b is made up of Japanese-owned plants in North America and the other half is scattered around the world, while Japanese plants in Japan make up Cluster 2b.

Figure 4-5

Regional Composition of Clusters

Cluster 1A MassProd Partial Participators (n=17)	Cluster 1B MassProd Human Capital (n=24)	Cluster 2A FlexProd Transitional (n=8)	Cluster2B FlexProd Japan (n=7)
3 US/N. America 6 Europe 5 New Entrant 3 Australia	10 US/N. America 7 Europe 5 New Entrant 2 Australia	4 Japan/N. America 1 US/N. America 1 Europe 1 New Entrant 1 Australia	7 Japan/Japan

With these clusters firmly established, we can now extend our interpretation of them. Clusters 1 and 2 roughly correspond to the MassProd and FlexProd types described in Chapter 2. Cluster 1A includes plants that have modified their MassProd organizational practices only slightly, with employee participation efforts involving only a portion of the workforce and very little change in HRM policies or the use of buffers. These plants also have low levels of technology, older product designs, and may have chosen their strategy of partial participation in lieu of opportunities for capital investment or new products. We might call this the MassProd - Partial Participation cluster.

Cluster 1B plants, on the other hand, while still broadly following a MassProd philosophy, emphasize the reduction of buffers and a "human capital" emphasis on recruitment, training, and job rotation over changes in work structure and participation. These plants have higher levels of technology, newer products, and are newer plants overall, where the emphasis has been "new investment", whether in technology or in workforce skills. This cluster, then, could be called the MassProd - Human Capital cluster.

Cluster 2A plants appear to represent a transitional status on the way to the full

FlexProd model. These plants reflect the early establishment of FlexProd HRM policies and the philosophy of minimal buffers but also an intermediate point in the slower process of implementing the group problem-solving activities and full Just-in-Time inventory arrangements with suppliers that the Cluster 2B plants (all in Japan) have established. These clusters can therefore be described, respectively, as the FlexProd - Transitional cluster and the FlexProd - Japan cluster.

In Chapter 5, I will move beyond the focus on production organization to consider the role of technology in the production system, and particularly the integration of technology with production organization. This will provide another opportunity for cluster analysis that will differentiate plants using both of these important constructs. We can then see how much the cluster structure identified above holds when technology differences are introduced.

CHAPTER 5

THE INTEGRATION OF TECHNOLOGY AND PRODUCTION ORGANIZATION

This chapter will present data analyses concerning what will be termed the "integration hypothesis" -- i.e. a hypothesis that manufacturing performance is most strongly linked to an integrated strategy that combines a flexible production system with high levels of automation. This hypothesis will be tested in a full multivariate analysis with various control variables in Chapter 6, but here the inter-relationship of these key factors will be explored in depth.

I will combine analyses of the continuous measures of production organization and technology with a cluster analysis of plants grouped according to these same variables. This will highlight distinctions among production system types outlined in Chapter 2 -- the traditional MassProd plants with low to moderate levels of automation, the Flexible MassProd plants that have high levels of flexible automation but are still managed according to a MassProd "organizational logic", and the plants where flexible automation is integrated with a FlexProd "organizational logic".

A. TECHNOLOGY IN AUTOMOTIVE ASSEMBLY PLANTS

Automotive assembly is a complex manufacturing process that has always involved the combination of both capital-intensive and labor-intensive operations. While the capital-intensivity of auto assembly has increased over the years as new technologies have become available, the fact that most final assembly work is still manual means that assembly plants are still more labor-intensive than many other manufacturing activities.

For example, both engine and transmission plants are now far more thoroughly automated than assembly plants. This makes assembly plants particularly well suited to the study of the organization/technology interface.

The major operations in automotive assembly coincide with plant departmental divisions: the stamping of metal panels from steel blanks; the welding of panels into a finished body; the painting of the metal bodies; and then the assembly of parts from suppliers and sub-assemblies (e.g. instrument panels) into and onto the painted body. Assembly work is, in many plants, further divided into a chassis department where the engine and transmission are fastened to the body, a trim department where interior furnishings (seats, carpets) and accessories (electrical accessories) are installed, and a final assembly area where wheels and tires are put on, gas and oil tanks are filled, and various system tests are conducted.

The assembly plant survey focuses on welding, paint, and assembly automation.

* Stamping automation is not covered. Stamping is not included in the Standard Activities used in calculating productivity, since some plants have stamping equipment on site (most notably the Japanese-owned plants in the U.S. and Japan) and most others receive finished stampings from large centralized facilities.

* Welding is the most capital intensive activity in an assembly plant, with the most advanced plants now having automated 95-100% of welds; often, much of this automation is flexible robotic equipment.

* Painting is in a more transitional state, with the most advanced plants now automating the painting of up to 75% of the car, but with many more plants maintaining a more equal balance between manual and automated procedures. Robotic applications are more limited here than in welding.

* The assembly department, considered in its entirety, still consists of largely manual tasks. Even the most advanced plants rarely have more than 2-3% of assembly tasks automated, and the vast majority of plants have no assembly automation at all. The assembly automation that does exists primarily consists of robotic applications.

Technology Measures

As described in Chapter 3, there are two technology measures. The first, called Total Automation, refers to the percentage of direct production steps that are automated, whether by fixed or flexible technology. This measure is the weighted average of the automation levels in different assembly plant departments and makes no distinction between new and old automation. The second, called the Robotic Index, measures the number of robots used in all departments of a plant, adjusted by plant scale. This measure focuses on the predominant type of flexible automation now in use, and thus reflects the extent to which a plant is following a "high tech" technology strategy.

These measures, despite their differences, provide similar characterizations of the technology levels of a given plant for the sample as a whole, as shown by the high simple correlation between them of $r=0.81$.

Figure 5-1 shows the distribution for both technology measures, together with descriptive statistics. The Total Automation measure has a somewhat bipolar distribution, with a large concentration of plants with above-average automation and a somewhat smaller concentration with below-average automation. Overall, it has a modest negative skew of -.316, as well as a relatively high kurtosis of -1.3. The Robotic Index, on the other hand, has a very heavy concentration of plants with none or very few robots, and another concentration of plants at the very high end of the distribution. The distribution has a statistically significant positive skew of .83. As a result, correlations with other variables will be somewhat distorted.[1]

Table 5-1 lists the means and standard deviations for the two measures by regional grouping. For Total Automation, the past predominance of manual operations in auto

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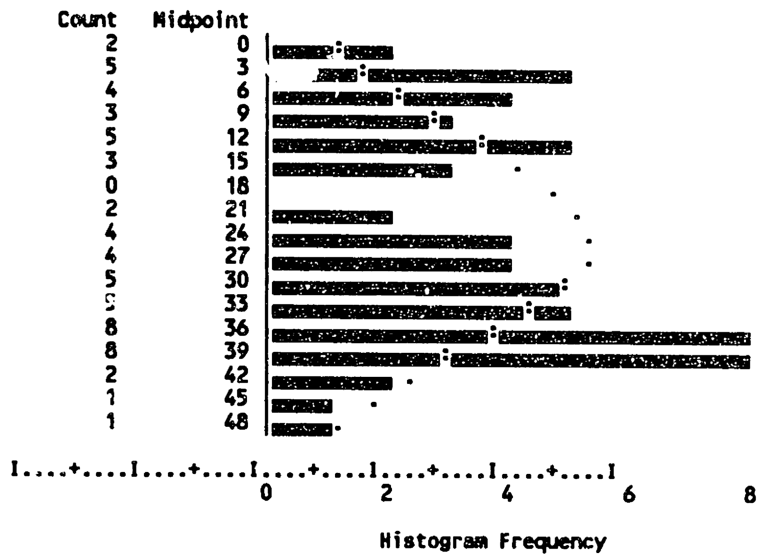
[1] To correct for this skew whenever the Robotic Index is correlated with manufacturing performance and other variables, it is transformed by taking the square root, which reduces the skew to -.042. The transformed variable will be identified accordingly.

Figure 5-1

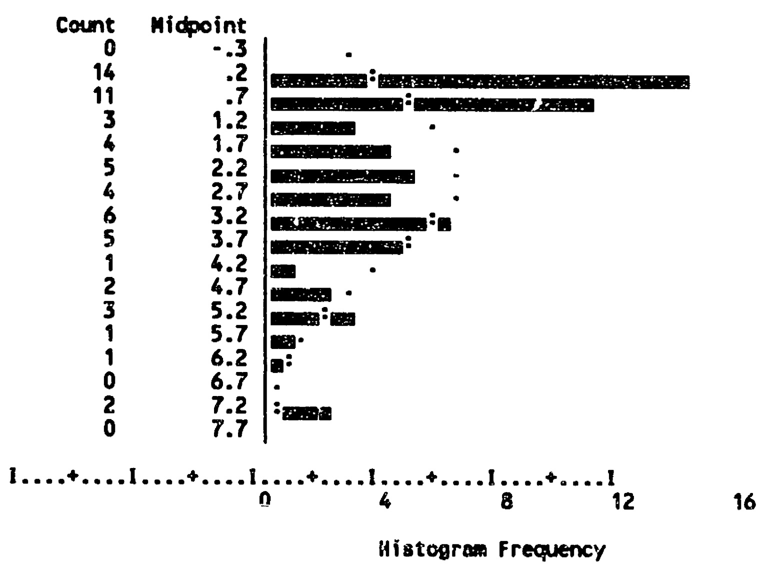
Histogram for Total Automation and Robotic Index

TOTAL AUTOMATION



Valid Cases 62

ROBOTIC INDEX



Valid Cases 62

Table 5-1

Technology Measures by Regional Groupings: Descriptive Statistics

Total Automation (Percent of direct production steps)

Company region/Plant region	Mean	S.D.
Whole sample	24.4%	13.8%
Japan/Japan	38.2	3.3
Japan/North America	35.7	3.5
U.S./North America	30.5	8.9
All/Europe	25.7	12.7
All/Australia	9.9	3.9
All/New Entrants	8.2	8.8

Robotic Index (Number of robots adjusted by plant scale)

Company region/Plant region	Mean	S.D.
Whole sample	2.175	1.93
Japan/Japan	4.38	1.74
Japan/North America	4.58	.92
U.S./North America	2.24	1.51
All/Europe	2.16	1.80
All/Australia	.487	.289
All/New Entrants	.559	.855

assembly is revealed by the fact that some plants (mostly in South and Central America but also in Europe and Australia) have less than 5% of their production steps automated, with one plant having essentially no automation at all.

The most automated assembly plants in the world are in Europe, with 48% as the highest automation level for this sample. But the variation in level of automation is very high in both Europe and the U.S., with heavy investments in technology for newer plants and minimal investments for older plants; for Europe, especially, the standard deviation is nearly half the mean.

Plants in Japan have the highest average automation level, at 38%, followed closely by the average for the Japanese transplants in North America of 36%, and the standard deviation in these regions is quite small. Finally, there is a huge automation gap between the primary auto-producing regions (U.S., Europe, and Japan) and Australia and the New Entrants, with the latter regions averaging only 8-10% total automation -- between one-third and one-fourth as much.

The regional distribution for the Robotic Index shows a wider spread, with an average concentration of robots in Japanese plants (index scores of over 4.3 in both Japan and the U.S.) that is double that of U.S. and European plants (average scores of around 2.2). Here, the standard deviation shows that the variation in level of robotics is about the same for the U.S., Europe, and Japan; there is much less variability for the mostly new Japanese plants in North America. The technology gap for robotics is wider than for total automation, with the average level for Australian and New Entrant plants at only about one-ninth of the level for Japanese plants. Clearly, Japanese companies are relying more heavily on robotics in their technology investments, and thus a higher percentage of their total automation is flexible.

Table 5-2 shows the breakdown of Total Automation by department, with results that reflect the technological trends described above. Automation levels are highest for welding, with Japanese plants the most automated, at around 87% -- a level that is 12% higher than U.S. plants, on average, 26% higher than European plants, and nearly 70% higher than Australia and the New Entrants. This distribution most nearly matches the bipolar distribution of the Total Automation measure for all departments.

The distribution in the paint department is even wider, with Japanese plants in Japan at a level of 55% -- 13% higher than the Japanese transplants in North America, 20% higher than U.S. plants, 23% higher than European plants, 31% higher than Australian plants, and over 40% higher than New Entrant plants. There is a modest positive skew in this distribution, with most plants still below the sample mean of 32% automation.

Finally, assembly plant automation reveals the most extreme variation in the implementation of new technologies. Since this automation has been implemented in so few plants to date, the distribution has a very heavy positive skew (3.9) and a very low sample mean of 1.1%. But some plants have invested very heavily in this technology, such as the two most automated plants (in Europe), which, at 8.2% and 11.6% respectively, are incredible outliers. Aside from these outliers, however, the pattern of regional technology differences is similar.

Figure 5-2 shows a scatterplot for Total Automation by the Robotic Index. Recall that the overall correlation between these two measures is $r=0.81$. But the relationship changes when the sample is divided into two equal groups on the basis of technology ($n=31$ for each group, with this dividing point the same as the median for Total Automation (.28) and the mean for the Robotic Index (2.175)). For the Low Tech group, there is a very strong linear relationship between the two measures ($r=.77$), with nearly all of these plants have virtually no robots. But for the High Tech plants, the correlation is weaker, at r=0.53. Clearly, for this group, we cannot assume that the two measures are interchangeable.

Since these two measures capture different aspects of a plant's technology level (and strategy), it is valuable to have a combined technology measure to examine. I create such a variable, called TechAll, by first dividing the Total Automation and Robotic Index distributions into quartiles. I then sum these quartile scores to get an index that ranges from 2 (first quartile for both variables) to 8 (fourth quartile for both variables).

I then recode the resulting seven TechAll categories into four categories: the first includes plants that have first quartile scores for both measures (i.e. a score of 2), judged to be the appropriate endpoint for the scale; the others all combine two adjoining scores (e.g. 3 and 4) into one category. Mean differences in the separate technology measures across TechAll categories can be found in Table 5-3a, while the regional averages for the combined TechAll measure are in Table 5-3b. The correlation between TechAll and Total Automation is r=0.94, and between TechAll and the Robotic Index is r=0.86 (both n=62).

I will use the TechAll variable, as well the two separate technology measures, in the examination of the link between technology and manufacturing performance that follows.

Technology and Manufacturing Performance

Economics characterizes production systems in terms of a production function, in which output is a function of capital and labor. Specifically, in the Cobb-Douglas production function that is commonly used, output equals the proportion of capital multiplied by the proportion of labor. In such an equation, labor productivity -- output per unit of labor -- is entirely a function of the level of capital, i.e. the level of technology. This

Table 5-2

Automation by Department by Regional Groupings:
Descriptive Statistics

Welding Dept. Automation (Percent of welds automated)

Company region/Plant region	Mean	S.D.
Whole sample	57.2%	34.6%

Japan/Japan	86.5	9.7
Japan/North America	87.5	8.6
U.S./North America	75.1	21.7
All/Europe	60.6	32.4
All/Australia	17.3	6.8
All/New Entrants	17.9	22.6

Paint Dept. Automation (Percent of paint coverage automated)

Company region/Plant region	Mean	S.D.
Whole sample	32.3%	17.5%

Japan/Japan	55.1	13.6
Japan/North America	42.0	13.6
U.S./North America	34.9	12.5
All/Europe	32.3	13.4
All/Australia	23.6	11.6
All/New Entrants	13.6	13.8

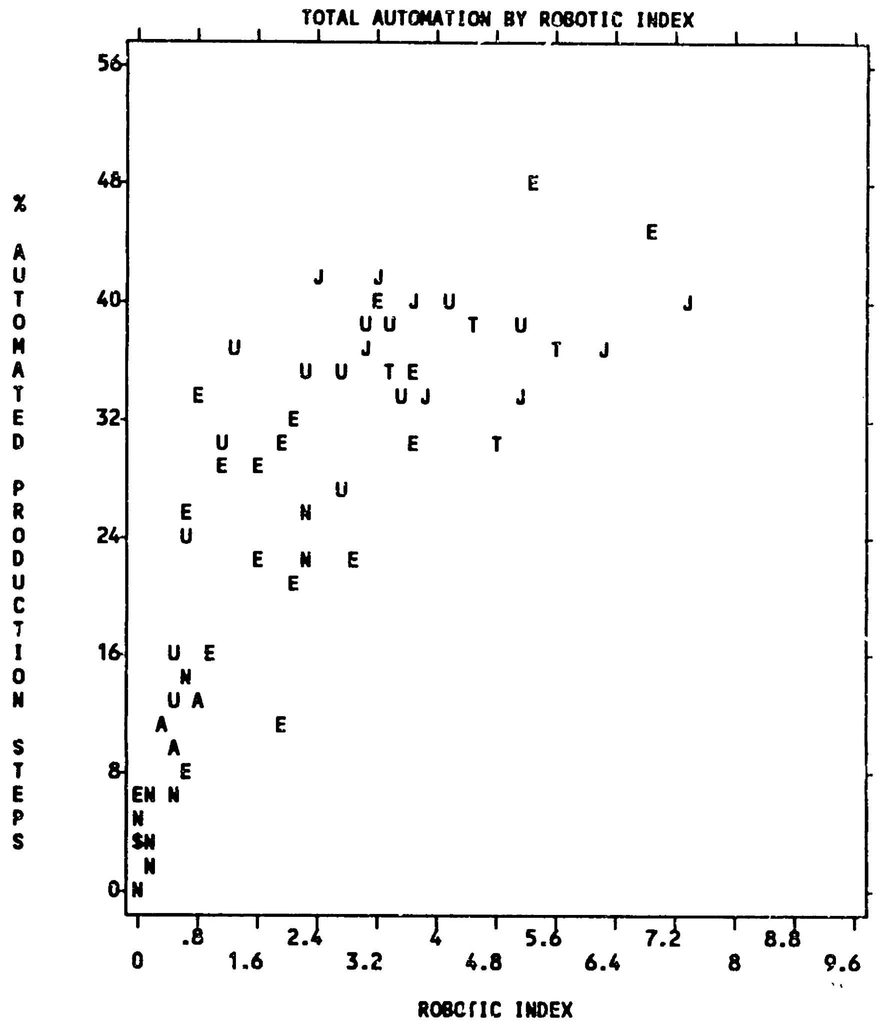
Assembly Dept. Automation (Percent of steps automated)

Company region/Plant region	Mean	S.D.
Whole sample	1.1%	1.9%

Japan/Japan	1.8	0.8
Japan/North America	1.3	0.7
U.S./North America	1.1	1.1
All/Europe	1.5	3.1
All/Australia	0.15	0.2
All/New Entrants	0.13	0.3

Figure 5-2

The Two Technology Measures Are Highly Correlated



62 cases plotted.

J:JAPAN T:TRANS U:US E:EUR N:NEWENT A:AUST
$:Multiple occurrence

Table 5-3a

Combined Technology Variable (TechAll):
Means for Total Automation and Robotic Index

Index	n	TotAuto	Robotic
TechAll = 1 (Low)	12	4.1%	.122
TechAll = 2	14	15.6%	.783
TechAll = 3	15	29.8%	2.03
TechAll = 4 (High)	21	38.0%	4.38

Table 5-3b

Combined Technology Measure (TechAll) by Regional Grouping)

Company region/Plant region	Mean	S.D.
Whole sample	2.73	1.13
Japan/Japan	4.00	.000
Japan/North America	3.75	.500
U.S./North America	3.07	.829
All/Europe	2.79	.976
All/Australia	1.66	.516
All/New Entrants	1.45	.820

proposition is as fundamental to our general understanding of production as the related proposition that there should be increasing economies of scale -- that productivity of all inputs (labor, capital, materials) should increase as the volume of output increases.

There is no such precise statement in economics of the expected relationship between technology and quality. But to the degree that quality is defined as the extent to which product design specifications are met, the greater precision and reliability that new technologies have typically brought to production processes should be positively associated with better quality.

Of course, economists acknowledge that the real world of manufacturing is more complex than a production function implies. Machines run under capacity, because of breakdowns, production bottlenecks, supply shortfalls. The quality of the "human capital" may vary due to the education and training workers receive, affecting their ability to operate complex equipment, to carry out set-ups and routine maintenance, or to remedy operational problems. But in general, economists would predict a very strong relationship between the level of technology and manufacturing performance, in terms of labor productivity or quality.

At first examination, the assembly plant data would seem to support these predictions, at least for productivity. The correlation between Total Automation and productivity is strong and highly statistically significant at $r = -0.68$ ($p = .000$, $n = 62$).[2] The correlation between Total Automation and quality is lower ($r = -.41$, $p = .002$, $n = 46$) but still statistically significant. Given that the Total Automation measure tells us nothing

[2] The sign is negative because productivity is better as labor hours per vehicle are lower. Thus higher levels of technology are strongly correlated with fewer hours per vehicle.

about the age or technological sophistication of equipment, this is impressive.[3]

The Robotic Index, transformed to correct skewness by taking the square root, has a slightly lower correlation with productivity (r= -0.64) and an almost identical correlation with quality (r= -0.42). It is somewhat surprising that this measure, which reflects recent investments in sophisticated, flexible technology, does not have a much stronger correlation with both outcomes, given that the need for productivity and quality gains has been given as the rationale for the vast investments in this technology in the past decade.

The TechAll variable, which combines the two technology measures, has virtually the same correlation with productivity as Total Automation (r= -0.66) and a somewhat higher correlation with quality (r= -0.45) than either separate measure. Combining the measures does not, therefore, reveal any substantially stronger link to performance.

Further evidence of relatively low returns to investments in technology, particularly for productivity, can be seen in correlations for the Low Tech and High Tech groups (each with 31 plants) established above. Table 5-4 shows that the correlation between productivity and technology is much stronger, along all three measures, for the Low Tech group -- for whom low productivity is strongly linked to low levels of technology is strongly linked to poor productivity -- than for the High Tech group -- for whom there is more variability in the link between productivity and the (higher) levels of technology.

The quality situation is more complicated. The correlation for the combined TechAll

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[3] Although it is also the case that the correlation between Total Automation and labor productivity may be somewhat inflated by the way the two measures are derived. Since Total Automation measures the percentage of automated direct production steps, we can expect it to be inherently related to the productivity measure, which includes the labor hours required for all non-automated (i.e. manual) direct production steps. This inherent link is moderated, however, by the fact that the productivity figure includes indirect and salaried as well as direct labor hours. This is particularly important, since many argue (e.g. Womack et al., 1990) that while direct labor hours may decrease with more automation, indirect labor hours often increase because of the greater technical complexity of the equipment per se and of the overall production process.

Table 5-4

Technology and Manufacturing Performance:
Correlations for Low-Tech and High-Tech Groupings

	Productivity (hours/vehicle)	Quality (defects/100 veh.)
All Plants		
Total Automation	-0.68 (.000)	-0.41 (.002)
Robotic Index (Sqrt)	-0.64 (.000)	-0.42 (.002)
TechAll variable	-0.66 (.000)	-0.45 (.001)
n	62	46
LowTech Plants		
Total Automation	-0.58 (.000)	-0.02 (.472)
Robotic Index (Sqrt)	-0.53 (.001)	-0.10 (.331)
TechAll variable	-0.58 (.000)	-0.13 (.287)
n	31	22
HighTech Plants		
Total Automation	-0.31 (.047)	-0.15 (.238)
Robotic Index (Sqrt)	-0.25 (.089)	-0.10 (.314)
TechAll variable	-0.19 (.159)	-0.11 (.306)
n	31	24

variable is virtually the same (and low, at around r= -0.12) for both the Low Tech and High Tech groups. The Robotic Index shows a similar pattern, while the Total Automation measure shows virtually no correlation for the Low Tech group and a modest correlation for the High Tech group. For all three measures, these split-sample correlations with quality are much lower than those for the whole sample. There is clearly tremendous variability in the quality - technology relationship across plants, regardless of the overall level of technology.

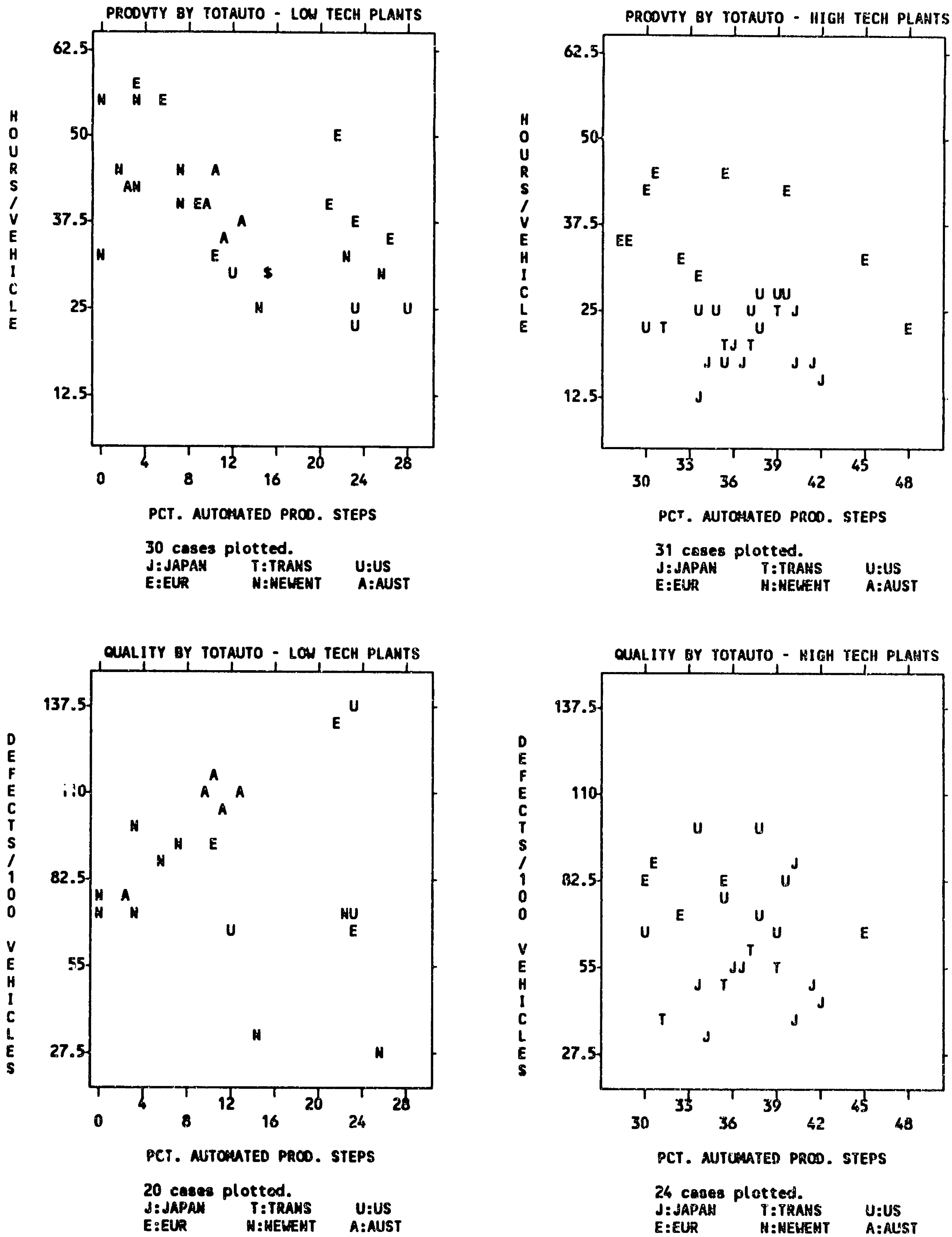
A look at scatterplots confirms these interpretations. The top half of Figure 5-3 shows two subsets of the scatterplot between the Total Automation variable and productivity, one for the Low Tech group described above, and the other for the High Techgroup, while the bottom half duplicates these plots for Total Automation and Quality. The same scatterplots using the Robotic Index as the technology measure yield similar results.

While the correlation between technology and manufacturing performance is impressively strong for the sample as a whole, this relationship is much weaker at moderate to high levels of automation. These data challenge the conventional economic wisdom and set the stage for examination of the "integration hypothesis".

B. EXAMINING THE INTEGRATION HYPOTHESIS

Chapter 2 sets out this hypothesis about the inter-relationship between technology and production organization. To summarize, it states that technology will contribute more significantly to performance in a flexible production system than in a mass production system. Under flexible production, technology strategy is integrated with a human resource strategy and a manufacturing philosophy that supports rapid learning, incremental

Figure 5-3
Productivity and Quality by Total Automation:
Low-Tech and High-Tech Subgroups



process improvement, small lot production, and (potentially) high product variety. In contrast, mass production uses technology to support the high volume production of a few standard products, to reduce labor costs, and to minimize reliance on human capabilities.

The data analyses related to the "integration hypothesis" are organized into two sections: the first examines the relationship between technology and manufacturing performance for subsets of plants defined by their Production Organization score; and the second uses the technology measures together with the ProdOrg variables in a cluster analysis to see whether the resulting groupings reveal the expected relationships.

Technology and Performance: MassProd and FlexProd Plants

First, I examine the relationship between technology and both outcomes for subgroups of MassProd and FlexProd plants, formed by using the midpoint for the Production Organization index (50 on a scale from 0 - 100). Table 5-5 shows that the correlation between technology and both productivity and quality is stronger in the FlexProd subgroup than in the MassProd subgroup, regardless of which technology measure is used. The one exception is the correlation between the Robotic Index and quality, where the MassProd coefficient is slightly higher.[4] This analysis broadly supports the integration argument about the importance of organizational context to the effective utilization of technology. I then further subdivide the sample by using the midpoint of the Total Automation scale (24%), generating four quadrants that reflect all possible combinations of technology and organizational context.

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[4] This is partly a function of the impact, in the small subset of FlexProd plants, of an unexplained large increase in quality defects between 1988 and 1989 for the plant with the highest Robotic Index score in the sample. Using an average quality score for this plant over those two years, the correlation in question increases from r= -0.21 (.206) to r= -0.30 (.120). Correlations for the other technology measures also increase with this change, to r= -0.36 (.081) for TotAuto and to r= -0.38 (.069) for the TechAll variable.

Table 5-5

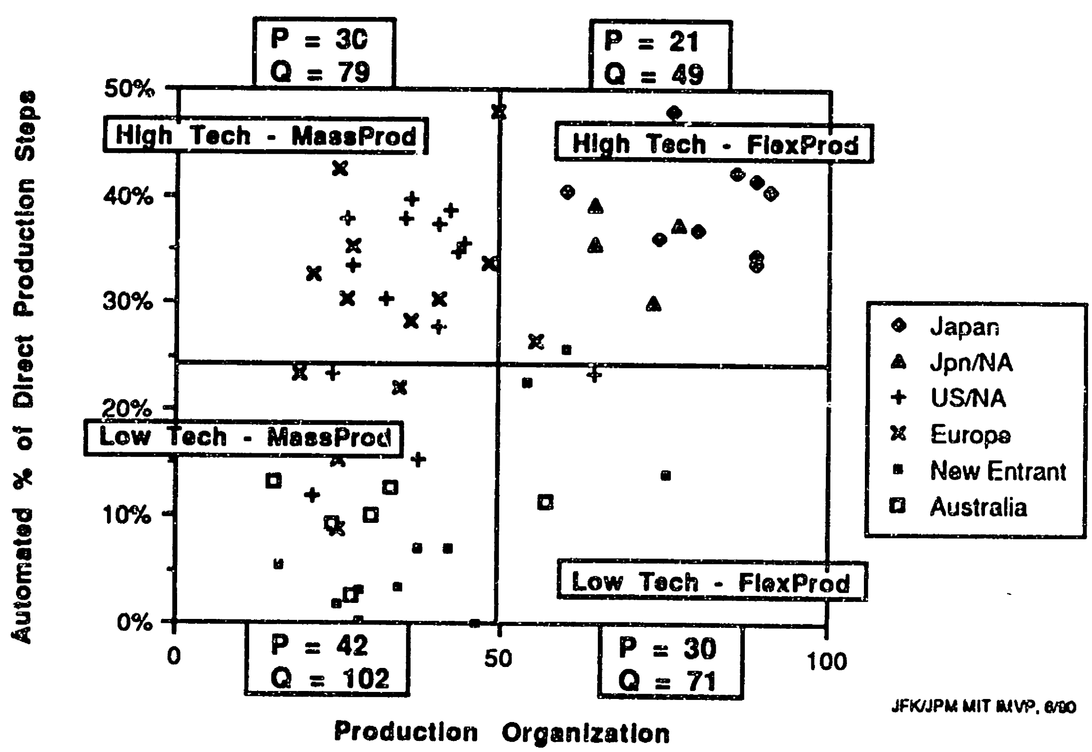
Technology and Manufacturing Performance:
Correlations for MassProd and FlexProd Groupings

	Productivity (hours/vehicle)	Quality (defects/100vehicles)
All Plants		
Total Automation	-0.68 (.000)	-0.41 (.002)
Robotic Index (Sqrt)	-0.64 (.000)	-0.42 (.002)
TechAll variable	-0.66 (.000)	-0.45 (.001)
n	62	46
MassProd Plants		
Total Automation	-0.61 (.000)	-0.21 (.138)
Robotic Index (Sqrt)	-0.51 (.000)	-0.23 (.116)
TechAll variable	-0.56 (.000)	-0.25 (.101)
n	39	28
FlexProd Plants		
Total Automation	-0.71 (.000)	-0.30 (.125)
Robotic Index (Sqrt)	-0.63 (.002)	-0.21 (.206)
TechAll variable	-0.71 (.000)	-0.32 (.103)
n	18	17

Figure 5-4 shows the average productivity and quality outcomes for each quadrant. Low Tech - MassProd plants take, on average, 42 hours to build a vehicle with a poor quality level -- over 100 defects per 100 vehicles, while plants in the High Tech - FlexProd quadrant have the best performance, taking only about 21 hours -- half as many hours -- to build a vehicle with superior quality performance -- an average of 49 defects per 100 vehicles. Plants in the High Tech - MassProd group perform at the intermediate level of 30 hours per vehicle and 79 defects per 100 vehicles; the very few plants in the Low Tech - FlexProd group have the same intermediate productivity level and slightly better quality results, at 71 defects per 100 vehicles.

Figure 5-4

Performance Averages for Technology/Organization Quadrants



Finally, I examine the integration hypothesis for overall manufacturing performance -- the simultaneous achievement of high productivity and quality. Table 5-6 shows the average values of key explanatory variables, using the four performance zones from above.

Total Automation is very low (15%) for the Low Productivity - Low Quality group, jumps up to around 30% for the High Prod-Low Qual and High Prod-High Qual groups, and increases to 36% for the "World Class" group. While the best performance is associated with the highest automation level, the amount of technology does not, overall, significantly differentiate among the three top performance groups.

The Production Organization index and its three component measures, in contrast, change steadily across the four groups, with the top performing group having the highest scores for the entire group of organizational variables. There is relatively little difference in the production organization component scores for the Low Prod - Low Qual and High Prod - Low Qual groups. Clearly, the much higher automation level for the latter group (more than double) is the primary source of productivity gain here. But the ProdOrg index and component scores change much more in moving to the top two groups, as Total Automation remains relatively level.

Table 5-6

Averages for Key Variables by Overall Performance Zone

Performance Zone	n	Total Auto.	Prod Org	Use of Buffers	Work System	HRM Policies
Low Prod-Low Qual	18	15.7%	33.3	46.2	25.0	27.4
High Prod-Low Qual	6	31.6%	38.4	54.5	34.1	26.7
High Prod-High Qual	15	29.3%	55.8	66.5	42.6	58.2
World Class Prod/Qual	6	36.4%	81.8	87.4	82.6	75.6

These findings also provide support for the integration hypothesis -- that the "organizational logic" of a flexible production system, combined with relatively high levels of automation, yields the best overall manufacturing performance.

Technology, Organization and Performance: A Cluster Analysis

Here I compare the results above, which rely on the somewhat arbitrary separation of plants into comparison groups, with a cluster analysis that groups plants based on their similarity across a number of differentiating variables. I build on the cluster analysis in Chapter 4, relying on the same method choices and simply adding the two technology measures to the set of clustering variables.

Like the ProdOrg variables, the technology variables are standardized before being used in the cluster analysis. As above, a Euclidean distance measure is used to form the similarity matrix and the "average linkage within groups" cluster method is used. An examination of the fusion coefficients at each stage of the clustering procedure reveals the biggest gap in values after the two and three cluster solutions are reached. The three cluster solution, for example, corresponds closely to the Low Tech - MassProd, High Tech - MassProd, and High Tech - FlexProd quadrants in Figure 5-4 above.

But there are advantages to considering the four and five cluster solutions as well. The four cluster solution separates out a group of Low Tech plants that corresponds closely to the Transitional FlexProd cluster in Chapter 4. This new cluster, naturally, corresponds closely to the Low Tech - FlexProd quadrant from Figure 5-4 as well.

The five cluster solution further divides the High Tech - FlexProd cluster, with one cluster containing the Japanese plants in Japan (that have both the highest levels of automation and the highest ProdOrg scores) and the other containing the Transitional FlexProd plants from Chapter 4 that have a relatively high level of automation (the

Japanese transplants in North America and a few other plants).

Overall, these groupings, particularly the five-cluster solution, match up nicely with the four cluster solution from Chapter 4 that was based on the production organization variables only. This can be readily seen by correlating the memberships of these different groups of plants. I create a variable that identifies the quadrant of the Total Automation by Production Organization chart (Figure 5-4) to which a plant belongs, called QUAD4. Table 5-7 then shows the correlations between this grouping and the cluster solutions resulting from the use of ProdOrg and technology variables (CLUSTEC4 and CLUSTEC5), both a high r= 0.79. Finally, Table 5-7 also shows the high correlation of CLUSORG2 and CLUSORG4, the cluster solutions resulting from the use of ProdOrg variables only (from Chapter 4) with CLUSTEC4 and CLUSTEC5. The fact that the correlations are highest with CLUSTEC5 (r=0.85) supports the decision to use this cluster solution in all further analyses.

Table 5-7

Correlations between Plant Groupings:
Technology/Organization Quadrants and Cluster Solutions

Grouping	Correlation with ProdOrg/Technology Clusters	
	CLUSTEC4	CLUSTEC5
QUAD4 (ProdOrg x TotAuto)	.79	.79
CLUSORG2	.84	.85
CLUSORG4	.79	.85

Table 5-8 shows the mean differences across the CLUSTEC4 and CLUSTEC5 groups for the ProdOrg index and its three component indices and for the two technology measures. These differences are to be expected, but t-tests also reveal them to be highly significant, with the exception of Use of Buffers (for which the only significant difference is between Cluster 3 and Cluster 4), HRM Policies (between Clusters 2 and 3 and Clusters 4a and 4b), and the Robotic Index (between Clusters 4a and 4b).

Table 5-9, then, shows mean differences for the key variables not used to form the clusters -- both performance measures and other independent variables. Most noteworthy is the similarity to the performance outcomes in Figure 5-4, with the Low Tech - MassProd cluster reporting nearly twice as many hours per vehicle as the High Tech - FlexProd cluster, and the two off-diagonal clusters (High Tech - MassProd and Low Tech-FlexProd) reporting the same intermediate productivity level.

Thus the cluster analysis also supports the integration hypothesis. It derives the clusters of plants so that the average distance among plants in each cluster is minimized for all the ProdOrg variables and both the technology measures. The resulting five-cluster solution reveals systematic and statistically significant performance differences across groups of plants that are distinct from one other (and internally homogeneous) in the way they combine technology and production organization. These differences are nearly identical to those resulting from a somewhat arbitrary groupings of plants into quadrants divided by the midpoint of the ProdOrg and Total Automation scales.

While these results are quite clearcut and convincing, they emerge from analyses that do not control for other factors that may well affect manufacturing performance, such as scale, complexity, and design age. In Chapter 6, I turn to a full multivariate analysis of manufacturing performance, in which the organizational and technological factors that have been emphasized so far will be supplemented by these other important independent variables. This will reveal whether the integration hypothesis continues to be supported when a fuller set of explanatory variables is considered.

Table 5-8

Validation of Group Average Cluster Solutions:
Mean Differences for ProdOrg and Technology Across Clusters

Index	C1	C2	C3	C4	C4a	C4b
ProdOrg	29.9	37.3	57.3	75.2	66.5	82.6
Use of Buffers	41.2 +	50.6 +	65.4	82.3	77.8 +	86.1
Work System	27.9 *	20.3	51.8	69.4	48.5	87.3
HRM Policies	20.7	41.0 +	54.7	73.8	73.3 +	74.3
TotAuto	8.4%	33.7%	25.1%	34.5%	29.5%	38.7%
Robotic Index	0.37	3.04	0.88	3.90	3.47 +	4.27
n of cases	18	20	5	13	6	7

All cluster mean differences are significant at $p < .05$
unless marked: * = $p < .10$; or + = not significant.

C1 = Low Tech - MassProd
C2 = High Tech - MassProd
C3 = Low Tech - FlexProd
C4 = High Tech - FlexProd

C4a = High Tech - Transitional FlexProd
C4b = High Tech - Japan FlexProd

Table 5-9

Validation of Group Average Cluster Solutions:
Mean Differences for Other Key Variables Across Clusters

Variable	C1		C2		C3		C4	C4a		C4b
Productivity	41.6		31 0	+	30.3	*	21.8	26.4		17.9
Quality	103.3		78.2	*	54.3	+	57.7	62.2	+	53.9
Product Age	7.5		4.2	+	4.5	*	2.6	3.1	+	2.1
Model Mix	35.2	+	24.6	+	27.7	+	36.8	25.5	+	46.5
Parts Complex	52.4	+	56.0	+	64.9	+	57.9	42.2		71.3
Scale	535.9		1103.5	+	1105.6	+	1181.8	923.2	+	1403.6
n of cases	18		20		5		13	6		7

All cluster mean differences are significant at $p < .05$
unless marked: * = $p < .10$ or + = not significant.

C1 = Low Tech - MassProd
C2 = High Tech - MassProd
C3 = Low Tech - FlexProd
C4 = High Tech - FlexProd

C4a = High Tech - Transitional FlexProd
C4b = High Tech - Japan FlexProd

CHAPTER 6

A MULTIVARIATE ANALYSIS OF MANUFACTURING PERFORMANCE

This chapter will present a multivariate analysis of manufacturing performance, including the production organization and technology variables highlighted in Chapters 4 and 5 as well as several key control variables related to plant scale, product complexity, and product design.[1]

I continue here with the parallel analyses begun in previous chapters, carrying out one set of multiple regression analyses that uses the separate, continuous measures of production organization and technology and another set that uses the clusters derived from these variables.

I also examine some alternative hypotheses about manufacturing performance and test the stability of the regression results by using dummy variables signifying location in Japan, Japanese management, and location in a low-wage country.

A. EXPLAINING MANUFACTURING PERFORMANCE

Control Variables

While past chapters have focused on production organization and technology, there are many other factors that can affect manufacturing performance. Chapter 3 describes four such variables, functioning primarily as control variables for these analyses:

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[1] Because of the large number of statistical analyses in this chapter, all tables have been placed at the end of the chapter, pages 191 - 209.

1) Plant Scale -- average daily production volume, with shifts of standardized length, excluding overtime;

2) Model Mix Complexity -- an index of product variety, based on the number of different platforms, body styles, and models built at each plant, adjusted by the number of different assembly lines and distinct body shops;

3) Parts Complexity -- an index of the variety of parts and parts combinations that must be coordinated by each plant, based on the number of main body wire harnesses, exterior paint colors, engine/transmission combinations, number of assembly area parts, percentage of assembly area parts common to all products, and number of suppliers to the assembly area;

4) Product Design Age -- the weighted average number of years since a major model changed for each of the products built at a plant.

Table 6-1 shows means and standard deviations of these variables, both for the whole sample and by regional grouping. The two complexity indices are placed on a scale from 0 to 100, where 0 is the plant with lowest complexity and 100 the plant with highest complexity in the sample. Plant Scale and Product Design Age are reported in units and years, respectively, without any scaling adjustment.

Model Mix Complexity is positively skewed, with over 80% of the sample having a score below 50, the midpoint of the scale. Three plants, with scores ranging from 85 to 100 (1 in Japan, two in New Entrant countries), have extremely high complexity compared with the rest of the sample, around 3 standard deviations from the mean. For example, the Japanese plant, with a score of 93, makes a 4-door sedan, a 5-door sedan, a 5-door minivan, and a 3-door sports car, all on a single assembly line. In contrast, another Japanese plant, with the lowest score in the sample (0), makes only a single 3-door hatchback.

Parts Complexity is more evenly distributed. The plant with the least Parts Complexity in the sample (a Japanese plant in North America) is the only one whose score (4.4) is more than 2 standard deviations from the mean. Products in this plant use only

7 different exterior colors, less than 5 wire harnesses, less than 10 engine types, and less than 20 engine/ transmission combinations. In contrast, products in the plant with the highest Parts Complexity score of 91 (in Europe) use 18 exterior colors, over 50 wire harnesses, over 50 engine types, and over 500 engine/transmission combinations.

The range for Plant Scale in the sample is enormous, from a low of 135 vehicles per day to a high of 3680 vehicles per day. Conventional wisdom in the U.S. auto industry would set the optimal plant volume, in terms of economies of scale, at 250,000 vehicles per year, or 1,000 vehicles per day (assuming a two week annual shutdown for model change). The sample average of 904 vehicles per day is quite close to this level, and just over one-third of the sample has daily volume in the range of 800 to 1200 (or, in annual figures, 200,000 to 300,000). Yet there are sizeable numbers of plants at either end of the scale distribution -- 45% below 800 vehicles per day and 21% above 1200 vehicles per day.

The largest plant, in terms of scale, in the sample is a European plant that is a substantial outlier in the univariate distribution, at 4.4 standard deviations above the mean. This outlying plant poses some problems for the regression analysis, as will be discussed below. The next largest plant (in Japan), at 2800 vehicles per day, remains within the normal distribution, at just under 3 S.D.s above the mean.

Finally, Product Design Age ranges from 0.7 years to 15 years, in a distribution with a strong positive skew. 89% of the plants have a design age of less than 8 years, and the remaining plants are evenly scattered between 9.5 and 15 years. The plant with the oldest average product design age, in Mexico, is still within the normal distribution, at 2.8 S.D.s above the mean.

Correlations among these variables will be included below in the discussion of the regression analysis.

Specifying the Regression Equation

The first question to address in explaining high performance manufacturing is the most appropriate model of interrelationships among the dependent variables and the independent variables. A good starting place in this case is the Cobb-Douglas production function that specifies the precise nature of the relationship between labor and capital inputs.

Cobb-Douglas is commonly applied to real-world production settings, for both conceptual and methodological reasons. Conceptually, this function assumes there is some substitutability of labor and capital, i.e. that different mixes of labor and capital (but neither factor exclusively) can achieve the same output quantity. This fits the assembly plant setting well.

It also assumes a constant elasticity of substitution, independent of scale, i.e. that the rate at which capital can be substituted for labor (and vice-versa) is constant at all levels of production. This allows the same production function to be applied across a sample regardless of the scale of production -- a valuable property given the range of production scale in the assembly plant sample.

The most significant advantage conceptually is that the simple Cobb-Douglas function is often supplemented to include factors that affect how capital and labor inputs are used. The constant elasticity of substitution (CES) model of Arrow, Chenery, Minhas, and Solow (1961) (of which Cobb-Douglas is a specific case, under the substitutability assumption described above) includes an "efficiency" parameter that affects both inputs. Alternately, when technical progress is being considered, a "technological innovation" parameter (typically represented as a function of time) is added to the Cobb-Douglas specification (e.g. Solow, 1957). Both of these parameters are used in ways similar to my treatment of the Production Organization variable -- as a factor that enhances or constrains how effectively both labor inputs and capital inputs are utilized.[2]

In terms of methodological advantages, Cobb-Douglas is an equation that is "intrinsically linear" (Neter, Wasserman, and Kutner, 1983) because, although its parameters are not linear, it can be easily converted, through a logarithmic transformation, to a linear form. Furthermore, in its log form, the coefficients reveal the elasticities of the inputs, i.e. the percentage change in the dependent variable (output) that results from a fixed percentage change in the independent variables (labor and capital inputs).

The Cobb-Douglas production function takes the exponential form of

$$Q = b_0 * K^{b_1} * L^{b_2}$$

where Q is output, K is capital input (investment) and L is labor input (hours). The relationship among the variables is multiplicative rather than additive, in accordance with the substitutability assumption, i.e. coefficients for both capital and labor inputs must have some positive value for output to be positive.

To incorporate the conceptualization of production organization context used here, a parameter (labeled 'E' for 'effectiveness') can be added that affects both the use of labor and the use of capital:

$$Q = E^{b_3}[b_0 * K^{b_1} * L^{b_2}]$$

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[2] There is also a considerable industrial relations literature on factors that affect the contribution of labor in the production function, but not capital. These include studies of effects of unionization on productivity (e.g. Brown and Medoff, 1978; Clark, 1984; Ichniowski, 1984) and of the effects of human resource policies on productivity (Ichniowski, 1990).

Dividing both sides by L to get labor productivity (output per labor hour) as the dependent variable yields the equation:

$$Q/L = E^{b_3}[b_0 * K^{b_1} * L^{b_2-1}]$$

The productivity methodology used in this research generates labor productivity in the form of hours per vehicle, or hours per unit of output (L/Q) -- the inverse of the customary measure. Thus positive effects of the independent variables on labor productivity will have a negative coefficient, e.g. more automation would yield fewer hours per vehicle. Taking the inverse of the previous equation produces the dependent variable in this form:

$$L/Q = 1/(E^{b_3}[b_0 * K^{b_1} * L^{b_2-1}])$$

Taking the log, this equation becomes:

$$\log (L/Q) = -\log b_0 - b_3 * \log E - b_1 * \log K - (b_2-1) * \log L$$

Finally, with variable names inserted, this equation is:

$$\log LaborProd = -\log b_0 - b_3 * \log ProdOrg - b_1 * \log TotAuto - (b_2-1) * \log LaborHrs$$

Several issues must be addressed before the regression equation can be finalized. The first issue is how to specify quality in the regression equation for that outcome. For consistency in treatment of the outcome variables, and with no clear theoretical basis for deciding, I will also apply a log transformation to Quality.

Second, the Total Automation variable is different from conventional measures of capital input. It is not, strictly speaking, a proxy for capital investment in its entirety, but encompasses only the tool and equipment stock of a plant -- and even then in terms of percentage of assembly steps that are automated rather than capital expenditures. However, since the investment in these tools represents the portion of capital spending that most affects the productivity of labor, it is far preferable to a more comprehensive investment measure that has little bearing on shop floor activities.

Furthermore, firm-level studies of capital and labor productivity in the auto industry, using conventional measures of capital stock, have found tremendous variation in labor hours per vehicle across American and Japanese companies but nearly equivalent levels of capital stock per vehicle (Cusamano, 1985; Lieberman, 1989). This also supports the use of a automation proxy for capital that is more likely, at the plant level of analysis, to have a direct effect on labor productivity.

Third, this equation includes labor hours as an independent variable. This variable was not part of the production system model outlined in Chapter 3. This is because I have chosen to use production scale as an independent variable, in order to investigate hypotheses about economies of scale. Labor hours and production scale are highly correlated (r=.85 for this sample), so that it makes no sense to include both variables in the regression equation. Thus, for theoretical reasons, I choose to substitute production scale for labor hours.[3]

This raises a fourth issue, of how to specify Scale in the equation. While there is no clear conceptual basis for deciding, there is a methodological consideration. As mentioned above, one plant is a substantial outlier in terms of scale. Early examination of residuals revealed that this plant was regularly identified as a Mahalanobis (multivariate) outlier. The log transformation of Labor Productivity, based on Cobb-Douglas, also served the useful empirical function of "pulling in" the distribution and eliminating the one outlier for that variable. Applying a log transformation to Scale is equally valuable, since it eliminates the outlier.[4]

The final issue is how to specify the other variables in the regression equation. One appropriate question is to ask where one might expect a variable to have a multiplicative relationship with other variables, as opposed to an additive relationship. The integration hypothesis discussed in Chapter 5 implicitly specifies a multiplicative relationship between production organization and technology, with respect to manufacturing performance, by claiming there is an interaction effect from the combination of a flexible production system

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[3] This substitution has virtually no impact on regression results. Regressions on both productivity and quality for the primary variables, one using Log Labor Hours and the other using Log Scale, have identical adjusted R^2s and F-statistics and very similar coefficients. The primary difference between the two productivity regressions is that the coefficient for Total Automation is higher -- no doubt because the correlation between automation and scale ($r = .63$) is considerably higher than the correlation between automation and labor hours ($r = .34$). In the quality regressions, however, the Total Automation coefficients are unchanged.

Indeed, without Scale in the regression equation, the effect of Total Automation on productivity may be overstated, because the technology variable captures all scale effects. So another advantage of including Scale, besides the ability to examine hypotheses about economies of scale, is that the technology variable may be more accurately specified.

[4] Outliers violate key regression assumptions of linearity and constant variance of error terms. Various writings on outliers (Neter et al., 1983; Cook and Weisberg, 1982; Belsley, Kuh, and Welsch, 1980; Barnett and Lewis, 1978) suggest either deletion or transformation for dealing with outliers. Given the small sample size, deletion is to be avoided if possible. So the log transformations have both theoretical and empirical value.

with high levels of automation. This supports the decision, above, to apply a log transformation to the ProdOrg index.

With the product measures (Model Mix Complexity, Parts Complexity, and Product Design Age), it is less clear what relationship is expected. To assume a multiplicative relationship here would be say that the effect of integrating production organization and technology will only hold when a particular complexity level or design age exists. With no theoretical basis for such a claim, it seems best to treat all the product-related variables the same way -- i.e. to leave them untransformed.

With all of these choices taken into account, the full regression equation used in this chapter will include a log transformation of Labor Productivity (LProd), Quality (LQual), Total Automation (LTotAuto), Production Organization (LProdOrg), and Production Scale (LScale) but not of Model Mix Complexity (Mix), Parts Complexity (Parts), or Product Design Age (AgeCar).

Regression Equations: A Multi-Stage Approach

The regression analysis has two main purposes. The first is prediction of manufacturing performance by the set of independent variables. The second is understanding the relative role of individual variables in contributing to the variation in performance outcomes. These can be best achieved through a multi-stage, hierarchical regression procedure, in which blocks of variables are added in logical sequence until the full variable set is reached. Thus both the full model and intermediate stages can be evaluated.

Accordingly, the LScale and LTotauto variables -- both of which reflect technical characteristics of the plant -- will be entered together as the first block of variables. Next, the LProdorg variable, which reflects a "bundle" of organizational characteristics, will be added, to see what contribution this "effectiveness" parameter makes to the prediction of performance. Finally, the product variables (Mix, Parts, and AgeCar) will be entered as a group.

The integration hypothesis will also be explored in more detail by including some alternative specifications of the technology and production organization variables. First, to capture the weaker relationship between technology level and performance for HighTech plants, I will substitute for the continuous TotAuto index a set of dummy variables indicating the quartile of the TotAuto distribution into which a plant falls. Only three dummy variables will be used (AutoDum1-3), with the top quartile of the most automated plants kept as the reference category. This equation will therefore test for statistically significant differences in performance for each technology quartile in comparison to the most automated plants, when all other variables are held constant.

Then, I will use dummy variables representing the five cluster groups identified in Chapter 5 (ClusTec1-5) in place of the TotAuto and ProdOrg indices. Here the High Tech/FlexProd-Japan plants (n = 7) will serve as the reference group for which there is no dummy variable. This equation will test for statistically significant differences in performance for each of the technology-organization clusters in comparison with the most advanced FlexProd plants in the world, when all other variables are held constant.

Thus, I will use the following sequence of regression equations:

1. Regressing LScale and LTotauto on LProd (or LQual)
2. Same variables as #1, adding LProdOrg as an IV
3. Same variables as #2, adding Mix, Parts, and AgeCar as IVs
4. Same variables as #3, substituting automation dummies for LTotAuto
5. Same variables as #3, substituting cluster group dummies for LTotAuto and LProdOrg

Table 6-2 provides descriptive statistics and Table 6-3 shows the correlation matrix for all variables included in these regression analyses. While some of the correlations among the IVs are relatively high, none are high enough to pose serious risks of multicollinearity. (Gujarati, 1978)

Regression Analysis for Productivity

Table 6-4 summarizes the regression results for LProd. The regression equations are identified by number. For each equation, the adjusted R-squared value, the F-value, and the sample size are given. For each variable, standardized coefficients (beta) and T-values are given. Significance levels for both T-values and F-values are marked by asterisk.

Equation 1 has an adjusted R^2 of 45.1%. The LTotAuto variable is highly significant while the LScale variable is not. The fact that LScale is not significant is due, in part, to the very high correlation between it and LTotAuto ($r = .635$).[5] The addition of LProdOrg (Eq. 2) boosts the adjusted R^2 to 58.3%, with both the technology and organizational variables having similarly high beta coefficients and significance levels and scale remaining insignificant.

Finally, the addition of the product variables (Eq. 3) increases the adjusted R^2 still further, to 63.4%. Now LProdOrg has the highest significance level, with a T-value of -3.1, but LTotAuto (-2.5) and Parts Complexity (-2.2) are both statistically significant, and AgeCar (-1.9) and LScale (-1.6) are nearly so. The beta coefficients give nearly equal weight to LTotAuto (-.33) and LProdOrg (-.32), followed by Parts Complexity (.25), AgeCar (.20), and LScale (-.21). For all three equations, all variables have the expected sign, with the exception of Model Mix Complexity, which has a negative coefficient but is not

[5] Overall, however, the effect of scale is not as great as might be expected from economy of scale arguments. In a regression on LProd with LScale as the only independent variable, the R^2 is only 15.1%.

statistically significant.

When the automation dummy variables are entered in place of LTotAuto (Eq. 4), the other variables remain relatively unchanged and the adjusted R^2 dips slightly in response to the additional degrees of freedom used. But the automation dummies do reveal that the integration hypothesis holds even when control variables are present. The dummy for the quartile of plants with the lowest automation is statistically significant, with a beta coefficient of .38 and a T-value of 2.3.[6] Knowing a plant is in this group is a reliable predictor of its (poor) productivity relative to the quartile of the most automated plants.

The dummy variables for the second and third quartiles are not statistically significant. They do have positive beta coefficients (.139 and .143 respectively), meaning that, on average, they do take more hours per vehicle than plants in the top automation quartile. But these coefficients are not significant because the standard error is so high. There is too much variability in productivity for plants at these moderate-to-high automation levels for a statistically significant effect to be found. The continued high significance of the LProdOrg index, when controlling for level of technology and other variables, further bears out the integration hypothesis in this analysis.

Finally, Equation 5, which uses the cluster groupings developed in Chapter 5, has the highest adjusted R^2 of all, at 66.8%. All of the dummy variables identifying the clusters are highly statistically significant, meaning that their productivity differs significantly from the reference group of FlexProd plants in Japan. Surprisingly, other variables having low or marginal statistical significance in the other equations are significant here, including Parts Complexity with a T-value of 3.7, LScale (-3.5), and AgeCar (2.4). Only Model Mix Complexity is not statistically significant in this equation.

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[6] The sign of this coefficient is positive because plants in this quartile have more hours per car (better productivity) than plants in the reference category.

This raises the question of the unique contribution of different variables in each equation. While the beta coefficients provide some idea of the relative contribution of different variables, they are strongly affected by what other variables are in the equation and by their intercorrelations. Since the intercorrelations are quite high for this variable set, it is valuable to find alternative ways to assess individual variables.

Norusis (1988) describes such an alternative, as follows:

> Another way of assessing the relative importance of independent variables is to consider the increase in R^2 when a variable is entered into an equation that already contains the other independent variables. A large change in R^2 indicates that a variable provides unique information about the dependent variable not available from the other independent variables in the equation.
>
> The signed square root of the increase is called the part correlation coefficient. It is the correlation between the dependent variable Y and an independent variable X when the linear effects of the other independent variables have been removed from X.

Thus the unique contribution of each independent variable to R^2 is calculated by squaring the part correlation coefficient. Then the shared variance resulting from intercorrelations among independent variables is calculated by summing the unique variance for all variables and subtracting this total from unadjusted R^2. (Tabachnick and Fidell, 1989) Table 6-5 presents these data for the same set of regression equations found in Table 6-4.

The unique contribution of any single variable is still heavily dependent on what other variables are in the equation. This is most clearly the case for LScale, which makes no independent contribution at all in Equations 1 and 2 (where its effect is totally suppressed by LTotAuto) but contributes around 2% in Equations 3 and 4 and 7.3% in Equation 5 when other variables are included. For most other variables, their unique contribution shrinks as other variables, with which they are intercorrelated, enter the equation. This can be seen clearly in the increasing percentage of shared variance among

IVs in moving from Equation 1 to Equation 3, from 18.8% to 48.9%.

Finding such a high percentage of shared variance provides support for the "configurational" perspective used here. These variables do covary together, and substantially so, at the production system level. The only problem is that it is difficult to interpret the coefficients of individual variables. Do LScale and AgeCar really have no statistically significant effect on productivity, as suggested by Equation 3, or is their effect suppressed by other variables with which they covary?

Equation 5 has the advantage of a very low shared variance (7.0%) (and, consequently, a very high total unique variance of 71.6%). Because cluster membership is not so highly correlated with the other variables in the equation[7], we find high unique contributions from not only all the cluster variables but also most of the control variables.

From this equation, we can conclude that LScale, Parts Complexity, and AgeCar are all valuable explanatory variables for productivity. It is equally clear, then, that Model Mix Complexity, which does not approach statistical significance in any of these equations, has virtually no relationship with productivity, contrary to expectations.

Regression Analysis for Quality

Tables 6-6 and 6-7 show results for the same set of equations with Log Quality as the dependent variable. With no clear theoretical reason to specify the relationship between dependent and independent variables differently for quality and productivity, the same transformations are used in these equations: log transformations of Quality, Scale,

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[7] Correlations of the cluster variables with Model Mix Complexity range from -.09 to -.23; with Parts Complexity, from -.21 to .12; with Scale, from -.52 (with Cluster 1) to .27; and with Product Design Age, from -.18 to .49 (with Cluster 1). Only two of these sixteen correlations are higher than .27.

Total Automation, and the ProdOrg index, and no transformations for the product variables.[8] Note as well that the sample size for the quality analysis is much smaller -- a total of 44 plants, compared with 56 for productivity.

It is immediately apparent from Table 6-6 that the independent variables in these equations do not predict quality as well as productivity, for the adjusted R^2 is considerably, and consistently, lower. Particularly noteworthy is the much weaker power of LTotAuto as an explanatory variable for quality, as anticipated by the correlations in Chapter 5.

While LTotAuto is statistically significant in Equation 1, the beta coefficient of -.37 is much weaker than in the same equation for productivity (-.69). Then, in the other equations, the beta coefficient for LTotAuto drops to the vicinity of -.10 and is no longer statistically significant; this is true even when the dummy variables for TotAuto are used.

With LTotAuto contributing so little, the adjusted R^2 for equation 1 is a low 10.5%. When LProdOrg is added in equation 2, there is a substantial jump in adjusted R^2 to 37.7%. It is strongly significant, with a beta coefficient of -.59 and a T-value of -4.3, and remains so in equations 3 and 4. The product variables, in contrast, are not statistically significant when added in equation 3. In fact, the adjusted R^2 drops to 35.2% because of the reduction in degrees of freedom from adding these variables. In Equation 4, the dummy variables for TotAuto capture the very different links to quality at different automation levels better than the continuous measure and the adjusted R^2 increases modestly to 39.1%.

Finally, in equation 5, two of the four cluster dummy variables (Low Tech - MassProd and High Tech - MassProd) are statistically significant but two are not, and no other variables are significant. Thus the defects per vehicle are substantially higher for

[8] As with productivity, the log transformation of quality has the valuable empirical consequence of making the distribution closer to normal by pulling in the two plants that were near outliers.

both the MassProd clusters than for the cluster of plants in Japan, regardless of automation level, as we would expect after seeing the relative contribution of the continuous technology and organization measures.

But the regression finds no significant differences in defects per vehicle between either of the Transitional FlexProd clusters and the cluster of plants in Japan, thereby confirming the comparison of quality means across clusters in Chapter 5. The adjusted R^2 for this equation drops to 28.3%.

Table 6-7 shows the shared and unique variance for each equation. Unlike the productivity equations, the shared variance is not high here, and the dominant effect of the LProdOrg variable is apparent.

Effect Sizes for Technology and Production Organization

The regression results for manufacturing performance raise a question about the integration hypothesis, since clearly the relative contribution of technology and production organization is different for quality than for productivity. Comparing the unique variance contributed by these two variables for productivity and quality is somewhat misleading given the high shared variance in the productivity equations. An alternative is to examine the effect size through the unstandardized coefficients.

In Equation 2, which includes LTotAuto, LProdOrg, and LScale as IVs, the fact that all variables are in log form makes it possible to interpret the unstandardized coefficients in terms of elasticities or rates of change.[8] For example, for LProductivity, the unstandardized coefficients for LTotAuto, LProdOrg, and LScale are -1.6, -.34, and -.002

[8] The unstandardized coefficients in Equations 3-5 cannot be easily interpreted in this way, because they combine untransformed, logged, and dichotomous dummy variables. But Equation 2 at least allows an assessment of the two primary variables emphasized in this data analysis: technology and production organization.

respectively. From this, we know that a 10% increase in TotAuto (the percentage of direct production steps that are automated) is, on average, associated with a 16% reduction in labor hours per vehicle. Similarly, a 10% increase in the ProdOrg score (on the scale from 0 to 100) is, on average, associated with a 3.4% reduction in hours per vehicle. The scale coefficient is very small, with a comparatively high standard error, so it is not statistically significant, making any calculation of effect size unreliable.

For quality, in contrast, the unstandardized coefficients for LTotAuto, LProdOrg, and LScale are -.39, -.48, and -.004 respectively. Thus, while a 10% increase in TotAuto brings about a 16% decrease in hours per car, it only results in a 3.9% decrease in defects per car (although this latter coefficient is not very reliable). Conversely, a 10 percent increase in the ProdOrg score yields a greater impact on quality than on productivity -- a 4.8% decrease in defects per vehicle vs. a 3.4% decrease in hours per vehicle -- a result that is bolstered by the fact that these LProdOrg coefficients are statistically significant in both the productivity and quality equations.

These results make it difficult to claim that the integration hypothesis holds for quality in quite the same way as it does for productivity. High quality is strongly related to the bundle of manufacturing practices, work organization, and human resource policies found in a plant, and quite unrelated to automation level. Thus FlexProd plants appear to have a clear advantage over MassProd plants with respect to quality -- regardless of their level of automation.

Observations about Product Variety

The analysis so far has, appropriately, focused on explaining productivity and quality outcomes. But there is another outcome of interest -- product variety. While I have emphasized the "flexible process" aspects of flexible production systems, one would expect to find "flexible products", i.e. high product variety, in these systems as well. While this research was not designed to address the factors affecting product variety, the data do suggest a few observations.

The Model Mix Complexity (Mix) variable is treated, in the regressions above, as an independent variable affecting productivity and quality. But it can also serve as a proxy for product variety, since it is an index based on number of different platforms, models, and body styles built at a plant.

As shown above, Model Mix Complexity is not a statistically significant factor for either productivity or quality. Interpreted in terms of product variety, this means that there is no consistent relationship between the number of different products a plant makes and its manufacturing performance, when all other variables are held constant.

Furthermore, the correlation between Production Organization (ProdOrg) and Product Variety (ProdVar) is nearly zero (r = .07). Thus MassProd plants do not necessarily have low product variety, and FlexProd plants do not necessarily have high product variety. This raises an important question: How can we speak of "flexible production" if it does not yield "flexible products"?

One clue lies in an examination of the scatterplot of ProdOrg by ProdVar. (Figure 6-1) Among the FlexProd plants (those with scores greater than 67) are the plant with the most product variety and the plant with the least product variety, with a broad range in between.

This suggests an important shift in how we think of flexibility. Rather than equating flexible production with high product variety (as Piore and Sabel (1984), for example, do implicitly), it may be more appropriate to associate it with the ability to choose whether to make a large number of products or a small number of products. A "flexible production" firm or plant could make this choice based on product strategy or market conditions at a certain point in time.[10]

Another implication is that product variety and other forms of complexity may be handled very differently under mass production and flexible production. Under mass production, complexity of any kind, whether in the product mix or number of different parts, may impair performance, since the system is organized to optimize performance with low complexity. Under flexible production, one important rationale for the development of flexible organizational capabilities may be the ability to absorb additional complexity, when necessary or desirable, without any performance penalty.

Summary

In summary, this multivariate analysis upholds results for the integration hypothesis, especially for productivity. For quality, it appears that the ProdOrg index on its own is a more significant predictor of performance, since the link between technology and quality is very weak. The control variables are intermittently significant for productivity, although Model Mix Complexity is not significant in any of these equations. None of the control variables help predict quality. All told, the results found in Chapter 5 are essentially unchanged when the set of control variables is added to the analysis.

Finally, there is virtually no correlation between Production Organization and Product Variety, challenging the use of "high product variety" as the defining criterion for flexibility, and supporting the view that flexibility is an organizational characteristic.

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[10] A manager at one of the Japanese transplants in North America -- the plant with the lowest product variety in the sample -- made a similar point when I asked why the plant was so "flexible" in terms of technology and production organization, when it was only making one 3-door model of a single product. His response was, "We must be flexible enough to build a single product." I interpret this as a statement about flexibility as the capability to respond to a wide variety of changing external conditions, as well as to carry out a particular product strategy. This plant is clearly capable of adding greater product variety at any time -- and, over time, it will almost certainly do so.

B. TESTING ALTERNATIVE EXPLANATIONS

The regression analyses reported above broadly support the findings of Chapters 4 and 5 with respect to production organization and technology while adding other variables as controls, and also shed light on the relative contribution of the control variables to productivity and quality. But these results, while strong, must be evaluated in comparison with alternative explanations to be convincing.

There are two questions to address in evaluating the results so far: 1) Is there a simpler explanation for performance differences? and 2) Is there a more complete (and more complex) explanation?

The answer to the latter question is clearly "yes", since there are many variables that potentially affect assembly plant performance that are not included in this study. The effect of such omitted variables might be partially captured if they are highly correlated with variables that _are_ included. Or such variables might, if included, help reduce the unexplained variance in performance results.

Two factors that almost certainly affect assembly plant performance and are inadequately covered by this study are supplier relations and design manufacturability. Assembly plant quality can be no better than the quality of supplied parts (although it can certainly be worse). Poor quality parts that are difficult to install or require repair can obviously affect productivity as well. Similarly, products that are poorly designed, so that parts don't fit together well, or that have a very complex design, with many parts to be handled and difficult assembly operations, can affect quality and productivity.

Both of these factors can be viewed simply as inputs to the assembly plant -- the quality of incoming parts, the simplicity of the design. But they can also be viewed from an organizational perspective, similar to the one applied here to the assembly plant. The impact of suppliers goes well beyond what emerges from their factories. The assembler-supplier relationship has a tremendous impact on the assembler's ability to reduce inventories, change products or part specifications quickly, and solve persistent product and/or process problems.

Similarly, designs that are easy to assemble are just one outcome of a close working relationship between design and manufacturing functions. This relationship also affects the speed of product development, the pace of continuous improvement efforts, and the effectiveness with which new design technologies can be utilized. I plan future work on both of these factors, examining the structures and processes that underlie assembler-supplier and design-manufacturing relationships.

In the Assembly Plant Study, only the Use of Buffers variable touches on the aspects of supplier relations mentioned above. In addition, the Product Design Age measure serves as a partial proxy for design-for-manufacturability. But beyond this, these important variables are currently underrepresented and cannot be adequately examined.

Thus, there clearly <u>are</u> more complete and complex explanations. But are there simpler ones? A simple explanation would be one that applies at a broader, more aggregated level of analysis than the assembly plant, and which thereby subsumes the variables considered here -- for example, a company or national level.

It would be intriguing to explore these data for a company-level effect, since there is good reason to believe that the commitment to a particular "organizational logic" is primarily the result of corporate decisions, with marginal local adaptation. However, such an analysis is impossible, for with a sample of 56 plants, variables for the 16 different companies represented would reduce degrees of freedom too much for meaningful analysis.

A national-level explanation can be investigated more easily. Such comparisons (such as the regional averages for different variables listed above) have an appealing "box score" quality and they coincide with the categories many of us use in thinking about issues of international competitiveness. But they are problematic when the task is explanation, for they presume that certain national characteristics (from macroeconomic policy to natural resource endowments to physical geography to the catchall of "culture") are universally and uniformly distributed, and logically prior from a causal point of view.

Three such national-level variables will be tested here. Two relate to Japan, and examine the degree to which high manufacturing performance can be explained by a plant's location in Japan, or by its operation under Japanese management. The third relates to wage levels, and examines the degree to which poor manufacturing performance can be explained by location in a low-wage country, where the automation levels, education/skill levels, and the incentives to increase labor productivity are all likely to be low. The question in all cases is whether these dummy variables can explain performance differences in this sample better than the variables already included.

Japan-Related Explanations

National-level explanations are common with respect to Japan. Much of the writing about the Japanese economy and Japanese management techniques over the years has emphasized the unique and culturally-determined characteristics associated with the startling growth and economic strength of Japan in the post-war years.

In contrast to such a "culturalist" view, I have argued in Chapters 2 and 4 that the innovations of flexible production originated in Japan, in unique historical, economic, and cultural circumstances, and that flexible production systems are thereby most developed and firmly established in that country. Yet the "organizational logic" of flexible production constitutes a set of structural arrangements, I argue, that is not linked to any particular cultural or economic context -- a "structuralist" perspective.

A pure "culturalist" challenge would argue that the regression results described above are best explained by whether or not a plant is located in Japan -- that the structural argument is wrong and that flexible production systems are wholly dependent on Japanese cultural norms governing exchange relationships of all kinds, from contractual relations with suppliers to employment relations with employees, or various other aspects of the Japanese political economy. I will call this the "strong culturalist" position.

Another "culturalist" explanation challenging the structuralist argument is more subtle and not inconsistent with the argument of transferability. Flexible production systems are certainly diffusing, this argument would go, but only Japanese managers really know how to make them work. Thus Japanese management is the prior condition needed to make the policies and practices of flexible production effective. In the absence of Japanese management, attempts to transfer flexible production systems will fail. This is a weaker argument because it accepts that all other factors that support flexible production are independent of national culture. I will therefore call this the "weak culturalist" position.

There is a diffusion issue at stake here as well. The strong culturalist position would argue that diffusion is impossible, while the "pure" structuralist position would see few impediments to diffusion. The weak culturalist position, on the other hand, implies that some cultural "stickiness" may slow the diffusion process, but not prevent it. The rate of diffusion thus becomes a critical issue, but one which cannot be addressed with the cross-sectional data available here. Future administrations of the Assembly Plant survey will allow this issue to be investigated.

Culturalist vs. Structuralist Explanations: A Japan Effect? The culturalist (strong and weak) and structuralist explanations will be tested by including dummy variables for

Japan Location and Japanese Management in the regression equations used in earlier analyses. These dummy variables are highly correlated with the ProdOrg index that measures the extent to which MassProd or FlexProd policies and practices are used. But since the FlexProd characteristics that are measured are not particularistic with regard to national culture, this correlation is not conceptually problematic.[11] The relevant question here is whether the Japan-related dummy variables are statistically significant factors for manufacturing performance <u>even when</u> the non-particularistic indicators of production organization are held constant.

Statistically, including the dummy variable preserves the relationship among key variables but allows a different regression line to be fitted, e.g. for plants located in Japan, parallel to (i.e. with the same slope) the regression line for plants not located in Japan but with a different intercept. In other words, this approach assumes that the relationship <u>between IVs</u>, for example, technology level and scale will be similar for both categories of plants, but that the relationship <u>between the DV and the set of IVs</u> will differ based on other factors captured by the dummy variable.[12] An alternative approach to the use of

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[11] The dummy variables are potentially problematic statistically, however, because of multicollinearity. Their correlations with the ProdOrg index are quite high (LProdOrg with JapanLocation - r = .592; and LProdOrg with JapanMgmt - r = .716). These are high enough to weaken the reliability of the regression coefficients somewhat, but not high enough to undermine the results. Gujarati (1978) reports that the variance around the regression coefficients for two correlated variables rises exponentially as the correlation rises. When r = .7, the variance is 1.96 times the variance in the absence of collinearity. While high, the real problem with multicollinearity arises with higher correlations. For example, when r = .9, the variance is 5.26 times the non-collinear variance and when r = .95, the variance is 10.26 times the non-collinear variance. (At r = 1 -- pure multicollinearity -- the variance is infinite.) Thus a correlation of .7 is acceptably low for our purposes. The tolerance limits used by SPSSX to assess each variable before entering it into the regression equation provide a further safeguard against destabilizing multicollinearity.

[12] The decision to add dummy variables to the existing equations, with its assumption of equal slope for the groups thus defined, is supported by a regression analysis that includes LProdOrg, a Japanese dummy variable, and an interaction term, in which LProdOrg is multiplied by the Japanese dummy variable. If the interaction term has a statistically significant coefficient, it means that the slope of the regression lines for each group are different. In this analysis (with

dummy variables is to drop Japanese-located and Japanese-managed plants from the sample and then repeat the regression analyses.[13]

While there are no absolute standards for assessing the results when introducing these dummy variables, we can make the following statements:

1. If the coefficient of key variables goes to zero and the coefficient of the Japanese dummy variable is statistically significant, this supports the "strong culturalist" perspective.

2. If the coefficient of key variables remains statistically significant and the coefficient of the Japanese dummy variable goes to zero, this supports the "structuralist" perspective.

3. If coefficients for key variables and the Japanese dummy variable are all statistically significant, this supports the "weak culturalist" perspective.

Regression Analysis for Productivity. Table 6-8 contains the regression results for two of the five equations used above (Equations 2 and 3), first including a Japan location dummy and then including a Japanese management dummy. Equation 2 includes LScale, LTotAuto, and LProdOrg as IVs, and Equation 3 adds the three product-related IVs. Equations 4 and 5 are not used in this analysis because of the complications of interpreting the results when the Japan dummies are added to equations that already include dummy

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LogProd as DV and JapanMgt as the dummy variable), the interaction term is not statistically significant, supporting the assumption of equal slopes. (See Table 6-14) Of course, by rights this analysis would need to be repeated for each dummy variable and each different equation to confirm this assumption throughout the analysis.

[13] This approach makes no assumption about the stability of the relationship between IVs and allows an entirely new regression line to be fit for the subsample. But it has two problems in this context. First, the number of Japanese-located and Japanese-managed plants are too small for a separate regression analysis. So by dropping Japanese-located plants, we only gain new information about non-Japanese located plants, whereas the inclusion of a Japanese location dummy variable provides information about both groups of plants. Second, even the larger group of non-Japanese located plants is affected by the great reduction in degrees of freedom. With such a small sample and so many IVs, this is a risk to be avoided if possible. Notwithstanding these differences, the results from these two approaches are quite similar. (See Tables 6-15 and 6-16)

variables that cut across countries.

Table 6-8 shows regression results when these dummy variables are included, using LProductivity as the dependent variable. For productivity, the addition of the Japanese dummy variables produces a modest increase in adjusted R^2, regardless of which equation or which dummy variable, over the analyses without dummies.

In Equation 2, which includes only LScale, LTotAuto, LProdOrg, and the Japan dummy variables, both LProdOrg and the Japan dummy variable are statistically significant, with LProdOrg having a beta coefficient that is somewhat higher than the JapanLoc dummy and nearly equal to the JapanMgt dummy. As in the original Equation 2, LTotAuto has the highest beta coefficient and statistical significance, although this effect is somewhat diminished by the Japan dummy variables.

As the product variables are added in Equation 3, however, LProdOrg ceases to be statistically significant, while JapanLoc and JapanMgt, respectively, do remain statistically significant. While no longer statistically significant, the beta for LProdOrg remains moderately high; from Equation 2 to Equation 3, this coefficient drops from -.29 (with JapanLoc) and -.26 (with JapanMgt) to -.15 (in both equations) with the T-value dropping from around -2.4 to around -1.3. The effect of LTotAuto remains somewhat smaller.

Clearly, the Japanese dummy variables are the source of the reduction in significance of LProdOrg in Equation 3. The other variables, as expected, have approximately the same coefficients and significance levels as in the original analyses without dummy variables.

Regression Analysis for Quality. With LQuality as the dependent variable, the results are quite different (Table 6-9). In Equations 2 and 3, LProdOrg remains strongly statistically significant while the Japanese dummy variables are not significant. Indeed, the Japanese dummy variables are barely different from zero, with very low T-values ranging from .2 to .3 for the JapanLoc dummy and at around -.6 for the JapanMgt dummy. (The fact that the signs are different for the two variables is another sign of their low significance.)

Thus the productivity and quality results seem to tell a slightly different story. The productivity results don't support the "strong culturalist" view, because the coefficients for LProdOrg remain moderately high even when the Japanese dummy variables are included. But nor do they unequivocally support the "structuralist" view, since the LProdOrg coefficients are not statistically significant in these analyses and the Japanese dummy variables are. Instead, they appear to support the "weak culturalist" view.

The quality results, on the other hand, provide much more support for the structuralist view. The Japanese dummy variables are not statistically significant in these analyses and LProdOrg is.

It is clear that the FlexProd "organizational logic" is strongly associated with quality wherever it is utilized, regardless of whether the management is Japanese. It may be that the transition to a flexible production system first yields quality improvements and only over time yields comparable productivity improvements. Or that non-Japanese managers are better able to understand how to apply the principles of flexible production to quality improvement than to productivity improvement.

These analyses also support earlier findings about plants that achieve both high productivity and high quality. These "world class" plants (shown in Figure 4.3, in Chapter 4) are entirely Japanese-managed. Thus Japanese managers may still have a monopoly on knowledge about successfully achieving both of these outcomes.

Correlations within Japan and Non-Japan Subsamples. A final test of the effect of these Japanese dummy variables on the relationship of production organization and technology to manufacturing performance is to examine correlations within subsamples. The structuralist view would expect performance differences to be linked to ProdOrg within the Japanese subsample, while the weak culturalist view would only expect this relationship to hold outside of Japan.

Table 6-10 presents Spearman rank-order correlation coefficients between the main dependent variables in the analysis above (LProductivity and LQuality) and the main independent variables, for plants located in and out of Japan and plants that do and do not have Japanese management.[14] Rank-order correlations are used because the number of Japan-located and Japanese-managed plants is too small for Pearson correlation coefficients to be reliable. However, the complementary subsets are large enough for this procedure; the Pearson correlations are presented in Table 6-11.

For Japan-located and Japanese-managed plants, LProdOrg has a statistically significant rank-order correlation with both productivity and quality. This measure of production organization, therefore, successfully differentiates among these Japan-affiliated plants. It also is strongly correlated with both performance measures for the non-Japan subsamples, whether Spearman or Pearson coefficients are used. This supports the structuralist view over the weak culturalist view.

These subsamples also reveal intriguing differences in the relationship between complexity and performance. For Japanese-managed plants, Parts Complexity is significantly correlated with both productivity and quality. But the correlation is negative, meaning that plants with more parts complexity have fewer hours and defects per vehicle;

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[14] While the correlations are reported for the variables as they were transformed for the regression analyses, these linear transformations do not affect the correlation coefficient; the correlations are the same for the untransformed variables.

correlations between Model Mix Complexity and performance are also negative, although not significant.

But for the non-Japanese subsamples, there is a positive correlation between the two complexity measures and performance -- the more complexity, the more hours (and defects) per car. All of these correlations are statistically significant except for Parts Complexity and quality. This supports the conventional manufacturing wisdom -- that performance can be boosted by cutting complexity.[15]

Thus complexity, of either kind, does pose a considerable challenge to a production system. Yet there are important strategic advantages in being able to handle this complexity. FlexProd plants, particularly those located in Japan, have clearly learned how to handle high levels of complexity without an adverse impact on productivity and quality, while MassProd plants have not. The Japanese transplants represent a transitional case, starting out with low complexity to facilitate the learning process, but with all evidence suggesting they will add considerable complexity over time.

Low-Wage Country Explanations

While the Japan dummy variables provide the chance to examine hypotheses about the sources of the high performance associated with flexible production, the use of a dummy variable signifying low-wage countries focuses instead on the mostly mass production plants at the low end of the performance spectrum. To what degree are the regression results above determined by plants in New Entrant countries (NE) that have low-wage rates (and hence low incentive to improve labor productivity), low skill levels, low levels of automation, old product designs, traditional production organization and (one

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[15] Indeed, most U.S. automotive companies have set out on major consultant-led efforts to reduce the complexity of products, parts, and options made in a given plant, as a way to improve productivity and quality.

expects) poor manufacturing performance?

Here I use the same analyses as in the section above: the inclusion of a Low Wage Country dummy variable in the two main regression equations for both productivity and quality[16], followed by a comparison of correlations within Low Wage and non-Low Wage subsamples. There are eleven Low Wage plants, located in Brazil, Mexico, Korea, and Taiwan; these same plants make up the New Entrant category in the regional breakdown of individual variable means.

Table 6-12 shows the regression results for both outcome variables. For productivity, Equations 2 and 3 show smaller (and less significant) coefficients for LTotAuto and AgeCar and larger (and more significant) coefficients for both LProdOrg and Parts Complexity. The Low Wage dummy variable has a positive sign and is moderately strong, with a T-value of around 1.6, but not statistically significant. This means that Low Wage plants do have higher hours per vehicle, on average, than non-Low Wage plants with similar characteristics, but not significantly so.

It also suggests that there is a very strong relationship between the (mostly low) automation levels and (mostly old) products of these plants and their productivity, since the strength of the automation-productivity and design age-productivity relationships drop so much when these plants are kept separate. Parts Complexity and Production Organization, on the other hand, are linked somewhat more strongly to productivity for non-Low Wage plants than for Low Wage plants, since their statistical significance increases when the Low Wage dummy is included; it seems likely that the effects of automation and design age outweigh the effects of this variable.

Thus the expectations about Low Wage plants for productivity are largely

[16] The parallel analyses for the subsample of non-Low Wage Country plants can be found in Table 6-17.

confirmed, with low levels of automation and old product designs having a strong impact on their performance.

For quality, the results are quite different. First of all, the coefficient for TotAuto is very high in Equations 2 and 3. Since we know that the Low-Wage plants have low levels of automation, this indicates that they tend to have better quality than Low Tech plants in non - Low Wage countries, since the automation-quality relationship is stronger when they are held separate. Similarly, since the coefficient for product design age also rises, we know that quality at low-wage plants is less affected by having older products than in the rest of the sample.

Further confirmation of this comes from the high and statistically significant coefficient for the Low Wage dummy variable, which here takes a negative sign. When all else is held constant, Low Wage plants have better quality, on average, than non-Low Wage plants. All told, the high statistical significance of TotAuto, ProdOrg, and the Low Wage dummy contribute to an adjusted R^2 for Equation 3 of over 51% -- more than 15% more than the same equation without the Low Wage dummy.

The Spearman rank-order correlations found in Table 6-13 provide further support for what we are learning about the Low Wage plants. For the Low Wage plants, ProdOrg, TotAuto, and AgeCar are significantly correlated with both productivity and quality. Within this group of plants, therefore, the variation in these variables is strongly linked to performance.

The correlations for the non-Low Wage subsample reveal the same patterns seen earlier, with ProdOrg, TotAuto, Scale, and AgeCar showing the strongest correlations to productivity and quality. The correlation between Parts Complexity and each outcome is quite low, not statistically significant, and has a positive sign for productivity and a negative sign for quality. This stands in contrast with the moderately high correlation in the Low Wage subsample, because the non-Low Wage subsample combines Japanese-managed plants, for which Parts Complexity is negatively correlated with performance, with non-Japanese plants, for which this correlation is positive. But it also indicates that, for the Low Wage plants, high parts complexity represents a performance impediment, at least in terms of productivity. Within the largely MassProd context of the Low Wage plants, high complexity is associated with more hours per car.

In summary, counter to the usual assumptions about Low Wage countries, there is strong evidence that several Low Wage plants are successfully implementing the principles of flexible production. The superior quality produced at some Low Wage plants (including the plant with the best quality level in the sample) is the most striking consequence of this to date. Productivity levels do conform more to conventional expectations. Also, these plants are not yet able to handle high complexity without a performance penalty. But it would be unwise to underestimate the future progress of plants in Low Wage countries. They may move more quickly to a full implementation of flexible production systems than plants in the U.S. and Europe.

Conclusion

Several strong findings emerge from this extensive multivariate analysis of manufacturing performance:

- The integration hypothesis, supported in Chapter 5 in the absence of control variables, is sustained by the full multivariate analysis, although more so for productivity than for quality, where the role of technology appears to be subordinate to that of production organization.
- The regression equations, in all the various specifications, both with and without

dummy variables, consistently yield statistically significant results ($p < .01$ for all F-tests) and high levels of variance explained (adjusted R^2 levels between 58% and 70% for productivity and between 28% and 52% for quality).

- The addition of Japan-related dummy variables weakens the explanatory power of the production organization variable somewhat. This lends some weight to the "weak culturalist" view of the sources of manufacturing performance, particularly for productivity. But the overall results, especially for quality, are even more supportive of the structuralist perspective taken in this dissertation.

- The addition of the Low Wage dummy variable reveals that, in terms of productivity, these plants do suffer from low levels of automation and old product designs. Yet, in terms of quality, plants in Low Wage countries are among the best in the world, an achievement that is most strongly associated with the partial adoption of flexible production principles. These results provide ample reason for rethinking conventional expectations of Low Wage plants.

- The regression analyses consistently reveal virtually no relationship between Model Mix Complexity and either outcome. Furthermore, we find that the relationship between Parts Complexity and performance varies dramatically for different groups of plants. Among Japanese-managed plants, plants with more complexity have better performance. Among non-Japanese plants, high complexity plants have poorer performance. Low Wage plants, where complexity levels are quite high, reveal this relationship most strongly. Most non-Japanese, non-Low Wage plants seem to keep complexity levels low. This suggests that, as with technology, there are important differences in how complexity is handled in MassProd and FlexProd organizational contexts.

- Model Mix Complexity can also be taken as a proxy for product variety. Thus, there is no relationship between either performance outcome and product variety.

Furthermore, there is virtually no correlation between Production Organization and product variety. In other words, flexible production plants do not always have high product variety and mass production plants do not always have low product variety. This suggests it is a mistake to make the high product variety the defining characteristic of a flexible production system. Flexibility may have more to do with the organizational capability to configure the production system for either high or low product variety, depending on market demand and product strategy.

Table 6-1

Control Variables by Regional Groupings:
Descriptive Statistics

Model Mix Complexity (0=Low; 100=High)

Company region/Plant region	Mean	S.D.
Whole sample	30.9	21.3
Japan/Japan	41.0	29.0
Japan/North America	15.1	10.4
U.S./North America	21.1	11.1
All/Europe	30.2	18.3
All/New Entrant Countries	42.6	28.2
All/Australia	31.2	16.5

Parts Complexity (0=Low; 100=High)

Company region/Plant region	Mean	S.D.
Whole sample	56.5	23.5
Japan/Japan	72.5	15.8
Japan/North America	30.0	21.4
U.S./North America	43.8	17.2
All/Europe	71.0	18.9
All/New Entrant Countries	55.5	22.7
All/Australia	38.9	20.7

Plant Scale (vehicles per day)

Company region/Plant region	Mean	S.D.
Whole sample	904.4	640.0
Japan/Japan	1384.9	771.4
Japan/North America	790.0	247.4
U.S./North America	835.6	156.5
All/Europe	1150.9	778.7
All/New Entrant Countries	605.6	530.3
All/Australia	267.5	98.6

Table 6-1 (continued)

Product Design Age (years since product(s) was introduced)

Company region/Plant region	Mean	S.D.
Whole sample	4.7	3.6

Japan/Japan	2.0	.97
Japan/North America	2.0	1.2
U.S./North America	4.5	2.6
All/Europe	4.7	2.6
All/New Entrant Countries	8.6	5.6
All/Australia	3.4	1.8

Table 6-2

Descriptive Statistics for Regression Analysis

Variable	Mean	S.D.
Labor Productivity (LProd)	1.48	0.156
Scale (LScale)	2.87	0.293
Total Automation (LTotAuto)	0.094	0.049
Production Organization (LProdOrg)	1.61	0.192
Model Mix Complexity (Mix)	31.13	21.08
Parts Complexity (Parts)	56.07	23.50
Product Design Age (AgeCar)	4.79	3.29

(n = 56)

Variable	Mean	S.D.
Quality (LQual)	1.86	0.173
Scale (LScale)	2.85	0.306
Total Automation (LTotAuto)	0.094	0.050
Production Organization (LProdOrg)	1.62	0.211
Model Mix Complexity (Mix)	31.95	21.59
Parts Complexity (Parts)	54.02	24.01
Product Design Age (AgeCar)	4.80	3.62

(n = 44)

Table 6-3

Correlation Matrix for Regression Analyses

	LProd	LScale	LTech	LOrg	Mix	Parts	AgeCar
LProd	1.0						
LScale	-.433	1.0					
LTotAuto	-.686	.635	1.0			n = 56	
LProdOrg	-.644	.284	.466	1.0			
Mix	.068	-.034	-.221	.113	1.0		
Parts	.144	.458	.050	-.037	.449	1.0	
AgeDes	.612	-.204	-.547	-.461	.091	.203	1.0

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	LQual	LScale	LTech	LOrg	Mix	Parts	AgeCar
LQual	1.0						
LScale	-.264	1.0					
LTotAuto	-.383	.668	1.0			n = 44	
LProdOrg	-.640	.310	.452	1.0			
Mix	.040	.079	-.171	.124	1.0		
Parts	-.044	.504	.176	.004	.532	1.0	
AgeDes	.288	-.221	-.579	-.482	.100	.225	1.0

Table 6-4

Regression Results:
Log Labor Productivity as DV - Standardized Coefficients
(T-statistics in parentheses)

Variable	Eq1	Eq2	Eq3	Eq4	Eq5
LScale	.005 (-0.04)	-.003 (-.03)	-.21 (-1.6)	-.24 (-1.8)*	-.38 (-3.5)***
LTotAuto	-.69 (-5.3)***	-.49 (-4.0)***	-.33 (-2.5)**	---	---
LProdOrg	---	-.41 (-4.2)***	-.32 (-3.1)***	-.32 (-3.1)***	---
Mix	---	---	-.11 (-1.1)	-.12 (-1.1)	-.05 (-.48)
Parts	---	---	.25 (2.2)**	.23 (1.9)*	.41 (3.7)***
AgeCar	---	---	.20 (1.9)*	.19 (1.7)*	.23 (2.4)**
AutoDum1 (0-12%)	---	---	---	.38 (2.3)**	---
AutoDum2 (13-24%)	---	---	---	.139 (1.2)	---
AutoDum3 (25-36%)	---	---	---	.143 (1.2)	---
ClusDum1 (Low Tech - MassProd)		---	---	---	.80 (5.1)***
ClusDum2 (High Tech - MassProd)		---	---	--- (5.1)***	.69
ClusDum3 (Low Tech - Trans FlexProd)		---	---	--- (3.5)***	.36
ClusDum4 (High Tech - Trans FlexProd)		---	---	--- (3.4)***	.37

Adj. R^2	45.1%	58.3%	63.4%	61.7%	66.8%
F for eq.	23.6***	26.6***	16.9***	12.1***	14.9***
N	56	56	56	56	56

Table 6-5

Regression Results:
Log Labor Productivity as DV - Shared and Unique Variance
(expressed as percentage effect on adjusted R-Squared)

Variable	Eq1	Eq2	Eq3	Eq4	Eq5
LScale	0.00%	0.00%	1.8%	2.2%	7.3%
LTotAuto	28.3%	12.3%	4.0%	---	---
LProdOrg	---	13.7%	6.5%	6.8%	---
Mix	---	---	0.7%	0.8%	0.2%
Parts	---	---	3.2%	2.6%	8.2%
AgeCar	---	---	2.3%	1.9%	3 2%
AutoDum1 (0-12%)	---	---	---	3.6%	---
AutoDum2 (13-24%)	---	---	---	1.0%	---
AutoDum3 (25-36%)	---	---	---	1.2%	---
ClusDum1 (Low Tech - MassProd)		---	---	---	15.4%
ClusDum2 (High Tech - MassProd)		---	---	---	15.7%
ClusDum3 (Low Tech - Trans FlexProd)		---	---	---	7.3%
ClusDum4 (High Tech - Trans FlexProd)		---	---	---	7.3%

% Shared var.	18.8%	34.5%	48.9%	47.1%	7.0%
Unadjusted R^2	47.1%	60.5%	67.4%	67.2%	71.6%
F for eq.	23.6***	26.6***	16.9***	12.1***	14.9***

Table 6-6

Regression Results:
Log Quality as DV - Standardized Coefficients
(T-statistics in parentheses)

Variable	Eq1	Eq2	Eq3	Eq4	Eq5
LScale	.02 (-0.08)	-.01 (-.04)	.04 (.19)	.10 (.49)	-. 1 (-.07)
LTotAuto	-.37 (-1.9)**	-.11 (-.65)	-.10 (-.44)	---	---
LProdOrg	---	-.59 (-4.3)***	-.66 (-4.4)***	-.64 (-4.3)***	---
Mix	---	---	.17 (1.0)	.13 (.80)	.03 (.07)
Parts	---	---	-.12 (-.61)	-.06 (-.29)	.17 (.78)
AgeCar	---	---	-.07 (-.39)	-.14 (-.76)	-.19 (-.99)
AutoDum1 (0-12%)	---	---	---	.19 (.74)	---
AutoDum2 (13-24%)	---	---	---	.23 (1.3)	---
AutoDum3 (25-36%)	---	---	---	-.12 (-.85)	---
ClusDum1 (Low Tech - MassProd)		---	---	---	.98 (3.5)***
ClusDum2 (High Tech - MassProd)		---	---	--- (2.6)**	.54
ClusDum3 (Low Tech - Trans FlexProd)		---	---	--- (.31)	.05
ClusDum4 (High Tech - Trans FlexProd)		---	---	--- (1.1)	.20

Adj. R^2	10.5%	37.7%	35.2%	39.1%	28.3%
F for eq.	3.5**	9.7***	4.9***	4.4***	3.1***
N	44	44	44	44	44

Table 6-7

Regression Results:
Log Quality as DV - Shared and Unique Variance
(expressed as percentage effect on adjusted R-Squared)

Variable	Eq1	Eq2	Eq3	Eq4	Eq5
LScale	0.01%	0.01%	0.04%	0.4%	0.01%
LTotAuto	7.8%	0.6%	0.25%	---	---
LProdOrg	---	27.0%	29.2%	26.0%	---
Mix	---	---	1.7%	0.8%	0.04%
Parts	---	---	0.5%	0.09%	1.0%
AgeCar	---	---	0.25%	0.8%	1.7%
AutoDum1 (0-12%)	---	---	---	0.8%	---
AutoDum2 (13-24%)	---	---	---	2.6%	---
AutoDum3 (25-36%)	---	---	---	1.0%	---
ClusDum1 (Low Tech - MassProd)		---	---	---	20.3%
ClusDum2 (High Tech - MassProd)		---	---	---	11.6%
ClusDum3 (Low Tech - Trans FlexProd)		---	---	---	0.2%
ClusDum4 (High Tech - Trans FlexProd)		---	---	---	2.0%

% Shared var.	6.9%	14.4%	12.4%	17.9%	4.9%
Unadjusted R^2	14.7%	42.0%	44.3%	50.4%	41.7%
F for eq.	3.5**	9.7***	4.9***	4.4***	3.1***

Figure 6-1

Plants with Flexible Production Organization Vary Widely in Degree of Product Variety

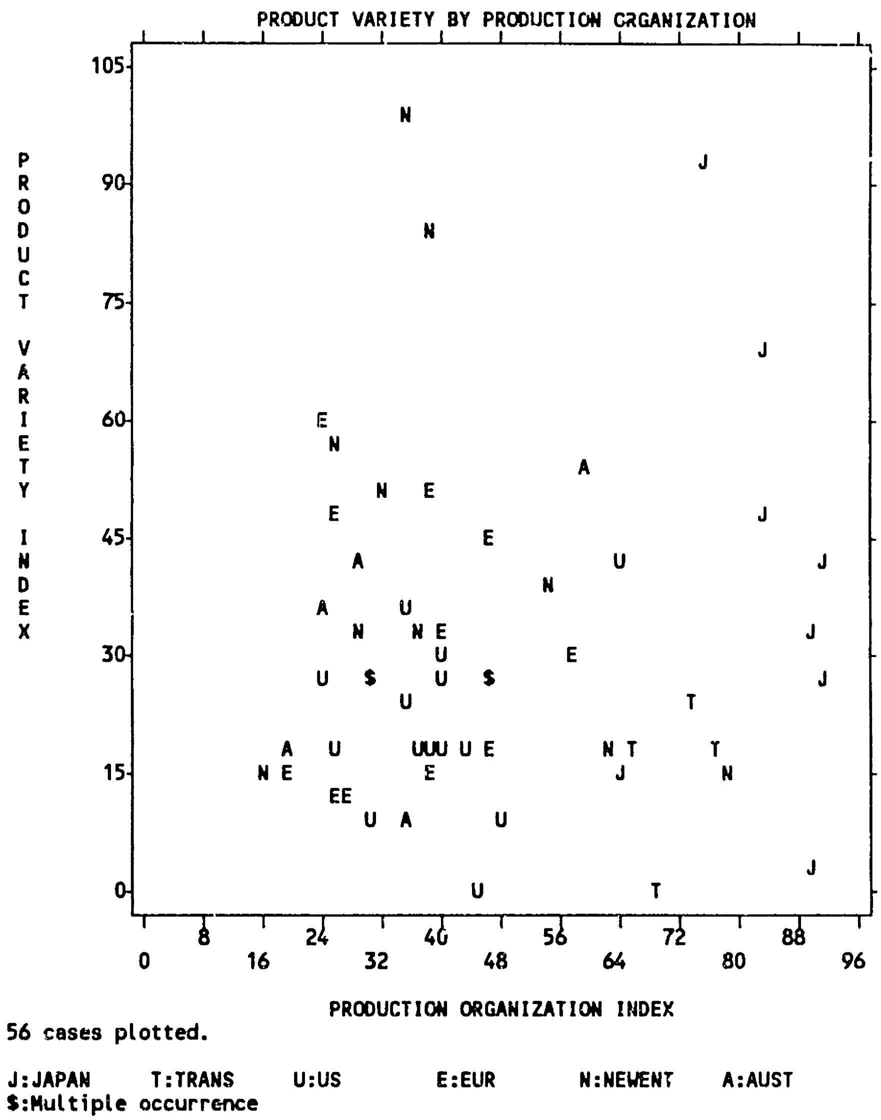

Table 6-8

Regression Results:
Log Labor Productivity as DV - Standardized Coefficients
Dummy Variables for Japan Location and Management
(T-statistics in parentheses)

Variable	Japan Location Dummy Eq2	Japan Location Dummy Eq3	Japanese Mgmt. Dummy Eq2	Japanese Mgmt. Dummy Eq3
LScale	.01 (.09)	-.26 (-2.2)**	-.03 (-.25)	-.25 (-2.0)**
LTotAuto	-.47 (-4.0)***	-.26 (-2.0)**	-.44 (-3.6)***	-.27 (-2.0)**
LProdOrg	-.29 (-2.6)***	-.15 (-1.4)	-.26 (-2.1)**	-.15 (-1.2)
Mix	---	-.06 (-.61)	---	-.10 (-1.0)
Parts	---	.34 (3.1)***	---	.27 (2.4)**
AgeCar	---	.18 (1.9)*	---	.19 (1.8)*
JapanLoc	-.23 (-2.2)**	-.33 (-3.3)***	---	---
JapanMgt	---	---	-.25 (-2.0)*	-.26 (-2.3)**

Adj. R^2	61.1%	69.5%	60.5%	66.3%
F for eq.	22.6***	18.9***	22.0***	16.5***
N	56	56	56	56

Table 6-9

Regression Results:
Log Quality as DV - Standardized Coefficients
Dummy Variables for Japan Location and Management
(T-statistics in parentheses)

Variable	Japan Location Dummy Eq2	Japan Location Dummy Eq3	Japanese Mgmt. Dummy Eq2	Japanese Mgmt. Dummy Eq3
LScale	-.01 (-.07)	.04 (.21)	-.02 (-.11)	.02 (.10)
LTotAuto	-.12 (-.68)	-.11 (-.46)	-.08 (-.43)	-.05 (-.23)
LProdOrg	-.61 (-3.8)***	-.68 (-3.8)***	-.52 (-2.8)***	-.58 (-3.0)***
Mix	---	.17 (.98)	---	-.18 (1.1)
Parts	---	-.13 (-.63)	---	-.12 (-.59)
AgeCar	---	-.07 (-.37)	---	-.07 (-.36)
JapanLoc	.05 (.30)	.03 (.19)	---	---
JapanMgt	---	---	-.11 (-.57)	-.12 (-.61)

Adj. R^2	36.2%	33.6%	36.6%	34.2%
F for eq.	7.1***	4.1***	7.2***	4.2***
N	44	44	44	44

Table 6-10

Spearman Correlation Coefficients
Log Labor Productivity and Log Quality by Key IVs
Subsets of Sample

Variable	Japan Location LPROD	Japan Location LQUAL	Non-Japan Location LPROD	Non-Japan Location LQUAL
LScale	-.83***	-.57*	-.35***	-.24*
LTotAuto	.02	.00	-.65***	-.36**
LProdOrg	-.54*	-.69**	-.43***	-.46***
Mix	.17	.24	.34***	.31**
Parts	.10	-.42	.42***	.15
AgeCar	-.21	-.21	.46***	.25*
N	8	8	49	38

Variable	Japanese Management LPROD	Japanese Management LQUAL	Non-Japanese Management LPROD	Non-Japanese Management LQUAL
LScale	-.76***	-.56**	-.36***	-.22
LTotAuto	-.29	-.01	-.61***	-.23*
LProdOrg	-.56**	-.41*	-.31**	-.25*
Mix	-.36	-.11	.31**	.26*
Parts	-.52**	-.50**	.37***	.01
AgeCar	.07	-.30	.37***	.11
N	13	12	45	33

Table 6-11

Pearson Correlation Coefficients
Log Labor Productivity and Log Quality by Key IVs
Subsets of Sample

	Japan Location		Non-Japan Location	
Variable	LPROD	LQUAL	LPROD	LQUAL
LScale	---	---	$-.20^{*}$	-.17
LTotAuto	---	---	$-.62^{***}$	$-.30^{**}$
LProdOrg	---	---	$-.44^{***}$	$-.52^{***}$
Mix	---	---	$.26^{**}$	.19
Parts	---	---	$.33^{***}$	.00
AgeCar	---	---	$.68^{***}$	.14
N	8	8	49	38

	Japanese Management		Non-Japanese Management	
Variable	LPROD	LQUAL	LPROD	LQUAL
LScale	---	---	$-.22^{*}$	-.18
LTotAuto	---	---	$-.58^{***}$	-.19
LProdOrg	---	---	$-.33^{**}$	$-.40^{**}$
Mix	---	---	$.21^{*}$	.12
Parts	---	---	$.27^{**}$	-.10
AgeCar	---	---	$.65^{***}$	.05
N	13	12	45	33

Table 6-12

Regression Results:
Log Labor Productivity and Log Quality - Standardized Coefficients
Dummy Variable for Low Wage Countries
(T-statistics in parentheses)

Variable	LProductivity as DV Eq2	LProductivity as DV Eq3	LQuality as DV Eq2	LQuality as DV Eq3
LScale	-.03 (-.30)	-.25 (-1.9)*	.18 (1.2)	.26 (1.5)
LTotAuto	-.33 (-2.1)**	-.22 (-1.4)	-.60 (-2.9)***	-.51 (-2.3)**
LProdOrg	-.46 (-4.6)***	-.36 (-3.5)***	-.46 (-2.9)***	-.47 (-3.4)***
Mix	---	-.14 (-1.3)	---	.22 (1.5)
Parts	---	.29 (2.5)**	---	-.27 (-1.6)
AgeCar	---	.14 (1.3)	---	.19 (1.1)
LowWage	.19 (1.6)	.18 (1.5)	-.51 (-3.5)***	-.60 (-3.7)***
Adj. R^2	59.5%	64.4%	51.2%	51.5%
F for eq.	21.2***	15.2***	12.3***	7.5***
N	56	56	44	44

Table 6-13

Spearman Correlation Coefficients
Log Labor Productivity and Log Quality by Key IVs
Subsets of Sample

	Low Wage Country		Non-Low Wage Country	
Variable	LPROD	LQUAL	LPROD	LQUAL
LScale	-.23	.02	-.26**	-.50***
LTotAuto	-.52*	-.53*	-.62***	-.57***
LProdOrg	-.47*	-.73**	-.64***	-.66***
Mix	.00	.53*	.01	.03
Parts	.41	.53*	.15	-.26
AgeCar	.83***	.72***	.44***	.36**
N	11	11	45	37

Table 6-14

Regression Results:
Log Labor Productivity as DV - Standardized Coefficients
with Japanese Management and Interaction Term (LProdOrg*JpnMgt)
(T-statistics in parentheses)

	LProdOrg and Dummy Vars. Only			Other Variables Included	
Variable	EqA	EqB	EqC	Eq2	Eq3
LScale	---	---	---	-.01 (-.08)	-.23 (-1.8)
LTotAuto	---	---	---	-.45 (-3.6)***	-.29 (-2.1)
Mix	---	---	---	---	-.09 (-.95)
Parts	---	---	---	---	.29 (2.6)**
AgeCar	---	---	---	---	.19 (1.8)
LProdOrg	-.64 (-6.2)***	-.39 (-2.7)***	-.38 (-2.6)**	-.25 (-1.9)*	-.13 (-1.1)
JapanMgt	---	-.36 (-2.5)**	-.07 (-.09)	.07 (.10)	.40 (.61)
Interaction (LProdOrg*JpnMgt)	---	--- (-.38)	-.29 (-.46)	-.33 (-1.0)	-.68

Adj. R^2	40.4%	45.7%	44.8%	59.9%	66.3%
F for eq.	38.3***	24.1***	15.9***	17.4***	14.5***
N	56	56	56	56	56

Table 6-15

Regression Results:
Log Labor Productivity as DV - Standardized Coefficients
Non-Japan Subsamples
(T-statistics in parentheses)

Variable	Non-Japan Location Eq2	Non-Japan Location Eq3	Non-Japanese Mgmt. Eq2	Non-Japanese Mgmt. Eq3
LScale	.08 (.59)	-.23 (-1.5)	.10 (.63)	-.23 (-1.3)
LTotAuto	-.60 (-4.2)***	-.35 (-2.2)**	-.63 (-3.9)***	-.38 (-2.2)**
LProdOrg	-.29 (-2.6)**	-.16 (-1.4)	-.23 (-1.9)*	-.12 (-1.1)
Mix	---	-.05 (-.46)	---	-.06 (-.45)
Parts	---	.36 (2.6)**	---	.38 (2.6)**
AgeCar	---	.22 (1.9)*	---	.21 (1.7)*

Adj. R^2	46.5%	56.5%	38.8%	50.2%
F for eq.	14.9***	11.4***	10.3***	8.4***
N	49	49	45	45

Table 6-16

Regression Results:
Log Quality as DV - Standardized Coefficients
Non-Japan Subsamples
(T-statistics in parentheses)

Variable	Non-Japan Location Eq2	Non-Japan Location Eq3	Non-Japanese Mgmt. Eq2	Non-Japanese Mgmt. Eq3
LScale	.08 (.42)	.09 (.40)	.09 (.40)	.10 (.34)
LTotAuto	-.19 (-.95)	-.10 (-.37)	-.18 (-.77)	-.10 (-.33)
LProdOrg	-.51 (-3.4)***	-.58 (-3.5)***	-.41 (-2.5)**	-.47 (-2.6)**
Mix	---	.25 (1.3)	---	.25 (1.1)
Parts	---	-.15 (-.65)	---	-.11 (-.44)
AgeCar	---	-.05 (-.26)	---	-.06 (-.27)

Adj. R^2	26.5%	24.1%	11.5%	6.6%
F for eq.	5.3***	2.9**	2.4*	1.4(n.s.)
N	37	37	33	33

Table 6-17

Regression Results:
Log Labor Productivity and Log Quality - Standardized Coefficients
Non-Low Wage Countries Subsample
(T-statistics in parentheses)

	LProductivity as DV		LQuality as DV	
Variable	Eq2	Eq3	Eq2	Eq3
LScale	-.02 (-.13)	-.27 (-1.7)	-.004 (-.02)	.10 (.45)
LTotAuto	-.33 (-2.1)**	-.26 (-1.7)	-.34 (-1.6)	-.29 (-1.3)
LProdOrg	-.50 (-4.1)***	-.47 (-3.6)***	-.49 (-3.4)***	-.51 (-3.0)***
Mix	---	-.15 (-1.1)	---	.17 (.92)
Parts	---	.40 (2.5)**	---	-.28 (-1.4)
AgeCar	---	-.02 (-.13)	---	.08 (.49)

Adj. R^2	50.4%	55.1%	47.1%	45.0%
F for eq.	15.9***	10.0***	11.1***	5.6***
N	45	45	35	35

CHAPTER 7

PROCESS AND STRUCTURE:

PROBLEM-SOLVING UNDER MASS AND FLEXIBLE PRODUCTION

In Chapter 2, I described mass and flexible production as having a different "organizational logic". One component of this logic consists of structural arrangements (the "structural logic"); this provided the conceptual base for the measurement of production organization in the International Assembly Plant Study and the data analyses in Chapters 4-6. The other component is the "cultural logic" -- in particular, the way in which individuals think about the production system and their role in its operation. I argued in Chapter 2 that under the "cultural logic" of flexible production, innovation is considered to be part of the production task, resulting in a different view of information processing, the division of labor, and coordination processes than under mass production.

In this chapter, I present the results of an exploratory study of problem-solving processes at three North American assembly plants. Daily problem-solving activities, I will argue, are organizational processes that provide a valuable window into the "cultural logic" -- a way to examine whether production activities are integrated with, or separate from innovation. The goals for the problem-solving study are twofold: 1) To gain a better understanding of the "cultural logic" of a production system; and 2) To examine the relationship between the "cultural logic" and the "structural logic" in daily production operations -- or what can also be understood as the relationship between process and structure.

The distinction I will make between process and structure in this chapter requires some definition. I define "structure" as "enduring patterns of work roles and administrative mechanisms that allow organizations to conduct, coordinate, and control work activities (Miller 1987). I define "process", in turn, as "how people get things done; a recurrent flow of events, the outcome of which depends on the combination and recombination of particular conditions" (adapted from Mohr, 1982). Using these definitions, structure may provide many of the conditions affecting process, but it cannot be wholly determinative of process, since it cannot control all the conditions affecting a sequence of human action.[1]

The data analysis in the preceding chapters shows a very strong relationship between the "structural logic" of a plant's production system, as measured by the Production Organization index, and its manufacturing performance. But I suggest at several points that it is the underlying organizational processes that these structural arrangements foster that are responsible for this link to performance, rather than the structural arrangements themselves. The problem-solving study provides the opportunity to develop a richer description of these underlying processes.

The problem-solving study also makes possible an examination of a key assumption underlying the earlier data analysis -- that the structural and cultural elements of a

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[1] I make this distinction because I find it analytically useful, although I am broadly sympathetic to the "structuration" view of Giddens (1976). He writes that "social structures are both constituted by human agency and yet at the same time are the medium of this constitution." The actions of individuals influence social structure, yet structures also constrain such action because they precede the individual act, being in part the outcome of the intertwining of previous individual acts. Thus structure is at once emergent from and constrained by social action, i.e. process. Thus for Giddens, there can be no question of a "link" between structure and process. Examination of social process reveals the social structure -- both its constraining and its dynamic aspects. If structure is essentially constrained process, a structure-process distinction makes no sense.

This view of structure and process is valuable as a corrective to the overly formalistic and deterministic perspectives on structure found in much of the classic sociological literature. But it poses many challenges as a research strategy, since it requires an intensive, longitudinal examination of social process. In this dissertation, the cross-sectional data from the Assembly Plant Study captures only the formal elements of structure. The fieldwork, on the other hand, provides a glimpse of social process under various formal organizational arrangements. Given this research design, therefore, a structure-process distinction is analytically valuable.

production system are aligned, so that the empirical assessment of the former also accurately captures the latter. Here, I examine that assumption by considering the structural and cultural logic of a production system as two separate dimensions.

In Figure 7-1, where the interaction of these dimensions is portrayed, the expected alignment between these two logics occurs in the cells on the main diagonal. The off-diagonal cells (MassProd structure and FlexProd culture, or FlexProd structure and MassProd culture) then raise several interesting questions about the dynamics of production systems. Are plants in these cells stable, or in transition between mass and flexible production? Does process or structure have the greater influence on how the production system in such plants actually operates?

Figure 7-1

Interaction between the Structural and Cultural Dimensions of a Production System

Structural Logic \ Cultural Logic	MassProd	FlexProd
MassProd	---	Ford
FlexProd	GM	Honda

The three plant case studies in this chapter -- from General Motors (GM), Ford, and Honda -- fill three of the four cells in Figure 7-1. The fieldwork reveals that the GM plant has a FlexProd structure and a MassProd culture, while the Ford plant has a MassProd structure and a FlexProd culture. The Honda plant is the "aligned" case, with both a FlexProd structure and culture.

In the next section, I describe the problem-solving study -- the perspective on problem-solving, the selection of problems to compare across plants, the selection of plants (and the process of gaining access to them), characteristics of the three plants that were selected, and the fieldwork methods used to study problem-solving processes. The case studies and a discussion section will follow.

A. OVERVIEW OF THE PROBLEM-SOLVING STUDY

Perspective on Problem-Solving

To examine problem-solving activities from a process perspective, I emphasize the sequential stages of problem-solving and the conditions that may affect each stage and overall outcomes. I follow a commonly used model of problem-solving, consistent with that found in March and Simon (1958), Tyre (1988), and Imai (1986), which includes the following stages:

1. Problem definition
2. Problem analysis
3. Generation and selection of solutions
4. Implementation
5. Evaluation - confirmation of results
6. Standardization - development of new routines

This model is not meant to suggest that all problem-solving activity necessarily involves all of these stages, or occurs in this particular sequence. It may be the case that much so-called problem-solving involves solutions looking for problems (e.g. March and Cohen, 1986), or implementation without search. Nevertheless, this multi-stage model is useful because it helps to focus attention on a sequential flow of activity over time, and provides a way to organize the observations from the fieldwork.

Because my fieldwork was not extensive enough to cover all stages of the problem-solving process adequately, this chapter focuses primarily on the first three stages of the problem-solving process -- problem definition, problem analysis, and the generation and selection of solutions.

Problem definition is the result of a problem situation being perceived by organizational actors in light of established routines and subsequently defined in relation to those routines. (Tyre, 1988) The definition chosen will affect all subsequent stages of the problem-solving process.

Problem analysis could also be described as "search activity." March and Simon (1958) see search -- "aimed at discovering alternatives or consequences of action" -- as the key variable in problem-solving activity, and as differentiating routinized or programmed activity (involving little or no search) from problem-solving.

The generation and selection of solutions is heavily influenced by the skills and knowledge that individuals bring to problem analysis, by the variety of perspectives brought by different individuals (representing different groups), by the way individuals and groups interact during the problem-solving process, and by organizational reward and control systems.

For each of these stages, I ask questions aimed at revealing differences in cultural logic:

1. Problem definition -- What counts as a problem? What information on problems is gathered and how is it used? What kinds of problems are considered legitimate for problem-solving and which are not?

2. Problem analysis -- Who is involved in problem analysis? How broad (and/or deep) is the conceptual knowledge they bring to the analytical task? What strategy guides the analysis? What search techniques and methodologies are used?

3. Solution generation and selection -- Who is involved in generating and selecting solutions? To what degree do they share a common conception of the problem? What approach to generating solutions is used, in terms of techniques, group activities, boundary-spanning activities? What criteria are used for selection?

Problem Characteristics

I chose to focus on problems with the following characteristics:

1) In-plant production-related problems that affect quality (and, to some extent, productivity);

2) Production problems that are not clearly traceable to one clearcut source (e.g. one machine, one work group) but have many possible sources.

There are several advantages of this choice. First, there are problems of this kind that are common to all assembly plants, regardless of other plant characteristics (scale, level of technology, production organization) or contextual characteristics (national differences in labor relations or supplier relations). Second, problems of this kind cannot be easily resolved by applying a standard procedure or methodology, so there is likely to be more variation in how successfully they are resolved. Third, problems of this kind are likely to require high levels of interaction and coordination during problem definition, problem analysis, and solution generation among individuals in multiple departments or functional groups. This increases the likelihood of gaining insights into the culture of the production system.

After discussion with my colleagues in the International Motor Vehicle Program and production managers from the auto companies, I selected three problem categories with these characteristics: water leaks, paint defects (chips, scratches, runs) and functional electrical defects (no connection, faulty connections or components). All are readily noticeable by customers. Indeed, all of them are measured in the J.D. Power consumer surveys used as the basis for the quality measure used in this research. Furthermore, all three problems have many possible sources (of which the examples that follow are but a few).

Water leaks, for example, can result from gaps left in the metal frame of the car after it is welded in the body shop, which can in turn result from poorly made or damaged stampings, from misadjusted welding jigs or malfunctioning welding equipment. Or they can result if the body sealer applied in the paint department before painting occurs is either missing or inadequate. Or they can result if the rubber weatherstripping applied in the assembly department is poorly attached -- which can in turn be due to metal burrs around window and door openings, bad weatherstripping, or sloppy installation.

Paint problems can similarly result from many sources. While the paint process can be affected by small variations in the paint itself, in the evenness of the spray from paint robots, or in the temperature and humidity of the plant and the bake ovens, the more elusive paint problems occur outside the paint booths. Painted bodies can be chipped or scratched by anything from a worker's belt buckle and a tool set down in the wrong place during a repair to a misadjusted conveyer or a redesigned jig. Misapplied sealer can prevent paint from adhering properly. Dirt can become embedded in paint because of inadequate cleaning after sanding, fibers coming off of gloves, conveyor lines between paint process steps that are not sealed off from the rest of the plant, paint ovens that are not cleaned often enough, and countless other reasons.

The third category, functional electrical defects, refers to problems affecting the operation of interior and exterior lights, instrument panel, wipers, radio, air conditioning. While some defects can be traced to faulty components, missing or faulty electrical connections account for many of these problems. The source of problems with connections can, as above, be multifold. If misapplied sealer covers a hole needed for a fastener holding instrument panel wiring, the fastener cannot be anchored and the unsecured wire can easily catch on something and break. Certain option combinations may pack so much equipment in the dashboard that wires have difficulty reaching their connectors. Two connectors may be pushed together without quite locking in place, and may subsequently vibrate loose. If electrical wiring is misrouted, a subsequent operation attaching parts may put a screw through a wire, creating a short-circuit.

These three problem categories can also be inter-related. For example, while heavy applications of sealer can help prevent water leaks, this increases the odds of mistakenly sealing over holes needed for fastening electrical wire harnesses. Other examples of these interrelationships are noted in the case studies.

Choice of Plants and Access Arrangements

My research sites for this study were three assembly plants in North America. Since I was interested in studying problem-solving processes, I chose plants that were relatively high performers in terms of quality and productivity within their company, reasoning that there would be a stronger likelihood of finding a readily observable level of problem-solving activity in such plants.

The choice of plants was heavily constrained by access opportunities. Originally, I had planned to visit a larger number of plants, to allow a sampling of a broader range of performance levels and other criteria, but I was not able to gain the necessary access. My time at each plant was also limited by the companies to less than I had originally hoped to spend.

I had the most difficulty gaining access to a Japanese-owned plant in North America for this problem-solving study. While I was able to visit five of the "transplants" for one or two days each, and to get survey responses from four of them, it was considerably more difficult to get access for a longer stay. I tried unsuccessfully to gain access to the NUMMI (GM-Toyota) plant in California and the Mazda plant in Michigan for this study. Ultimately, one of the three Honda plants in North America agreed to let me visit. I made two 1-day visits to the plant in the fall of 1988 and was about to arrange a longer stay when my contact, a senior Japanese manager, was seriously injured in a car accident. As a result, my return visit of three additional days was delayed until the fall of 1989. In total, I spent five days at the Honda plant.

The U.S-owned plants were somewhat easier to gain access to. I had already visited the GM plant in connection with other research, and thus already had contacts through whom I could arrange my visit directly. The Ford plant was selected after consultation with the head of the manufacturing division at the corporate level, and arrangements were made through the division office. I spent a full week, continuously, in each of these plants in the spring of 1989.

Plant characteristics

For reasons of confidentiality, I will not provide many details about these plants. I identify the plants only by company name, have omitted or modified references that would indicate plant location, and have changed the names of any individuals who are mentioned in the case studies.

Table 7-1 shows a limited number of characteristics of the three plants, drawn from their responses to the assembly plant study. Several of these variables are expressed in terms of a range, again to preserve confidentiality. Of the three plants, two are U.S-owned plants and one is Japanese-owned. The GM and Honda plants were built in the 1980s, while the Ford plant was built before World War II but was then extensively retrofitted for a new product in the 1980s. The GM and Ford plants are represented by the United Auto Workers union, and the Honda plant is non-union.

All three plants achieve better-than-sample-average productivity and quality (although none achieve the World Class status of under 25 hours per vehicle and under 50 defects per 100 vehicles); the Ford plant has the best productivity and the Honda plant has the best quality. The Ford and Honda plants have high levels of technology, while the GM plant is relatively low-tech. The GM and Honda plants have Production Organization scores that place them in the Transitional FlexProd cluster, while the Ford is squarely in the MassProd cluster. The GM and Ford plants have a relatively high level of production, while the Honda plant has a considerably lower level of production and, at the time of the fieldwork, was still in the midst of an increase to its full production capacity.

Table 7-1

Selected Characteristics of Plants in Problem-Solving Study

Characteristic	GM	Ford	Honda
Regional Category	US/NA	US/NA	J/NA
Plant Age	Built in 1980s	Built pre-1940 Retrofitted in 1980s	Built in 1980s
Union status	Unionized	Unionized	Non-union
Productivity (hours/vehicle)	20-25	15-20	20-25
Quality (defects/100 vehicles)	70-80	70-80	50-60
Total Automation (% automated prod. steps)	23%	35%	39%
Production Organization (0 = MassProd)	64	43	69
Production Scale (vehicles per day)	700-900	900-1100	500-700

Fieldwork Activities

At all of these plants, I sought and received permission to walk around the plant, to talk with workers, team leaders (where applicable), quality analysts, engineers, and production managers, to observe work processes, and to gather relevant documentation (e.g. statistical data gathered to document problems, daily quality audits, minutes of quality circle meetings) In each plant, I asked about the same production problems, talked to people in the same kinds of jobs, and observed the same production processes and quality-focused group activities.

At the GM plant, I carried out 23 interviews and attended four meetings -- one work team meeting, two meetings of quality improvement groups, one informational meeting -- as well as a daily quality audit meeting. At Ford, I carried out 19 interviews and attended three daily meetings -- two meetings of quality improvement groups and one meeting of department heads -- as well as a single meeting of two Employee Involvement groups and one meeting with representatives from another plant. At Honda, I interviewed 20 people and attended one meeting of a quality improvement group.

Some of these interviews were scheduled, semi-formal sessions, while others were essentially extended conversations prompted by my shop floor observations. Besides these interviews, I spoke briefly with many other individuals.

At Honda, most of my interviews took place in a meeting room off the shop floor or in the cafeteria, while at GM and Ford, most of my interviews took place in the offices of various employees or at their work station on the shop floor.

I tape-recorded most interviews in offices (and meeting rooms) and also took extensive notes, trying to record key phrases and comments verbatim as much as possible. I took notes but did not tape interviews on the shop floor (or in the cafeteria). I supplemented my notes soon after each interview and typed up field notes each night. I did not transcribe the interview tapes but referred to them when writing the field notes.

The three cases are based on these field notes. Each case presents some general background information about the plant and characteristics of its system for identifying quality problems. Subsequently, accounts of problem-solving activity told to me during interviews, and my own observations from the field work are roughly organized, for analytic purposes, into one section on problem definition and another section on problem analysis and solution generation and selection. But since field observations rarely fit so tidily into such categories, I have tried to maintain a strong narrative flow for each case. Following the case presentations, I will discuss the evidence of differences in "cultural logic" in these three plants, in terms of orientation towards information processing, the division of labor, and the coordination process.

B. GENERAL MOTORS (GM) PLANT

Background

The GM plant is one of several built in the 1970s and 1980s where the initial work organization was based on the team concept. The entire production workforce is organized into teams of 15-20 members with an elected team coordinator. Many of the other work organization and human resource policies associated with flexible production have been implemented at this plant -- job rotation, decentralization of quality responsibilities, suggestion systems, elimination of many status barriers, relatively high levels of training. At this plant, unlike other GM plants that opened around the same time, the team concept has proved relatively successful, persisting despite a few strong challenges and in fact endorsed by a solid majority of the workforce in three local contract votes during the 80s.

Plant management is quite strongly committed to the participative culture of the plant, and is active in a busy schedule of meetings in various cross-department and cross-level groups. The union is also generally supportive, though inclined to stay neutral on most specific matters, and has pushed over time for more codification of team responsibilities and leadership structure in the local contract -- matters that were originally worked out by each team and its supervisor. The plant has reverted to some more traditional practices during the 1980s; for example, team members rarely rotate among jobs anymore.

While this plant was an early implementor of work teams, it is only relatively recently that it has begun to implement some of the manufacturing practices associated with flexible production -- reduced parts and work-in-process inventories, the full integration of quality inspection into production jobs, etc. The technology in the plant is almost all of mid-1970s vintage, when the plant was built, and there has been almost no investment in new technology since that time. People in the plant express some frustration with this, especially where persistent quality problems are attributed to, for example, outmoded paint booths. Yet most speak with pride of the plant, and what they see as its successful products, its high quality ranking, and its unique culture.

Of the three problem categories, paint chips were viewed as the most significant, followed closely by electrical defects. Water leaks were reported to be a relatively minor concern.

Quality System

The plant has an elaborate structure of quality-related groups and roles. Each team has a Quality Coordinator who samples a certain number of cars per day, keeps Statistical Process Control (SPC) charts, and attends the daily plant audit meetings (see below). Each department has a Quality Analyst -- an hourly person jointly appointed by union and management for a one year term, who is assigned to support quality improvement activities. Each department also has a Quality Improvement Team (QIT) that meets monthly, headed by a member of the top management group and including shift superintendents, engineers, and first-line supervisors. The department QITs also meet periodically to discuss problems one department causes for another.

Under the QITs are Quality Action Teams, short-term task forces set up to address specific problems, nominally with hourly and management members, although an inspection of QAT minutes reveal low attendance by managers. Finally, there is a Plant Quality Council made up of senior management and top union officials.

GM still primarily uses internal quality audit data for identifying quality problems. The audits that "count" are carried out by corporate auditors who visit the plant unannounced once a week. They follow a standard methodology and assign weights for various defects to get an overall score. This is then compared with both other GM plants and cars made by other companies but sold by GM. The plant replicates these audit procedures daily for its own internal problem identification purposes. In addition, GM arranges for an outside vendor to conduct a survey of new car owners, called CAMIP, which generates another quality score, but plant quality control staff give CAMIP little credence, because it is based on a small sample of cars and the data are quite outdated by the time they reach the plant, from 7 to 19 months after the car was built.

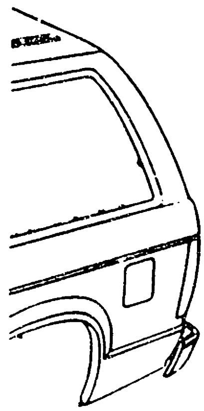
Efforts are underway in the GM division of this plant to make customer-based warranty data the primary quality measure, quickly available through an on-line data base. These data are currently collected on a "defects per thousand vehicles" (DPTV) basis for preassigned "job codes" reported by maintenance personnel at the dealers, but only reported to the plant after considerable delay.

In general, senior plant management is attempting to increase their reliance on customer-based measures and worker identification with customers as the most important judge of their work. Several programs have been started to achieve this goal. Under the "drive home" program, a few workers each night take a newly-built vehicle home for a thorough check and report their findings at the next day's audit. Periodically, quality control staff call recent buyers of vehicles from the plant to ask about their experience with it. I saw minutes from occasional visits that groups of workers have made to dealers in other states, to learn more about what kind of quality problems are reported. But it is still the internal quality audits, and the control systems linked to them, that provide the data and incentives guiding most problem-solving activity.

Problem Definition

"Avoiding Corporate": Design-related Problems. One consistent frustration for groups identifying quality problems is the difficulty in getting any design-related changes made. This ultimately affects what is defined as a problem. There is a tendency to define problems in a way that allows the plant to deal with it independently, without lengthy and frustrating interactions with corporate designers.

The time involved in processing a design-related change, alone, is a disincentive. I was told that the typical engineering change involving parts in this GM division takes 210 days to process. In addition, members of various department QITs told me that several persistent quality problems pressed by the plant have been completely resisted at the design level. The Trim QIT gave me the example of the routing of the tube carrying window washing fluid to the back windshield, which brings it so close to several fasteners for other parts that it frequently gets pinched or blocked. The QIT suggested an alternate routing but the designer insisted that the original routing was adequate and that any problems were the fault of the plant.



JOB # ____________

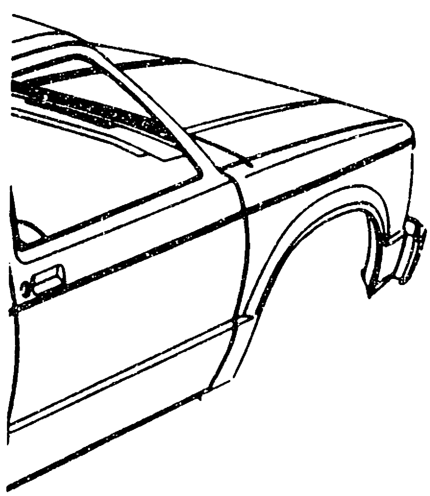
COLOR OK ____________

BUMPERS OK ____________

OPEN DEFECT # ________

COMMON LANGUAGE
FOR PAINT INSPECTORS

PD - PAINT DROPS
PF - PICTURE FRAME
POL - POLISH
PS - PAINT SPOTS
REF - REFINISH
S - SEALER
SAG - SAG
SAND - SANDED
SCR - SCRATCH
SD - SOLVENT DROPS
SM - SANDING MARS
SS - SAND SCRATCHES
SSHY - SEALER SHY
TP - THIN PAINT
TU - TOUCH UP
WC - WRONG COLOR
WD - WATER DROPS
B - BOILS
BE - BULLS EYE
BL - BAD LINE
CRP - CRACKED PAINT
CRT - CRATERS
DP - DIRT
DRY - DRY SPRAY
E - ELPO
GM - GRIND MARKS
MI - MISSED INSP.
MOTT - MOTTLED
MP - MARED PAINT
NS - NO STRIPE (HOOD)
OC - OFF COLOR
OP - ORANGE PEEL
OS - OVER SPRAY
PB - POWDER BUMPS
WM - WIPE MARKS METAL
D - DING
BM - BAD METAL



Another example under discussion during my visit involved a long-term and repetitive problem with the car horn either failing to operate and going off randomly -- a highly visible problem and one of the most common electrical problems serviced under warranty. The supervisor for the trim department line where the horn was installed told me that the problem involved the wire connecting the horn button to the rest of the instrument panel wiring. First, this wire is connected and then the horn button is fastened to the steering wheel. The wire was generally cut long enough to allow a good connection to be made while the horn button was not yet fastened to the steering wheel, but it would bend and often get pinched when the horn button was fastened on. When the wire was shortened to avoid this pinching, the connection would often be pulled loose before the horn button was in place.

This problem was first formally registered in the plant's "5 Phase Problem Resolution Process" in October 1988. (Figure 7-2) The initial response was to ask the operators involved to take extra care and to experiment with some different installation methods. By November, the QAT working on the problem proposed the use of a different kind of wire - a coiled wire with "memory", i.e. designed to spring back to a shorter length after being stretched. By January 1989, the QAT worked with a supplier to test some different "memory" wires, and found that it cut defects dramatically. So that same month, a formal request for a design engineering change to the memory wire was sent to Detroit.

The week I was there, April 1989, the QAT for the Trim Dept. had just gotten word that their request would not be approved because the cost -- 94 cents per wire -- was too much. The department superintendent, announcing the news, was angry. He had gone to a big divisional meeting at which this proposed solution was discussed, and had suspected that no action would be taken; this confirmed it. An engineer at the meeting speculated that the design engineers might be examining wire with more "memory" capabilities than the plant needed - like the cord connected to a telephone handset which needs its memory capabilities during daily use over several years. Others wondered why the design engineers wouldn't consider a lighter gauge, and thus cheaper, memory wire.

Unlike the superintendent, most other QIT members seemed cynical, resigned, unsurprised by the lack of response. While this horn problem would continue to be spotted and repaired, either at the plant or by dealers, it would cease to be defined as a "resolvable" problem. The plant's 5-Phase Problem Resolution sheet on this problem concludes the section on Problem Elimination with the statement "Re-design required for complete problem elimination".

The dominance of cost concerns in design matters often effectively precludes the identification of certain problems. In asking about electrical defects, I learned about persistent problems from using the "56 connector". This part got its name from the 1956 purchase by GM of an old Frigidaire parts plant. As part of the purchase agreement, the plant was to provide a small plastic connector for electrical wires at a very low fixed price (a few cents) in perpetuity. While versatile, this connector is very easy to misinstall; the electrical connection can appear to be complete when it is not. A division-wide Electrical Task Force identified the use of the "56 connector" as one of the major sources of defects. But there was huge resistance to switching to newer, better connector designs, because of the low cost of the "56". Despite some substitution, the "56" is still used in many operations.

As a result of experiences such as this, groups are often inclined to focus on problems that can be addressed without involving the corporate level. For example, the plant has had a persistent problem with a bracket on the brake pedal subassembly to which cables for both the cruise control and for the power brakes are attached. The bracket often moves when the cruise control is used, resulting in misadjustment of the brake cable.

While the engineers, supervisors, and operators I talked to agreed that the problem was a poor design -- that the cruise control and brake cables shouldn't be attached to the same bracket, and that the bracket was in a bad location -- the problem was defined in terms of the design of the clip holding the cruise control cable to the bracket, and a new, stiffer clip with a longer flange was ordered from the supplier. Upon investigation, I learned that this latter solution involved a small enough change in clip specifications that it could be worked out directly between the plant and the supplier, a process that took only 3 weeks. To define the problem in broader terms would require, it was claimed, an endless battle with designers in Detroit.

Lack of a Common Language. One difficulty with problem definition is finding a common descriptive language that can be understood across departmental (and organizational) lines. I found two different examples of how the plant coped with this issue.

The Quality Analyst (QA) for the Paint Department was reviewing his daily audit of vehicles for paint "mutilations". I noted the highly picturesque language he used to describe these defects - boils, craters, bulls eyes, sags, runs, orange peel, dings, mars, scratches, cracks, grind marks, powder bumps. He said the plant has been trying to make sure everyone uses the same language for describing paint problems -- in the plant but also the dealers when they file out a warranty form for a repair.

Figure 7-3 shows the form the paint QIT developed that lists this common language. This attention to language does mean more consistency in the reporting of types of defects but, according to the QA, there are still tremendous differences in the standards individuals use in determining whether or not to report a defect, and the category into which it fits.

The Final Line Quality Analyst also referred to the use of language in defining problems. She checks with the in-plant auditors daily to find out which problems might

5 PHASE PROBLEM RESOLUTION PROCESS

Figure 7-3

1. PROBLEM DEFINITION:

N6320 - Horn Wire (Button)
N0200 - Horn Assembly
N2880 - Horn Relay

DATE: 10-27-88

2. IMMEDIATE FIX (IN USE):

- Revamp of horn button installation - All involved assembly technicians.
- Proper method and awareness exhibited among technicians.

DATE: 11-3-88

3. ROOT CAUSE DETERMINED:

Information obtained thru dealer representative and independent dealer contacts - most frequent cause of all three codes charges to be that of pinched wire at horn button assembly.

DATE: 11-10-88

4. IRREVERSIBLE CORRECTIVE ACTION (IMPLEMENTED):

- In house trials with new wire concepts (1/89) - Inland/Engineering
- Request for re-design of horn button wire with built-in memory after complete assembly.

DATE: __________

5. FOLLOW-UP VERIFICATION (PROBLEM ELIMINATION):

Dealer claim warranty equal time comparison. Re-design required for complete problem elimination.

DATE: __________

NATURAL OWNER(S) Trim Department

SUPPORT Engr/Reliability

AREA Team 41

ISSUE DATE: __________

affect her area. Then, she would visit the supervisor or work team that was most likely, based on her experience, to know what had happened. Sometimes, they would point her to some upstream process. As much as possible, she would investigate these, and, after some negotiation, settle on which department would be assigned the responsibility. She then would write up a problem statement. Much of the process, she explained, involved interpreting how different departments defined the problem. "Different people in different departments use different words for the same problem. I change the language around some to be sure the guys on my line can tell what I mean."

Problem Analysis/Generation of Solutions

The Audit System: Placing the Blame. The in-plant audits are the basis for a twice-a-day ritual held in a special area in the front of the plant. The day's quality scores are announced by the Quality Analyst for each department, together with an explanation or defense of a bad score and cheerleading for a good score. Several of the vehicles that were audited are parked around the speaker's podium and used to point out problems both during the audit meeting and throughout the day. All quality coordinators, supervisors, superintendents, and senior managers are expected to attend the meeting, and any visiting guests are invited.

The daily audit numbers are now perhaps the most important performance measure for the department, and the daily exposure of the departmental score only intensifies the degree of concern about what this number will be. The audit system requires that every problem be assigned to a department, both to tally the departmental score and to allocate the costs of repair. Since not every problem can be easily attributed to a single department, the assignment of problems is often the focus of intense negotiations among Quality Analysts, supervisors, and department heads. Problem analysis is heavily influenced by the need to "place the blame."

The Quality Analysts play a key role in problem analysis, since they are supposed to "root cause" problems, i.e. find out the real source of problems. The QAs do try to track down whatever information they can about problems, but since they do not have the time or resources for a full investigation, they usually rely on one of two approaches: 1) An automatic assignment of a problem to the department that should have spotted it, i.e. the repair or inspection group that usually finds problems in that part of the vehicle; or 2) Negotiating with representatives from other departments about where to assign a particular defect.

One example of the former approach emerged when I observed one of the plant's full-time auditors inspecting a vehicle. He found two small "dirt" spots on the hood ("dirt" refers to any foreign matter caught under the paint) and, in checking the ticket, found they had been identified by inspectors at the end of the paint department but then "bought off" (i.e. passed through without repair) by the paint reprocess group at the end of the line. He told me this defect would be charged to the paint reprocess group because they had failed to repair it.

When I asked how this would help with identifying the source of the dirt problem, he replied, "The reprocess guys are responsible. It's their job to catch this. If you have a repair team, it's because you need it to catch this kind of problem." This is a clear reflection that, despite the rhetoric about "building in" quality, the existing audit system still reinforces the "inspecting in" philosophy.

The latter approach -- negotiating over where to place the blame -- is influenced partially by what is known about the problem, partially by the number of defects already accruing to a given department that day (in the interests of insuring that no department looks too bad -- or too good).

In neither case, obviously, is much effort made to identify the true source of a problem, with the goal of eliminating it. Problem analysis, such as it is, is almost entirely concerned with assigning financial accountability. The plant's production manager expressed his concern about this, saying, "We spend too much time around here worrying about 'Who shot John?'".

The most dramatic example of this preoccupation with costs and accountability involved a special study of paint "mutilations" (chips, scratches, etc.) carried out by the Qas the week I was there. On my first day, I attended a meeting of QAs organizing a week-long plant-wide audit in which 50 vehicles per shift would be examined for paint mutilations at several points in the assembly process -- at the end of the body shop, at the end of the paint shop, at two points in the assembly department, and after final repair. Quality coordinators from the teams assisted with this audit, which involved marking the location of mutilation on charts with sketches of the right and left fenders, bumpers, and other body parts.

Over the course of the week, the QAs were able to tally the incidence of mutilations by location on the car and by department where they occurred. I was quite impressed by this extensive data collection, and asked what it would be used for -- imagining that this would become the basis for further investigations by some QIT or QAT. The answer: the data would provide corporate and plant auditors, for a given paint mutilation, with a probability of which department was most likely responsible. This would provide a more "objective" basis for the assigning of quality defects and costs to the guilty department. I asked whether the data were also likely to be used in later problem-solving efforts. The group of QAs laughed -- "Who has time for _that?_", they said.

Guerilla Action on Electrical Defects. The plant's quality manager was well aware of the relatively little time actually devoted to tracking down the "root cause" of problems.

To cope with this problem for electrical defects, he went outside the formal quality structure to authorize some guerrilla action, in the form of an ex-Quality Analyst named Bill. Bill had been a very active QA during his single-year term, to the point, he felt, where many were threatened by his aggressive approach to finding electrical problems. The quality manager then arranged for him to have a job as a "floater", or utility man moving across teams, with Tuesday and Thursday afternoons free for a special, unofficial "electrical ramp audit" -- a check of the electrical system for cars that had completed all inspection and repair steps at the plant and been "sold" to the GM sales division.

These cars were removed to a parking lot ("ramp") about 1/2 mile from the plant to await transport. Bill, armed with a few tools, would drive down, check in with the security guards, and randomly pick 30-50 cars to inspect. Compared with the official in-plant auditors, I found his inspections to be conspicuously more thorough (more things tested), more systemic (examining multiple functions separately <u>and</u> simultaneously rather than only separately), and much more intense, in everything from his work pace to the vigorous tug he gave to wires when looking for loose connections.

Bill kept up a running commentary about the problems he was finding during my afternoon with him. Loose connections - probably because an operator pulled his air gun away too soon or the torque was set too low (or too high, causing threads to strip). (In one case, he said two operations requiring different torque were combined in the same job, guaranteeing that the air gun torque would be wrong for one of them.) No connection, missing screws, missing wires - "guys being paid $15/hour who aren't doing their job." Inoperative reverse lights - "this switch should be adjusted as late as possible, but the process won't allow it -- so it gets adjusted and sealed up, and then some later process knocks it out of whack". Pinched horn wires -- see above. "Black eyes" (uncharged batteries) - vendor problem, not caught by repair. Bill's "root cause" analysis -- based on experience rather than any detailed investigation -- identified a wide range of problem sources -- design, supply, poor process specification, poor operator performance.

Bill said management was generally responsive to his findings, but that he didn't officially report some problems that he thought would cause big problems for department superintendents. ("I tell them about the problems, though -- sort of my version of blackmail".) I followed him back to the plant, where he borrowed a computer from a secretary to enter, somewhat surreptitiously, his data into a 1-2-3 spreadsheet and to print out a rough report for the quality manager. In the first 13 weeks of 1990, he had checked 913 cars and found 97 defects, a rate of 106 defects per thousand (or 10.6 defects per 100 vehicles) -- this after the full array of plant inspections and repairs. In a later interview with a department superintendent, I mentioned Bill as a real "go-getter". He replied, "But he'll never get anywhere, because he raises too many questions."

Role of Quality Analysts. Bill's experience indicates the dual nature of the new roles created to support the quality effort in the plant. For most QAs, it was clear that the training, experience, and exposure to new perspectives had permanently changed their feelings about their capabilities. Janet succeeded, despite considerable resistance, in demonstrating that a small modification in a tool would eliminate an installation problem with a new part after a model change. Her "reward" through the suggestion system of $300 seemed less important to her than the triumph of a good idea over a entrenched process. The QA for paint, Tom, had been a real "hellraiser" when he worked on the line, according to one superintendent. Once becoming a QA, though, he was asked to lead a study group visiting other GM plants in the same division, and even a competing Ford plant to find out how they handled paint mutilations. He took great pride in showing me his report from that trip, a very professional document with several clear recommendations; one, proposing a new carrier for bumpers, complete with his hand-sketched diagram of the design and his assessment of the impact on various departments of making the change.

But on the whole, the Quality Analyst position has only a marginal impact on the level of problem-solving activity in the plant. Quality Analysts are jointly appointed by management and the union for a one-year term. Once the term is ended, the ex-QA returns to the job of whichever person is appointed to replace him/her. This short-term appointment is intended to prevent the creation of a permanent group of employees in a role whose authority boundaries are quite unclear, and to allow more people to receive the benefits of a position that takes them off the line and provides new skills. But this policy means that a QA's experience, negotiating and communication skills, knowledge about production problems, and relationships with team leaders, supervisors, and superintendents are lost after a year -- or, rather, underutilized as ex-QAs like Bill return to the line.

This may, in part, account for the "devil-may-care" attitude of some QAs. As one QA, Tom, put it, "I've got nothing to lose, so I do what I want, say what I want." The year as QA can also lead to other special assignments. Janet, the QA in trim, said, "The way I see it this is one hand in the cookie jar." She was advocating for a new position of warranty analyst to be created, to do more research on "root causes" than QAs can now afford to do. But for other QAs, the experience of having little impact in a highly visible job was profoundly frustrating. Sam, QA for the Trim Department, told me he felt powerless to do much about the problems he would identify. In particular, he found the daily audit a humiliating experience, because "you stand up there and say your department had all these defects and everyone's looking at you but you can't do a damn thing about it."

Summary

The GM plant, despite having many of the structural arrangements of flexible production, is constrained on many fronts in its efforts to achieve the corresponding "cultural logic". This is true in part because the changes in work organization and human resource practices were motivated by the goal of achieving participative management and were not, until recently, linked substantially to changes in manufacturing practices. But more significantly, it results from a corporate product design group that resists efforts of the plant to become involved in the innovative process and from a cost accounting system that creates considerable incentives to assign blame for problems and disincentives for any thorough attempt at "root cause" problem analysis. The predominant use of internal quality audit data rather than customer data and the tenuous nature of new quality improvement roles such as Quality Analyst are further indications of a culture that is still dominated by a mass production way of thinking.

C. FORD PLANT

Background

The Ford plant is the oldest I studied, built before World War II and regarded for most of its history as a "good" plant -- good workforce, good labor relations, good performance. It was completely retrofitted in the 1980s for a new product, and has been dedicated to that product ever since.

It is in many ways a traditional mass production plant, at least in terms of the structural characteristics measured by the Production Organization index. There are no work teams. The number of job classifications, while somewhat reduced during the 80s, is still high compared with the 3-5 classifications of most flexible production plants -- over 90 unskilled and over 20 skilled classifications. While labor relations are good, there are relatively few joint labor-management initiatives and structures. Training levels are modest, compensation is subject only to the corporate-wide profit-sharing plan, many status differentials still remain, and relatively few employees are involved in Employee Involvement groups.

The plant has made considerable efforts to reduce its use of buffers, but it is somewhat constrained by a supply base that is only gradually able to support a "low buffers" policy. This fact encourages a cautious approach from plant managers to buffer reduction, even in areas the plant could control. As a result, parts and work-in-process inventories and the size of the repair area are still large by flexible production standards. Thus in manufacturing practice, the plant also has many characteristics of mass production.

But it is the plant's emphasis on quality improvement, described in greater detail below, that most resembles a flexible production plant, despite the fact that there has been relatively little structural change (at least of the kind measured by the Production Organization index). As a consequence, there is a much higher level of problem-solving activity in the plant than its mass production structure would suggest. The tension between a culture that pulls towards flexible production and a structure that pulls towards mass production is one of the primary themes of this case study.

Like the GM plant, employees speak with considerable pride of the high performance of their plant, the success of the product they build, and their strong reputation within the corporation. Managers and workers alike spoke of a strong work ethic among employees, a "hands-on" attitude and high shop floor visibility from the management team, and a history of constructive, although not necessarily cooperative labor relations fostered by strong and long-serving plant managers and union officials. Many also spoke to me about the impact on the attitudes of plant employees of a period in the early 1980s when the plant suffered massive layoffs. They attributed much of the commitment to quality improvement in the plant to a strong desire to avoid such crises in the future.

The plant has quite a high level of automation, although a modest level of robotic applications. I saw relatively little emphasis on "high tech" technology as the solution for the plant's quality problems. Instead, the emphasis was on how to improve the functioning of the production system, in whatever way possible.

Of the three problem categories, all were viewed as significant, with electrical defects viewed as the most serious, followed by paint chips and water leaks. The plant manager told me that these problems ranked first, third, and fourth, respectively, on the plant's "Top Ten" list of problems.

Quality System

Ford now organizes the quality structure in all its plants not by department but by product "subsystem". Eleven subsystems have been defined, with a group assigned to each. Among the subsystems were all three of the problem categories I chose for this part of the research: water leaks, electrical defects, and paint problems.

Each subsystem group meets daily, and is chaired by a member of the plant's operations committee, made up of the plant manager and all department heads. Other members include a "vertical slice" of the plant organization: design engineers (sent from Detroit for a 2-year stint in the plant under a new program called QPRESS), process engineers, supervisors, and hourly workers. A full-time "coordinator" -- generally a process engineer -- is assigned to each subsystem group as staff. This subsystem structure was fully implemented at the plant I visited, and accounts for much of the problem-solving activity I saw there. I attended the water leak and electrical defect meetings each day.

The Ford plant carries out much more data-gathering about quality problems than the GM plant. This is a function of several decisions in recent years. First, Ford has gone much further than GM in switching from internal to customer-based data as its primary source for identifying quality problems. This includes not only warranty claims reported through dealers but verbatim comments from mailed surveys and phone calls to new owners. The plant also still collects its own internal audit data, so there is a wider range of quality measures in use than at GM.

Second, each subsystem group collects a tremendous amount of data, vastly more than the GM plant, using Statistical Process Control and Pareto graphs and "8D" charts, named after an eight-stage problem-solving process developed by W. Edwards Deming, the much-consulted (by Ford, among others) quality control guru. These graphs and charts are reviewed at the daily meetings but are also expected to form the basis of the Production Operations Report (POR), that is presented semi-annually to corporate staff during an in-plant review process.

Third, in the absence of work teams and team coordinators like those at the GM plant, Ford has created a new hourly position at this and a few other plants, called Zone Improvement People, or ZIPs. A ZIP is assigned to a subsection of a department, and authorized to take a variety of actions to prevent a quality problem from leaving their zone: watching cars for uncaught defects and flagging them, contacting upstream or downstream supervisors to discuss a quality problem, filling out SPC charts, replenishing needed supplies, and otherwise serving as a liaison between workers and management on quality issues. ZIPs are permanent positions, paid a small hourly bonus, and are said to be popular assignments. The ZIPs I met were all high seniority workers who had bid to get the job. ZIPs, working with supervisors, either generate or oversee much of the data-gathering activity in the plant.

Thus Ford, by promoting customer-based measures of quality, organizing quality-related problem-solving into cross-functional groups, and creating new liaison roles, has raised the priority of quality as a goal and facilitated the plant's development of the organizational processes of flexible production.

Problem Definition

Customer vs. Plant-based Data. The plant is still adjusting to the increased reliance on customer-based measures. One department superintendent told me that the problems identified during internal plant audits correspond much more closely with their sense of current and persistent quality problems than any of the customer-based measures. But, he said, they find that if they focus on "drying up" the problems listed high on the internal audit, the customer measures improve as well. This suggests that the internal and customer data are ultimately identifying the same problems, but that the plant cannot always see the underlying link.

This hidden link is undoubtedly a function of the time lag for the customer data, the use of different language by customers, and the way that dealers assign warranty codes for repairs, among other things. But it also reflects the skepticism with which manufacturing people view the quality perceptions of anyone outside the plant (something which perhaps also accounts for the slow embrace of customer-based measures at the GM plant).

This skepticism is partially due to a common management reaction to the customer-identified problems -- a nearly automatic acceptance of the customer definition of the problem, followed by an equally automatic data-gathering assignment. Several supervisors described their frustration with this process. As one said, "A hot item comes up on the NVQ (New Vehicle Quality) audit and management jumps on it, tells us to chart it. One time, we had some cars going to Taiwan and we had a report that the seat belts were rattling. So they told me to chart it ten times a day. But there's no way [at this point in the trim dept.] that you can tell if the belt will rattle, before the whole interior is in. But those are the charts that get started and get continued. Other problems that don't make the hit parade never get charted."

Thus employees in this plant are often pulled between the customer-based data the corporation now wants them to rely on and the internal data that still makes more sense to them. As a result, problems are often "officially" defined, in reports of various kinds, in terms of the customer measures but people in the plant discuss them in terms of the internal measures.

"Don't Touch Metal": Defining Problems by Costs. As at the GM plant, problems are often defined -- or left undefined -- in terms of cost. In the sealer area, I heard about a persistent problem (since beginning production four years earlier) with the drip rail - the metal rim around the door opening intended to carry off rain water. A piece of weatherstripping over the outer lip of the drip rail prevents water from leaking into the car, but the lip is quite short, so that weatherstripping often will not seat well. The weatherstripping has been redesigned a few times, but the problem persists. It is made worse by the slightest variation in the thickness of the sealer placed along the drip rail - too thin and the result is leaks, corrosion, wind noise, but too thick and the weatherstripping will pop off. I asked what it would take to solve the problem, and was told, "a longer lip". I asked if they had proposed this and was told, "No way - you don't touch metal."

This same response reportedly arose on other occasions too. Changes in the design of sheet metal parts is considered too expensive to change until a major model change -- potentially eight years for this particular product.[2] The same is true for problems that

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[2] I have no data on the actual costs of altering sheet metal design, but they may very well be too high to justify a change in these circumstances. However, there is no way to assess the costs, in terms of customer perception, of quality problems that persist over the full life cycle of

would require a change of tooling to resolve. So the problem ceased to be defined in terms of the drip rail -- instead, it was seen as a sealer problem or a parts (weatherstripping) problem.

At one subsystem meeting, someone remarked to me, "We just gather all the data and let Dearborn [corporate headquarters] decide what to do. Sometimes they decide it's cheaper to let the customer find the problem than for us to fix it." Whether or not this is an accurate reflection of quality attitudes in Dearborn, it certainly suggests that employees expect a certain percentage of the problems they identify to be ruled out-of-bounds for serious resolution activities because of cost concerns.

When problems persist and nothing happens (especially where a design issue is involved), employees may just stop mentioning them -- another way in which problems "disappear". In the trim department, I learned that the "premium sound" stereo system, installed infrequently as an option, has such a cumbersome bundle of components and wiring that it doesn't fit well into its assigned cavity in the floor under the dashboard, especially given a short cycle time. This then causes an unsightly bulge in the carpet.

To make it lie flat, workers would often use a hammer to knock it into place, but this could break wires and connectors. The supervisor for this area told me he had mentioned this so many times without response that he stopped listing it as a problem. When the plant manager came by one day to ask why this problem wouldn't go away, the supervisor said, "I didn't have the heart to say we've been raising it for months with no response." (More likely, perhaps, he was worried about criticism for ceasing to report it.) This reticence was unusual, since the chance to tell the plant manager about a pet problem

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a product. Indeed, the product from this plant, highly praised in terms of its design, developed a reputation for persistent quality problems a few years after its release. This design problem also makes clear the great disadvantages of a lengthy product development cycle, which prolongs the time until such basic changes can be made.

was said to be a good way to be sure it got attention.

Design Engineers in the Plant. At the Ford plant, unlike GM, design engineers are stationed in the plant, through the QPRESS program. As a result, manufacturing people report less frustration with design, better communication, and more optimism that design-related problems they find will be addressed. Still, many signs of the functional divide between design and manufacturing remain.

The QPRESS engineers, assigned to the plant for a two-year term, are keenly aware of their pioneer status. While most were glad to have some hands-on experience in the plant, they worried about the effects on their careers. Would this time at an assembly plant really count in their favor at promotion time? How much was their lack of visibility in Dearborn hurting them?

They protect themselves, in part, in the way they define problems encountered in the plant. Their analytic procedures categorized all problems as design-related, vendor-related, or plant-related. One QPRESS engineer told me that he was really only responsible for design-related problems, but that on occasion, to preserve good relations with plant engineers, he would spend some time on a "plant" problem. On the whole, he was critical of the plant for their failure to make more progress with their assigned problems. Yet, as far as I could tell, many of the "plant" problems had some design implications. Thus, by largely confining themselves to problems they felt were appropriate to their expertise, it seemed to me that the QPRESS engineers hindered rather than facilitated the integration of production and innovation activities.[3]

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[3] I didn't have the chance to ask plant engineers how they felt about the presence of QPRESS engineers in the plant, but my general impression was that there was considerable tension between these groups, with the QPRESS engineers feeling unappreciated and underutilized, and the plant engineers resenting the higher status and stand-offish attitudes of the QPRESS group.

Problem Analysis/Generation of Solutions

Definition as Diagnosis. At first observation, the amount of attention to problem analysis at the Ford plant is very impressive. SPC and Pareto charts, the 8D problem-solving process sheets, and other data-based reports on quality problems are visible in profusion at meetings at all levels, from the daily subsystem meetings to the daily plant manager's meeting.

But over the course of my visit, I began to notice that the data on quality problems were not, in fact, treated very analytically. To define the problem in a certain category was, at the same time, to diagnose its cause. Based on past experience, most individuals, from production workers to management, seemed to feel that they understood the source of a problem immediately. Attention was therefore focused on choosing a solution, based on resources available, interdepartmental jockeying, and so forth.

An examination of 8D forms provides the best example of this. Figure 7-4 displays five 8Ds. The following commentary applies to the first four examples; the fifth reflects an analytical rigor and thoroughness that was a rare exception in the group (over 50) of 8Ds that I reviewed.

The problem definition is brief and substantiated by reference to one of the various quality reports. What is listed under the "root cause" section of the report is, in effect, a further description of the problem, with the source often implicit but with no evidence of any direct attempt to test these assumptions.

The "actions taken" section, whether long or short, appears haphazard, with no indication that solutions were systematically considered, tried out, and then either accepted or rejected for implementation. Unlike the "root cause" section, actions are described with many details, bristling with specification numbers, name of new vendors or products that will be tried out, specialized terms for parts of the car. Occasionally, a general reference to some organizational action, such as an "operator awareness program" will appear as well.

Finally, the evaluation section is scanty, either listing "before" data only, or "before" and "after" data for the problem rather than for various solutions that were attempted. The "after" data, unlike the extensive "before" data, are usually confined to a single day, raising the possibility of a "managed" number chosen to show results.

In general, the 8Ds appear to be used more to report on the activity level of the subsystem group, to show that the required processes are being fulfilled, rather than to diagnose, systematically, the sources and possible solutions to a problem. From these 8Ds, you can tell the degree to which the subsystem group is busy, energetic, attentive to detail, creative in its range of actions. What you can not tell is what might be the actual "root cause(s)" of the problem, which of the attempted solutions was derived to address them, and whether a given attempt actually reduced the problem incidence or not.

Thus when a problem recurs, as most in the plant do, typically the subsystem team generates a new list of activities or tries to add inspection/repair activities to "dry it up". Rarely is the problem reanalyzed, rarely are earlier actions reassessed. With past activities already documented and reported, the key is to generate new documentation, to provide proof of continued activity. Thus "continuous improvement" becomes less a process of incremental problem resolution than a process of energetic solution implementation. While it is hoped that the implemented solutions will remove problems, the central concern is to show adherence to the ordained organizational processes and to draw a plausible link between actions taken and a short-term quality improvement.[4]

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[4] When I presented this view of how 8Ds were used to the plant manager, he agreed that few people really understood the philosophy behind this process. In fact, he had just attended an all-day training session on using 8Ds at the division level and was requiring all department managers to come in the next Saturday to go through the same training.

8-DISCIPLINE REPORT

(1) **TEAM CONTACT**

PHONE NO: 1390
ASSIGNEE:
ACTIVITY: BACKLITE AREA
DATE OPENED: 11/2/88
YEAR/CARLINE:
COMPONENT:
INITIATOR:
PLANT:

(2) **PROBLEM DESCRIPTION:** QUARTER GLASS AND BACKLITE LEAK.

PARETO SOURCE/RANK:

CNVO	NVO	PROBE	INSP. STUDY	WARRANTY	FOCUS EVAL. FLEET	FIRST RUN	FIELD LIAISON	OTHER
	3		2					

(3) **ROOT CAUSE(S):**

A: UREATHAN BEAD NOT TO SPEC.
B: BENT FLANGE.
C: UREATHAN PRIME NOT TO SPEC.

(4) **ACTIONS:** Specify: / P=Permanent - I=Interim \ S=Service

(5) ACTION DATE: TARG. EFF. OASIS

(6) ~~VERIFICATION~~ Interim/Perm: SHOW DATE, MEAN & VARIATION INDICATOR(S) BEFORE AFTER

Action	TARG.	EFF.	OASIS	Verification
A. SET UP CHART TO CHECK UREATHAN BEFORE GLASS INSTALLED.	11/2			A. 4S QTR Glass np = .30 R/S QTR Glass np = .50 Back Glass np = .20
B. SET UP CHART TO CHECK BENT FLANGE.	11/2			B.
C. SET UP CHART TO CHECK UREATHAN PRIME.	11/2			C.

(7) **PREVENTION:**

(8) **CONGRATULATE YOUR TEAM:**

WATER6.8D

8-DISCIPLINE REPORT

(1) TEAM CONTACT

PHONE NO: 1476 YEAR/CARLINE:
ASSIGNEE: COMPONENT: Deck Weatherstrip
ACTIVITY: Trim INITIATOR:
DATE OPENED: 9-21-88 PLANT:

(2) PROBLEM DESCRIPTION: Deck weatherstrip leaking on decklid flange.

PARETO SOURCE/RANK:

CNVQ	NVQ	PROBE	INSP. STUDY	WARRANTY	FOCUS EVAL. FLEET	FIRST RUN	FIELD LIAISON	OTHER
	2	1	2	8	3			

(3) ROOT CAUSE(S):

Bad decklid flanges.
Excessive amount of sealer on flange.
Deck weatherstrips too short or too tight for flange.
Deck lid rubber not installed properly.

(4) ACTIONS: Specify: / P=Permanent - I=Interim \ S=Service
(5) ACTION DATE:
(6) VERIFICATION: Interim/Perm: __ SHOW DATE, MEAN & VARIATION

	ACTIONS	TARG.	EFF.	OASIS		INDICATOR(S)	BEFORE 9/2/88	AFTER 9/6/88
A.	Added 3M double back tape to deck flanges at reverse shingle joint. A 4" strip.		8/14		A.	1st Run Chart	40/520 leaks	14/520
B.	Checking 5 per hour to verify that installed to process.	9/30			B.	U CHART	.069	
C.					C.			

(7) PREVENTION:

(8) CONGRATULATE YOUR TEAM:

8D.CM3

8-DISCIPLINE REPORT

(1) TEAM CONTACT

PHONE NO: 769-1323
ASSIGNEE: _
ACTIVITY: Q-PRESS
DATE OPENED: 6-6-88
YEAR/CARLINE:
COMPONENT: Deck Lid W/STRIP
INITIATOR: 4TH QTR. BINNING MTG.
PLANT: _

(2) PROBLEM DESCRIPTION: Water leaks into luggage compartment along lower back panel.

PARETO SOURCE/RANK:

CNVQ	NVQ 1 2 3 4	PROBE	INSP. STUDY	WARRANTY	FOCUS EVAL. FLEET	FIRST RUN	FIELD LIAISON	OTHER
1	1/19		2			#1		

(3) ROOT CAUSE(S):

Symptom: Insufficient force of tertiary seal fin against mounting flange to prevent water from entering carrier tracking around flange, crossing over in waterfall area and leaking into trunk area.

(4) ACTIONS: Specify: / P-Permanent - I-Interim \ S-Service

(5) ACTION DATE: TARG. EFF. OASIS

(6) VERIFICATION: Interim/Perm: __ SHOW DATE, MEAN & VARIATION INDICATOR(S) BEFORE AFTER

A. PM 212477 (I) Redesigns seal fins in carrier to maintain seal fin contact to mounting flange. A 500 unit trial will be conducted once parts are received at Assy. — TARG. 9/27, EFF. 9/26 — A. 10/494

B. PM 212477(I) extended for 500 unit trial at .Assy. — EFF. 11/9 — B. 5/20(20 min.soak) 8/420(in-line)
NOTE: The 20 min.soak leaks were at the split ends of weatherstrip. which if joined together in production stock, will eliminate these leaks.

C. CN 102653(P) is written to release new w/strip with vulcanized joint. PM 102653 is being issued to allow 45 days trial at both assy.plts. — C.

(7) PREVENTION:

(8) CONGRATULATE YOUR TEAM:

NVQWIR9.8D

CONCERN ANALYSIS REPORT

INITIATOR:
PHONE NO: 769-1567
ASSIGNEE:
ACTIVITY: Paint
DATE OPENED: 9/25/87

1) TEAM CONTACT:

2) PROBLEM DESCRIPTION:

Sealer under paint showing through as dirt in prime and enamel.

(3) SPECIFIC ROOT CAUSE:

SYMPTONS:	Pareto Rank /Source
A. Excess sealer applied in body shop.	3 / INSPECTION STUDY
B. Redeposited sealer from bonderite.	1 / DRIVE TEAM
C. Sealer applied (clean/up) on sealer deck.	3 / WARRANTY

(4 & 5) ACTIONS (Interim/Permanent/Service):

	Implement Date
A. Elimination of notch in drip channel to prevent "fall through to door frames.	11/87
B. Replacement of 225 with 240B on roof/drip rail.	10/87
C. Operator awareness program.	
D. Added additional filter vessel in stage 1B of phosphate.	7/88
E. Replaced clogged filter restraining baskets in phosphate filters 1A and 1B.	9/88
F. CRCR written to change 240B sealer suppliers to reduce redeposited sealer	10/88
G. Install stronger filter bags in phosphate to prevent blowouts	11/88
H. Acid cleaned phosphate	11/88
I. Trialed 249 sealer in place of 240 sealer around shock tower in body shop to reduce sealer redepositing	12/88

(6) VERIFICATION:

	Quantification Indicator	Before	After
		5/88	10/88
Sealer under paint chart	P-BAR	.007	.005

(7) PREVENTION (Plant actions and cross-functional team actions):

(8) CONGRATULATE YOUR TEAM:

8-DISCIPLINE REPORT

(1) TEAM CONTACT:

PHONE NO:
ASSIGNEE: =I
ACTIVITY: Q-Press/
DATE OPENED: 9/23/87

YEAR/CARLINE:
COMPONENT: Deck Lid
INITIATOR:
PLANT:

(2) PROBLEM DESCRIPTION & PARETO SOURCE/RANK

DESCRIPTION:
Water enters deck lid via deck lid weatherstrip at the lower back panel.

SOURCE/RANK

CNVO	NVO	PROBE	INSP. STUDY	WARRANTY	FOCUS EVAL. FLEET	FIRST RUN	FIELD LIAISON	OTHER
	#2	0	2	8		#1		

(3) ROOT CAUSE(S): The current design of the upper back area of the Sedan allows water to run off the backlite and into the upper back panel trough unimpeded. The water is directed toward the deck lid weatherstrip carrier because of the downward sloping upper back panel/weatherstrip mounting flange. The water builds up because the side troughs cannot drain the water off fast enough. As the carrier is sitting in the water, any sealing flange step, sealer build up, fin to mounting flange interruption, or any other defect allows water to enter the carrier and then travel down the side troughs. The water crosses over the top of the flange at the reverse shingle joint or the lower radius and falls into the luggage compartment between the mismatch in the lower back to lower back reinforcement. The cross over is further aided by the LH outboard corner of the lower back reinforcement being out of print and forces the carrier to sit high on the flange.

(4 & 5) ACTIONS
Identify as Interim (I)/Permanent (P)/Service (S):

	ACTION DATE TARG.	EFF.	OASIS
1. Revise trim to allow proper w/strip installation. Prototype parts due 11/5/87.		11/5/87	
2. Revise w/strip retention fins from dense rubber to foam rubber. Add sponge rubber lip to base of w/strip carrier to divert water away from upstanding flange and shingle.		11/18/87	
3. Revise retention fins to a sponge material.		12/7/87	
4. 250 piece w/strip trial w/revised sponge grippers & lip to be run.		1/11/88	
5. 100 piece w/strip trial w/tertiary fin added to to be run.		2/11/88	
6. (lower back panel supplier) to send samples made to spec. So far, parts are not to spec.	TBD		
7. A new d/lid rubber with hard rubber inner fins will be tested (500 pcs) during 9/27/88. We expect it to resist water intrusion better than the current design.	9/27/88		

(4) & (5) ACTIONS (CONTINUED)

8. We are testing to determine feasibility of requesting redesign of b/lite rubber from E8DB-54424A00-AA to modified E80B-54424A66-A (mldg back window outside lower) which will help fill the large gap below the back window and also provide a "step" for water to jump over gap at top of deck lid. Test due. 9/28/88 10/13/88

9. Eliminate notch R&L at joint. 9/21/88 10/5/88

10. Lwr the LH inner back 1mm to 3mm 7" from new LH edge toward ctr to get constant 18mm across lwr back inner. 9/21/88

11. Incorporate the new trim change per samples reviewed in on 7/28/88 which eliminates interference by Z954 line. 9/21/88

12. CR/CR to be issued for changes 4, 5, & 6. CR/CR # 371327.

(6) VERIFICATION

	INDICATOR(S)	QUANTIFICATION BEFORE	AFTER
	Presently, P-Bar #2 Shift	.041	
	#3 Shift	.049	
1. Trim was effective in eliminating the interference to the w/strip on 50 units.	Plant Trial	100% intfer.	0% intfer.
2. Trial of 50 w/strips with softer durometer rubber retention fin.	11/18/87	50%	leaked
4. 250 piece trial.	1/11/88	0/250	leaked
5. Trial of 494 deck rubbers with new fins & new length.	9/26/88	10/494	
6. Trial of 420 deck rubbers with new fins & new length ran in	11/9/88	5/20 (20 min soak) 8/420 In-line	

* NOTE: The 20 minute soak leaks were at the split ends of deck weatherstrip. If the joint is connected together on production stock, this will stop the leak.

(7) PREVENTION:

(8) CONGRATULATE YOUR TEAM:

Indeed, the profusion of data reports and charts, as a symbol for problem-solving activity, was a clear impediment to problem analysis, both because of the time spent generating it and because its sheer quantity tends to obscure rather than illuminate. This tendency is exacerbated by the fact that a major component of the quality improvement effort is the Production Operations Report (POR) prepared by each subsystem group for review by corporate staff. Considerable time at subsystem meetings, and even at Operating Committee meetings, was spent reviewing the POR "book" -- a compilation of quality measures, SPC charts, 8D reports often numbering as many as 100 pages -- with more attention being paid to whether it was complete than to how thoroughly problems were being analyzed.

Quality vs. Cost. While some of this behavior undoubtedly reflects the natural tendency to follow the cues of the organizational control system, it is a necessary response to a central, unresolved tension within the Ford system, between quality and cost. This issue was raised in my initial meeting with the plant manager and comptroller. The comptroller said, "We can't continue to be all things to all people. We may need to spend more to keep improving our quality record." This statement seems to reflect the old expectation of a tradeoff between cost and quality. But over the course of the week, I came to understand his remark in another way -- that the plant needs to be free to spend more money in some areas to make quality improvements that will, over time, save money in other areas. In other words, short-term cost concerns often constrain problem-solving activities.

I saw several examples of this during my visit. On the first day, I accompanied the electrical subsystem coordinator while he checked out a problem in the instrument panel subassembly area. A supplier representative (United Technologies) assigned to the plant joined us, since the problem was with UT-provided wire harnesses.

Right when we arrived, the lunch whistle blew. The operator stayed a few minutes to show us the problem. A plastic block where several wires connect had been taped directly adjacent to a plastic locator pin, used to situate the wire harness in the instrument panel; the block and locator pin were supposed to be taped at a 180 degree angle to one another. The operator had, therefore, to break the tape in order to make the connection and insert the locator pin. Without the tape, the chance of broken wires or loose and rattling connectors increases, so, as a makeshift remedy, the operator was fastening the wires down with a "chicken strap" (a thin plastic strip designed to lock as it is tightened) to hold the wires together. This was tough to do in the required cycle time.

Much of what ensued was impressive. The operator gave up part of his lunch hour to help explain the problem. The electrical coordinator carefully checked the inventory to determine the incidence of the problem; a whole pallet was incorrectly taped. The supplier representative, clearly accepted by plant personnel as part of the "team", busily researched the problem that day and reported his findings at the electrical subsystem meeting the next day. A speedy resolution seemed imminent.

But instead I learned, later in the week, that the supplier had discovered nothing about how the wires should be taped in the Ford specifications for the part and that, according to the contract, the cost of remedying the problem fell to Ford. A decision was made, therefore, that the specification would be adjusted but that until then, the rest of the defective parts would be used, since it would cost too much to replace or rework them. This virtually guaranteed a higher level of defects that would need to be repaired or, in the worst case, might slip through to the customer.

Another example related to the drip rail weatherstripping described above. In an attempt to achieve a consistently uniform application of sealer under the weatherstripping, the process engineers, ZIPs and operators in the sealer deck had worked to develop some new metal tips for the sealer guns. These new tips were shaped to produce the right-sized ribbon of sealer, but required a sealer compound of a thinner consistency for smooth application. A new sealer was being tested, and the plant checked each batch carefully to be sure it would work in the new tips.

Early in the week, the ZIPs told me they had had to reject two new barrels of sealer that were too thick. By the end of the week, despite positive results from using the new sealer tips, the paint superintendent had ruled that the two barrels of sealer had to be used, because there were no contractual grounds to demand a refund from the supplier (i.e. the sealer met the specifications of the contract). The operators were forced to switch back to the old sealer tips.

Both of these examples point to difficulties with supplied parts and the dominance of cost concerns in resolving these difficulties. In the first case, the effort to assign cost accountability took precedence over finding a way to minimize the quality impact of the problem. In the second case, a concern about material costs short-circuited a successful problem-solving initiative. In neither case was the accounting system able to balance the (measured) cost of replacing or reworking the faulty parts with the (unmeasured) cost of inspection, repair, and, potentially, a dissatisfied customer.

This cost concern can also pull the plug on experiments meant to test problem solutions. This tension was nicely captured in two comments at the water leak subsystem meeting. The head of the group, while reviewing an 8D, noted the lack of actions taken and told them "it is better to take a wrong action than none at all." Another senior manager at the meeting then immediately chimed in to say "but don't deliberately take a wrong action." This latter attitude -- try new things as long as you don't make a mistake -- seems likely to stifle experimentation.

I learned of two other cases in which the divisional control and accounting systems made it more cost-effective to follow an "inspect it in" than a "quality the first time" philosophy. One of the chassis lines began to find globs of dried sealer blocking a hole needed for installing a grommet for the emergency brake cable. I joined a QPRESS engineer who was reluctantly pressed into service to investigate the problem. He checked some vehicles in the sealer area that didn't seem to have the problem, then went down to the sealer area and found some that did. On the theory that the sealer might be running in the paint oven, the engineer proposed covering the hole with tape on the sealer deck, and then removing it later on the chassis line.

The engineer didn't talk to the operators or the ZIPs on the sealer deck. When I talked to them later, they attributed the problem to a recent changeover, for some sealing tasks, from application by brush (more precise but more labor-intensive) to application by spray (more risk of overshooting). They worried (as did their supervisor) that the tape, when removed, might tear off some sealer around the hole and cause leaks. Besides, they said, there was noone who could apply the tape -- a job requiring clean hands.

It later emerged that the paint superintendent had switched from brush to spray to eliminate two sealer positions. To cope with the resulting problems, he proposed assigning a new person to do taping under a PSO (a Production Service Order, meant to be a temporary corrective action that is paid for by the division rather than the plant) -- even if this meant having one person spend all their time taping that hole. (PSOs were relatively common; I came across several.) While less efficient as a way to assign work, this solution shifted the costs of a quality solution from the plant to the division.

<u>The Return of Inspectors</u>. This same dynamic was being played out on a much broader scale during my visit. During the daily meeting of the plant manager's staff, I learned about plans to reintroduce a contingent of inspectors into the plant to help reduce the level of quality problems. This seemed such a striking repudiation of the "build it in,

don't inspect it in" quality philosophy that I asked many people about it.

A plant engineer told me that the plant had, in the early 80s, a large group of repairmen and inspectors who were very busy, and worked a lot of overtime. This continued into the early years of producing the current model, even as quality improved, because the group, accustomed to the income, continued to generate long lists of repairs to be done. In reaction, and to send a signal about a new quality philosophy, all inspectors had been eliminated and the number of repairmen cut back considerably, both in 1987.

Now, because of consistent problems, especially with electrical defects, many in the plant are worried that they cut back too far. The manager of the trim and chassis department told me that the plant is under great pressure to improve its quality. Its rate of quality improvement, impres[illegible]ly high in the first two years of the new model (nearly 40%), has dropped as the easier problems are eliminated to a rate of 8-9%. Their quality measures reveal that many problems are not being fixed on the line and, without inspectors and repairman, are reaching customers. Furthermore, another Ford plant had recently zoomed to the best quality scores in the division after adding a new group of inspectors.

Cost is again a factor, because the division is willing to pay the costs of the extra inspectors (though not of extra repairmen). The inspectors would be "the last line of defense"; the trim and chassis department manager told me his top priority was a 100% recheck of all electrical items by inspectors. Many mentioned that this plan was not inconsistent with their quality philosophy but merely a short-term effort to prevent defective cars from reaching customers while other needed changes are made; they said that Mazda's new Flat Rock plant outside Detroit did exactly the same thing in their first year of production.

But others worried that this was a step onto a slippery slope leading right back to the traditional quality philosophy of previous years. "How can we tell operators they have to catch and prevent quality defects as part of their job if their job pace is unchanged and we've just added a whole new bunch of inspectors?" said one. Many felt that, just on symbolic terms, this move sent the wrong signal. But others felt the action was a pragmatic response to their situation, and that they would have the discipline to use inspectors only to provide quality feedback, while insisting that the responsibility for quality remains in the departments.

Summary

This case study suggests the difficulty of remaining in a transitional state between mass and flexible production. While the Ford plant sustains an impressive level of problem-solving activity, and appears to have created a new set of expectations around quality, these efforts fall short of the goal of integrating innovation and production, often because of contradictory signals sent by management control systems, by the cost-oriented framing of problems, by the use of problem-solving mechanisms more for reporting than for true analysis. Having taken some steps towards a "fragile" flexible production system, the plant was seemingly beginning to backtrack towards the safety of mass production buffers.

D. HONDA PLANT

Background

The Honda plant is relatively new, still increasing its production volume (and thus its employment), and currently building only a single product. Like the other Japanese "transplants" in North America, it has transferred practically all of the elements of the flexible production system used by its sister plants in Japan: minimal repair area and in-process inventories, work teams and problem-solving groups, job rotation, extensive training, minimal status barriers, and bonus pay based on plant performance.

I found the mostly young workforce quite enthusiastic about Honda as a company, proud of the success of its products, aware of their status as pioneers in a cross-cultural experiment, and intrigued by Honda's unique culture, particularly its attempts (described below) to avoid many of the routines and bureaucratic procedures common to large organizations. Although I heard some complaints from workers about Japanese managers who were too demanding or difficult to communicate with, I more often heard complaints about American managers and supervisors whom workers felt did not consistently follow Honda's principles. Managers in turn told me that most workers arrived with utopian notions of what it would be like to work in a Japanese plant and went through a difficult adjustment process in the first six months, but then became quite loyal to the Honda approach. Finally, I heard some reports of tensions accompanying the increased rate of production at the plant, which required a reconfiguration of all jobs and a somewhat faster work pace.

There is a high level of technology in the plant, though not as much as the most technologically-advanced plants of U.S. companies; one senior manager said an American manager would say it is only 70-80% automated. This technology is highly flexible, giving the plant the ability to produce multiple models, although current demand for the single product that is made is high enough that product variety is not likely to increase very soon.

Of the three problem categories, I found little concern about electrical defects, but considerably more about water leaks and paint chips. The lack of concern about electrical defects surprised me, given the centrality of this problem at both the GM and Ford plants. Several quality LQ coordinators and the head of the assembly department told me that electrical defects are very low because of good incoming parts, good design of the wiring system, particularly the routing of wire harnesses, and a consistent, standardized work process. The main problem, one engineer told me, is when electrical connectors don't seat fully. He said they try to teach workers (called "associates") to listen for the snap. (One intriguing advantage the plant has is that it is so quiet that an associate can actually hear this snap -- something impossible in the GM and Ford plants, where the noise level is considerably higher, although typical for most assembly plants.)

Quality System

Quality is described as the top priority of the plant, which has already matched quality levels of plants in Japan. Most quality responsibilities are integrated into production jobs, but there are small groups of coordinators responsible for liaison activities for different aspects of quality, identified as Line Quality (LQ), Parts Quality (PQ), Vehicle Quality (VQ), and Quality Engineering (QE).

LQ coordinators are assigned on the basis of the "zones" of 4-6 teams that make up departments. The assembly department has 4 LQ coordinators (one designated as LQ "team leader") covering 11 zones. When problems are identified by team members, the team leader notifies the LQ coordinator, who then gather information about the problem. If it is a parts problem, s/he contacts the PQ coordinator, who is responsible for contacting the vendor, working out a plan with the vendor for a permanent solution ("countermeasure") and developing a temporary countermeasure.

VQ coordinators work in the final repair area, and often relay information about problems back to the LQ coordinators, although LQ may also alert VQ about a problem that will show up post-process. QE is the group responsible for research on warranty claims, handling quality problems between the plant and the customer (both transit and dealer), quality testing, and long-term quality planning.

Honda chooses not to use an elaborate system of quality measures. The main quality measures used in the plant are Outstanding Rejects - the average number of rejects in a sample of 100 cars after the final dress-up line (when all the departments have their last chance to fix any defects spotted upstream); Total Rejects per Unit, which is all problems spotted, regardless of which are repaired before the final line; and Straight Ship - the percentage of vehicles from a given department that can be shipped without rework of any kind.

During daily production, VQ coordinators keep track of problems by listing them on a flipchart near their final inspection area, and all day long, a steady stream of LQ and PQ coordinators, QE engineers, managers and team leaders come by to find out what is listed. Otherwise, quality charts are much less visible than at the Ford plant. Each department has one central area where quality, production, and cost information is tracked over time. The team rooms, where quality circles also meet, have SPC, Pareto, and fishbone charts for current projects posted. But all charts are current and in use, unlike the Ford plant where the profusion of charts includes many that are incomplete and outdated. Warranty information isn't coded at the dealers. Rather, each warranty claim contains a full page of written information about the problem and its repair that are then further researched by QE. The Honda sales organization that "purchases" vehicles from the plant does carry out unannounced audits to check "fit and finish"; at first, this happened monthly, but because of the small number of defects found, this now only takes place every other month.

Instead of elaborate quality reports, Honda emphasizes having people actually see quality defects directly. Within the plant, it is extremely common for the LQ, PQ, and VQ coordinators, team leaders, and even workers to go to another part of the plant to see a car with a defect. Persistent quality problems that are under investigation by QE are documented with sketches and photos as well as testing data. The quality coordinators are even sent to visit dealers to examine unusual problems first-hand. The philosophy, the plant manager told me, is that when a person sees a quality problem, s/he is more likely to analyze it systemically, to communicate the problem more accurately to others in his/her team or work area, and to be motivated to find a preventive remedy.

Problem Definition

Too Much Quality? I heard many stories about Honda's willingness to make strenuous and costly efforts to prevent any known defect from reaching the consumer. But, according to one American engineer, Japanese managers approach this commitment differently than most American employees. "The Japanese managers take the view that we should find and fix all major quality problems first, and then fix as many of the minor problems as time permits," he said, noting that "major" and "minor" are defined in relation to how customers will react. In contrast, he said, "the Americans, once they buy in, tend to become zealots." Showing me a barely visible spot of dirt under the paint on the roof, he said, "A Japanese manager would let this go -- but most American workers wouldn't."

As a result, the American plant is known as the "pickiest" Honda plant, and regularly reports the highest defect rates in the company.[6] As one worker told me, "We build the best quality cars in the world, but it's only because we take so long on them."

This emphasis on quality as the overriding goal of the production system is an

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[6] The tendency for American and Canadian workers to become, at first, overzealous about quality was reported to me at nearly every Japanese transplant I visited. The transplants that have been open the longest claim considerable success in training these workers over time to distinguish between defects that are "customer acceptable" and those that are not. At U.S.-owned plants, on the other hand, I found a number of managers who believed that their quality audits were oversensitive to paint defects in comparison with Japanese plants, and correspondingly undersensitive to other quality problems that emerge over a longer time period, such as electrical defects. This is, perhaps, overcompensation by U.S. companies to the prevailing view, a few years back, that Japanese cars enjoyed a particular quality advantage in the "fit and finish" area.

important part of Honda's socialization of its American employees. This was emphasized in conversations I had with the senior Japanese manager of the operation. We talked first 11 months after Job 1, at which point the plant was at 60% of its planned production capacity. He explained that the plant's productivity, in terms of employees per car, was at about 80% of the target level. This was necessary, he said, because the workforce was still acquiring the skill and experience it would need to reach Honda's quality standards. In fact, he expected that this training process would take two more years -- a full three years after Job 1, a three to four times longer "ramp-up" period than U.S. companies use.

Assigning Responsibility, not Blame. Quality problems are assigned to different departments, but with an important difference from the GM and Ford plants. One senior American manager told me, "The accounting system is deliberately designed to minimize the time spent figuring out who's to blame." Some Honda plants, he said, have a miscellaneous category for problems (such as water leaks) that can't easily be pinned to a specific department. At this plant, the management team decided that it was important to assign defects to some department, in the interests of calling attention to problems, but without any attempt to attribute blame, e.g. all body "deforms" assigned to the body shop, all paint chips to paint, and all water leaks to assembly.

When these departments repair a problem, they can (although it's not required) write up a report for other departments, describing the "root cause" -- both a way for a department to explain their defect level and to help other departments improve. These reports often do tally the percentage of defects that the repairing department believes come from other departments, but these figures are kept separate from the main quality measures for the plant.

There are no budget penalties assigned for a quality problem -- for either the department that fixes it or the department that may have caused it. As this same manager explained:

> The reason to want to fix the problem is so we don't lose a customer -- not so costs won't accumulate. It doesn't really matter how it gets paid for.... If I find a problem and then piss off Charles by not fixing it or trying to blame him for it, then I have two problems. Honda's philosophy is that a problem with our product is a problem for the whole company, not for an individual or department.

According to one department head, this system disturbs some Americans, who feel there is not enough accountability in the system. "It doesn't help the rapport between departments," he said. Despite the absence of any accounting penalty for a high defect rate, some people feel it would be more fair for defects to be attributed to the department that caused them. But Honda eschews such a system.

A similar philosophy of control systems is found in the budget for the launch process. "There's just one giant line item covering the launch," said the senior American manager. "The Japanese managers told me 'the worst thing you can do during a launch is to put a budget in.' We're just now [after 3 years] starting to deal with real budgets." In addition, he said, Honda doesn't assess management performance based on how much you're under budget, since this encourages "grandstanding and shortsighted cost savings". Instead, managers are assessed on how well they've used the budget they have.

Problem Analysis/Generation of Solutions

Breaking Down Status Barriers: "Everyone Builds Cars" Honda attempts to encourage problem-solving across organizational boundaries by breaking down status barriers between organizational groups. Physically, one is struck immediately by the completely open layout of the administrative and management offices -- rows of desks facing each other, without partitions or other physical dividers. Even the president of the American manufacturing organization has only a plain desk in the corner. All employees wear the same white overalls and, often, a Honda cap. There are no separate offices for managers in the plant either, just more open areas with desks. The offices are generally quite empty; one manager called it "nothing but a giant inbasket". Most meetings, whether between managers, purchasing and suppliers, or of a problem-solving group, take place in the cafeteria. Otherwise, practically everyone in the plant is out on the shop floor.

Managers and engineers also carry out a regular daily stint of work on the assembly line -- one hour a day, four days a week, a reflection of the plant's philosophy that "everyone builds cars." I accompanied one QE engineer, who spent forty-five minutes filling in for an absent operator on the engine dress line, where the engine is readied for installation.

He spent a little while looking over the Operation Standard for the job, refreshing his memory, asked a few questions of the next worker on the line, and began. The job involved inserting and tightening some bolts, slipping a metal sleeve over some locator pin, and doing "marker checks" -- checking to be sure some previous operation was correctly completed and then marking that part with an orange, green, or yellow marker. He explained that he liked the chance for some "hands-on" work. "I worked in a unionized plant once, and we weren't allowed to touch any of the equipment. It was totally frustrating. Here I feel like I'm close to the action."

Countermeasures, Spontaneous Meetings, and "Y-gaya". I asked the head LQ coordinator, Tom, in the Assembly Dept. to talk me through the process for dealing with a production problem. He gave the example of a fuel line pipe with a deform in it. When a worker spots the problem, he contacts the team leader, who in turn finds the LQ coordinator for that zone. The LQ person writes down the Vehicle Identification Number (VIN) of the vehicle, calls PQ (since a part is involved), and inspects the problem first-hand.

The PQ person shows up and is shown the problem directly, before going off to call the vendor and find out how many bad parts are in storage. Meanwhile, the LQ determines how many lineside parts are bad and discusses with team leaders and other LQs what kind of temporary countermeasure might be appropriate.

One possible countermeasure, if the parts problem is found to be intermittent, is to have an operator, a team leader, or an LQ do a "marker check" -- inspecting all parts and putting a bright colored mark on all those that are OK, so this is clear to downstream processes. Another, when feasible, is to have any available PQ coordinators actually repair the parts in an special area near the line. When this happens, Honda charges the supplier for the rework, at three times the price paid for the part. Faced with such a charge, and eager to keep their relationship with Honda, many vendors are quick to send their own personnel to the plant to carry out this short-term rework. Neither of these remedies, or anything closely resembling them, was in evidence at the Ford and GM plants.

One example of supplier responsiveness involved Honda's engine plant. The Friday before my visit, VQ discovered a problem with the engine's torque converter. It turned out that a small cam used in engines for another plant had been accidently inserted into the engines intended for my field site by a vendor to the engine plant; the two parts were identical except that the other engine cam was 1 mm longer. By Monday, the day of my visit, personnel from the engine plant were at the assembly plant fixing the problem.

If the problem comes from an upstream process rather than from a part, the LQs again take the initiative, going to the upstream area both to communicate the problem and to discuss and implement temporary countermeasures. The LQs may request multiple countermeasures. For example, for one water leak problem involving an unsealed gap in the inner wheel arch, Tom asked the paint LQ to do a temporary 100% inspection of the seal for that gap and the weld LQ to check the specifications of the robot applying welds in that area.

When a problem is major, with no obvious countermeasure, the LQ can make the judgement call to get VQ involved as well. VQ will often then call an immediate cross-departmental meeting, paging whichever VQ, LQ, PQ, and QE coordinators s/he feels is appropriate; managers sometimes attend as well. The meeting could happen almost immediately, in one of the areas teams use for their meetings. "Meetings can get big," he said, "but we find that they're a good way to let everyone know what's going on."

Tom reiterated several of the principles I had heard in other interviews. First, the importance of showing problems to people first-hand. He gave an example of finding a gas tank with a serious deform in it. Since the LQ in the body shop wasn't familiar with the problem, he went and got the assistant manager of weld and two operators and brought them down to assembly to look at the problem. "That way, they get the feedback and they can analyze the problem at the same time."

Second, the priority placed on mobilizing whatever resources are needed to prevent defects from accumulating, without consideration of organizational position. Tom said,

> It can be a bit sensitive, dragging a manager back to your department to see something. But we don't have much trouble. It's probably because quality is so important -it gives us a lot of authority... It's partly because of the way Honda is. It's clear as soon as you step into this plant that there are no visible signs of differences between levels. If we think managers should know, we tell them. Not by going up the ladder from team leader to coordinator to manager but directly."

Third, the formation of ad-hoc groups to address problems, with members dependant on the problem, rather than having an elaborate formal structure of groups and meetings. Honda has a term for this approach -- 'y-gaya' -- which translates as "just do it" or "act forthrightly". A key element of 'y-gaya' is that anyone with relevant knowledge of a problem is included, regardless of rank, and the norm is that senior people listen and those closer to the problem speak.[6]

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[6] In an interview in Boston with a former president of Honda in Japan, I asked how the philosophy of 'y-gaya' is preserved, given the natural tendencies in large organizations for individual status within a hierarchical structure to determine 'voice' in decision-making processes. His first reaction was surprise at the question -- "there is no other way". He went to say, in

Fourth, the importance of "face" skills - communicating in complex, data-intensive, and emotionally-intensive situations. Tom explains what it's like telling another department about a quality problem they're having:

> People are handpicked for this job, depending on how well they can communicate. There can be a lot of animosity out there. You don't want to tell [a team leader or LQ] how to do their job or be too opinionated. We may not understand why they're having a problem. You can't assume you know the reason. You have to think over what you're thinking before you say it.... Working on a problem together -- getting it down in black-and-white -- really helps.

A VQ coordinator, Philippe, described the give-and-take between people during the problem-solving process:

> When you come up with a countermeasure, anybody can challenge it. A bullshit countermeasure isn't worth a damn. You've got to have the data to show it is effective.

The "Five Whys". Much of the process for finding a permanent countermeasure involved the careful, iterative examination of possible sources and remedies of the problem. This process, pioneered by Toyota but now common in all the Japanese companies, is known as the "five whys". The answer to the first "why" about a problem is often based on the easily observable or familiar antecedents to its occurrence. An attempted solution based on this relatively automatic diagnosis is unlikely to be successful for long, because there are other "root" causes still uncovered. These root causes are more likely to be uncovered when the answer to the first "why" is questioned in turn.

For example, I learned about one case where the brakes in a car didn't work well

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essence, that 'vertical slice' groups, formed spontaneously in response to a problem, were the only way to get all the necessary perspectives for solving a problem, and that senior managers perpetuate the necessary norms by modeling the behavior they expect from others in such a group -- encouraging contributions from those at lower organizational levels, listening respectfully, probing for reactions from others. I was reminded of an observation made by Smith and Misumi (1988) that the status of Japanese managers is vested not in their position or specialized expertise but in their seniority and range of experience, so that they are less threatened by the participation of highly capable subordinates.

during testing - a safety problem, ranked as the most serious of all quality problems. The first "why" revealed that a metal pin had fallen into a brake subassembly and was causing a jam. The second "why" led to an examination of the work stations where the subassembly was attached, to no avail. The next set of "whys" led to the supplier, and to material handling between the supplier and the plant.

Finally, a Japanese engineer, convinced that the pin looked familiar, successfully tracked it to an upstream machine, unrelated to the brake system. The pin had been replaced during routine maintenance, hadn't been thrown out, had fallen into the engine compartment, and eventually into the brake subassembly. The documentation of this problem-solving process, covering several pages, was augmented by a plastic envelope containing the mangled pin!

In walking through the sealer department, I saw other examples of how employees at Honda communicate information about production problems and their solution. A large bulletin board, some twelve feet long, was covered with tips about applying sealer. The Operations Standards for various sealer jobs were posted, and next to them, a list, complete with sketches, of "good" and "bad" sealer technique. Further down was a display of handmade sealer tools designed by team members. Most were dual-purpose, with a brush at one end and a scallop-shaped piece of black rubber at the other, used to spread and smooth out the sealer, and each was customized to a particular job.

Simple experiments to test potential solutions for quality problems could be seen when walking around the plant. The plant was, at the time of my visit, struggling with one water leak problem brought about by a design change that eliminated the use of sealer around one part of the door. The fixture holding the front seat belt was moved forward, in this new design, directly onto the door post. Sealer on the door post was eliminated, therefore, to guard against getting any on the seat belt, and replaced by a self-adhesive tape that wasn't sticking very well. The LQ coordinator showed me an experiment involving the heating of this tape under a heat lamp before application. An SPC chart next to this experiment showed the careful tracking of "before" and "after" data. Soon, he said, they would try something else, and then evaluate which was the better solution.

Operations standards are a key feature of Honda's approach to quality, for its role both in insuring uniformity of process and in the problem-solving process. Associates are expected to adhere to these standards quite strictly, and I heard various complaints about this "rigidity" from some Americans. But these Operations Standards can be changed by a quality circle. The group must first prove that it can meet the current standard, in part to provide a baseline of data against which to measure changes. It can then devise and test modifications in the standards, using the "5 Whys" and other problem-solving techniques, and, if improvements in safety, quality, and productivity are found, these can be implemented. If the change involved is major, QE may carry out data collection and analysis too before approving it.

Interestingly, some of the American managers and engineers I spoke with felt that the plant needed more explicit training in these problem-solving techniques, which Japanese managers tended to take for granted. A proposal to bring Kepner-Tregoe, a U.S.-based consulting firm known for training managers in a standard problem-solving methodology, was under consideration. My guess, based on conversations with Japanese managers, is that they see the development of "continuous improvement" skills as based more on experience and philosophy than technique, and they will prefer to carry out this training through in plant, "on-the-job" efforts rather than through an outside consultant.

One example of the view that problem-solving experiences provide valuable learning for the plant occurred the first day of one of my visits. Because of unseasonably warm weather, the cooling system, which had been shut down in anticipation of winter, was restarted. Due to complications this caused with the heating system, one degreasing booth and one bake oven in the paint shop operated below their usual temperature for a few hours. The underbody coat of paint didn't adhere well, and this, in turn, fouled up the application of the top coat. Several cars had to be scrapped, the paint department was down for hours, and production for the day was off by 100 cars. As problems go, this was a big one.

While I was present when the news of this problem was announced to some senior managers, I did not observe the efforts to deal with this problem first-hand. But I was struck by one remark made by a Japanese manager later in the day, when we discussed the incident. He said, "What the plant can learn from experiences such as this will one day be its greatest asset." My interpretation is that this was a statement about the value of systemic learning -- and of the value of production problems in stimulating that learning.

Multi-source Problems: A Special Task Force. I learned about a special task force that had recently been set up to investigate water leaks, paint chips, and body dents -- all problems whose sources can be in multiple departments and whose solutions require cross-department cooperation. Paint chips were viewed as particularly serious at that time, especially in the assembly department where many new hires were starting work each week.[7] I interviewed two young hourly workers who were assigned to this task force on a full-time basis for three months.

Their first task was collecting data from the different departments. They decided to ask for extra detail in the records kept on these problems, and developed some new forms for this. They also have spent time working as repairmen in the final VQ line, and try to observe different operations in the plant as much as possible. This latter activity can

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[7] Unlike the Ford plant, where rubber pads are commonly used to protect auto bodies from being scratched by belt buckles or tools, the Honda (and GM) plants attempt to minimize these sources of paint chips by careful training and adherence to job specifications.

be tricky, they say, because "a guy feels like you're checking up on him." They try to move the emphasis away from evaluation.

> We're not supposed to say 'it's your fault'. The point is that it's a plant-wide problem, not a department problem. It doesn't really matter who did it - the idea is 'teamwork'. Some of the managers forget this sometimes -- they get too worried about their numbers. I'd say something if I had the nerve.

They point to the recent increase in line speed and increased pace of bringing on new hires as important sources of problems, particularly paint chips. "A lot of these guys are young, it's their first real job, they're making good money, living at home, and they just want to have a good time. They don't give a damn." They contrast this with the early launch period. "We were hired in groups of 10, and building 60 cars a day. People were learning so much. I had three processes to do myself. Now there are four guys doing them." They expect to recommend some additional manpower, some revision of operations standards, the establishment of more quality circles to take on certain problems.

On their assignment, they report, "It's an honor to be asked. Besides, if you say 'No', you might not get asked again. You figure, it can only help." They and the two other hourly workers on the task force have been assigned an office area; they meet weekly with their advisors (managers from the respective departments); and they attend a weekly communications meeting that includes all senior and department managers and report on the status of their project.

They described this last meeting at length. "40 pairs of eyes on you. These managers are probably wondering 'who are these guys anyway?' This is the time when a lot of the Japanese really learn what we're doing. They ask a lot of questions." They will make a final presentation at this meeting in two more months and then at a meeting for the whole plant between shifts.

<u>The GAP team</u>. One quality circle, I learned, had recently won a competition of

such groups in the plant, and was on its way to the all-Honda competition in Japan. I arranged to sit in on a dry run of their presentation just before their departure.

The three associates, two men and a woman, delivered a very snappy, sophisticated 15-minute presentation, using two overhead projectors and a slide projector for split-second transitions between bullet points, charts, cartoons, and photos. The whole presentation was scripted and synchronized with the visuals, with playful sequences where the three would rapidly pass phrases back and forth.

The group, called the Glove Action Project, began meeting in 1988, a year before my visit. Its seven members held 18 meetings, and put in 133 overtime hours and 49 volunteer hours. The group had both a facilitator and a Japanese advisor. Its chosen problem -- the Kevlar gloves needed for hand protection against both heat and metal spurs in the weld shop were disappearing, getting lost, and wearing out. The gloves are expensive to replace, and there is a safety risk if people don't use them. The cost of replacing gloves had reached $361 a week; the group set a goal of reducing all glove-related expenses by 25%.

After a slow start, when the group had trouble sorting out how to proceed, they began a "root cause" fishbone analysis for four categories: man, machine, method, and material. The group reviewed some early ideas it had rejected: buying an industrial washing machine to wash gloves at the plant was judged too expensive, cheaper gloves were found to be inadequate in terms of comfort and safety, and requiring that old gloves be handed in before new gloves would be issued (the method used in Japan) was rejected as "babysitting."

Eventually, the group settled on four countermeasures: better glove boxes, locked when not in use so that outside contractors in the plant wouldn't take any, and new laundry bins; buying extra-large cotton gloves to be worn over the Kevlar gloves for protection; an education campaign to encourage people to return gloves at the end of the day (including GAPman cartoons and a yellow line "The Point of No Return" near the plant exit with boxes for glove drop-off; and glove repairs arranged through the manufacturer. Within a few months, they were recovering 42 extra pairs of gloves a week, worth $183. Gross annual savings were $12,500, minus $3,000 in overtime expenses, for net savings of $9,500 per year.

After the presentation, I talked with the three presenters. Howard said they had encountered some antagonism during the process -- posters torn down, the yellow line burned off the floor by fork lift tires. But the mood really changed after they made an initial presentation to the weld dept. Rather than focusing on cost savings, they emphasized the frustration of not having enough gloves to go around at the end of the week, and the ways in which the department could affect this availability. Soon, instead of regarding the glove situation as "GAP's problem", people began to go along.

The in-plant competition seemed to have energized the group. Beth-Ann, the clear creative leader of the group, said that many of their ideas didn't really come together until they began trying to pull together a presentation. Howard said he had revived some old drawing skills for the posters, cartoons, and presentation visuals. Sam, a real shop floor leader, had gone from being biggest skeptic to strongest advocate. All seemed excited about the trip to Japan (with some misgivings about resentment from their coworkers upon their return) and eager to begin their next project.[8]

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[8] The experience of this Honda quality circle is markedly similar to Robert Cole's recent observations in Japan, where employee presentations about problem-solving activities, from QC circles made up of production workers to high status engineering department, were standard practice. He writes:

> These presentations play a central role in diffusing best practices ... relating not only to quality but to the introduction and operation of new technology. Witnessing the steady stream of such presentations gets one to thinking about the factory as a school and not just a producer of goods and services. These presentations help insure that the same mistakes

Summary

The Honda case study shows the alignment between the "structural logic" and the "cultural logic" that was missing in the GM and Ford cases. Both corporate-level policies, in terms of product design and accounting systems, and plant-level manufacturing and human resource policies reinforce the ongoing processes of problem-solving that integrate innovation and production activities. The case study also reveals many unique aspects of Honda's culture: the emphasis on seeing quality problems before trying to define, analyze, or solve them; the preference for spontaneous meetings prompted by the emergence of a problem rather than a permanent structure of problem-solving groups; the "everyone builds cars" and the "y-gaya" philosophy, both of which facilitate participation of employees at different organizational levels during these meetings; the reliance on many simple experiments, both to find the "root cause" of a problem (the "five whys") and to test possible countermeasures; and the use of public presentations to communicate information about specific solutions and effective problem-solving processes, and to reinforce a culture that values problems as an opportunity for learning.

E. DISCUSSION

These three plants can be characterized along the "structural" and "cultural" dimensions of mass production and flexible production "organizational logic" as follows.

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are not made twice and they bring about broad employee participation in corporate activities. Typically, these problem-solving presentations include a history of the problem-solving activity, including a discussion of the blind alleys and failure modes that were pursued. Thus, they document a process by which failure and errors are overcome to produce success. in so doing, we see that errors and failures are treated as positive learning experiences. Top management officials, who often attend such sessions, associate themselves with an event in which learning from failure is a key theme. (Cole, 1990, p. 12)

The GM plant has many of the structures of flexible production, but its problem-solving processes are more traditional, reflecting a mass production culture. The plant's history, with its emphasis on a participative culture rather than new manufacturing policies, and corporate-levels constraints, in the form of corporate accounting systems, design change policies, and supplier relations, account for this gap between structure and process.

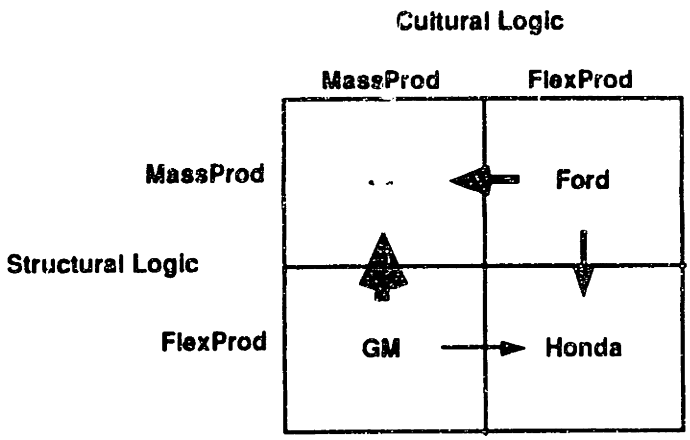
The Ford plant represents the opposite case -- a plant that structurally resembles mass production but that has successfully implemented a wide variety of effective problem-solving processes. Here, a history of labor-management cooperation, a corporate push towards quality improvement, the establishment of cross-functional problem-solving groups, and the on-site presence of design engineers account for the structure-process gap. Yet the traditional structure does exert a pull towards traditional processes, leaving the plant at an awkward transitional stage in the move towards flexible production.

The Honda plant comes closest to flexible production, in both structure and process. In fact, this relatively new plant is still implementing the formal structures of flexible production (e.g. New Honda Circles (quality circles)) but has already been quite successful in establishing the "continuous improvement" mindset among its employees. There are fewer inconsistencies and tensions between corporate and plant-level policies, and between structure and process than at either of the U.S. company plants.

The location of each plant on the structural and cultural dimensions of the "organizational logic" is shown again in Figure 7-5. The arrows between cells suggest the likely dynamics for these plants, with the size of the arrow reflecting the strength of the pull towards another cell. For the GM plant, with its FlexProd structure and its MassProd culture, the strongest pull is towards the "aligned" mass production cell, and the weakest pull is towards the "aligned" flexible production cell. For the Ford plant, the pull towards each of different "aligned" cells is more nearly equal, but the case study suggests that in the absence of further moves towards flexible production, the stronger pull will be towards a return to "aligned" mass production. Only the Honda plant, in the "aligned" flexible production cell, is likely to be stable.

Figure 7-5

Dynamics of the Interaction between Structural and Cultural Dimensions



To summarize the findings from the three cases, I will discuss them in terms of differences in information processing, the division of labor, and the coordination process, attempting to link the fieldwork observations with the "ideal type" distinctions between mass production and flexible production culture.

Information Processing

As described in Chapter 2, under mass production, people tend to see problems as an obstacle and to guard information, while under flexible production, they tend to see problems as an opportunity and to make information transparent.

Differences among the three cases in information processing can be seen in the following areas: sources of data about problems, how problems are communicated, and what is regarded as a legitimate problem.

When problems are viewed as an opportunity, data will be drawn from customers, rather than the plant, in as much detail as possible, since customers are the critical judge of what constitutes a problem. Information about a problem must be as transparent as possible so it can be thoroughly understood by those trying to find its "root cause". Any problem, regardless of type, will be regarded as a legitimate locus for learning.

When problems are viewed as an obstacle, data will be drawn from internal inspections that are used primarily to assign blame, in the form of cost responsibility, to the appropriate department. This approach creates incentives to guard information about problems in the hope of minimizing blame. In addition, problems will only be regarded as legitimate to the degree that they do not conflict with other, higher priorities, such as design standardization or cost minimization.

In these terms, the GM plant is closest to mass production. It relies most strongly on in-plant audit data, with no timely customer-based data available. These audit data are used primarily to affix cost responsibility rather than to guide the search for a "root cause". This prompts a great deal of negotiation over which department will get the blame for a problem, which takes precedence over efforts to eliminate the problem.

Even GM's anticipated move to using warranty data cannot be seen as a true shift to customer-based data. These warranty data are reported in the form of "labor codes" -- the code for the type of repair job needed, chosen by the mechanic at the dealer. There are thousands of these codes, each very specific. A repairman (or a back-office clerk) must translate the actual diagnosis and action taken into one or more codes. For complex problems, these are likely to be incomplete, or to describe symptoms rather than causes.

The plant, following these codes, may be sent off in the wrong direction.

Furthermore, the GM plant has encountered so many frustrations in its attempts to resolve design-related problems at the corporate level, that there is a strong tendency to avoid problems that require design changes or to recategorize them as other types of problems. This results partly from the unresponsiveness of design to manufacturing concerns (there being remarkably little direct interaction between designers and the plant) and partly from cost concerns.

Ford relies on a broader mix of data about problems, including in-plant audits, warranty data, and customer surveys and reports that return verbatim comments to plants. Data from all these sources are combined to provide a single record of all current quality concerns. But the data from outside the plant is not transparent to managers and workers in the plant; they place more faith in the in-plant data, which corresponds more closely to their intuitions about problems. Thus despite the broader array of data about problems, remedial actions tend to be based on the in-plant data alone.

Relationships between design and manufacturing are better at Ford than GM, in part because of the on-site presence of young design engineers. Thus design-related problems are seen as legitimate to pursue, although due to frustration about the slow response time, these problems are sometimes still not raised. Cost concerns are the more significant barrier to raising certain quality problems. Such common perceptions as "you don't touch metal" become the unspoken criteria for whether it is legitimate to pursue a particular problem.

The Honda plant treats problems as opportunities most consistently. In-plant data are communicated simply and broadly, often on large department flipcharts and bulletin boards rather than on paper reports. Honda also uses customer-based data most extensively, requiring a one-page report from the dealer for each warranty problem, with descriptive statements from both customer and repairman, rather than warranty codes. The customer orientation is apparent in the frequency with which employees at all levels refer to actions and decisions that were based on "what the customer expects from us".

A high priority is placed on the transparency of information about problems, with the philosophy that actually seeing a problem is the key to understanding it. Vehicles with defects in the plant are held aside until relevant people from upstream departments can come to see them. In addition, quality staff from the plant travel frequently to see actual defects at dealers.

Finally, the accounting system emphasizes responsibility for problem-solving, rather than blame for problems. Paint problems are always charged to the paint department, regardless of their source. In addition, departments are judged less on the basis of cost-savings than on how they use the budget they have. Taken as a whole, these policies reduce the incentive to hide problems, although they do not eliminate inter-departmental tension about the source of problems.

Division of Labor

Chapter 2 also describes mass production culture as oriented towards a fractional division of labor, in contrast with the holistic division of labor of flexible production.

Differences in the division of labor among the three cases can be seen in three areas: who is involved in problem analysis; what sort of conceptual knowledge they bring to the analytical task; and what methods of analysis they employ.

With a fractional division of labor, problem analysis is regarded as a task for managers, engineers, or manufacturing staff, and not appropriate for workers. This task is approached from the point of view of functional specialization, with experts taking on problems judged appropriate for their expertise. When a problem is multifaceted, these specialists often have difficulty finding a common language for understanding its source and how to eliminate it.

With a holistic division of labor, much responsibility for problem analysis is pushed down to the level of work teams, with managers and engineers in a support and monitoring role. Each problem is viewed as requiring a unique mix of expertise and experience, beyond any particular functional specialty. As a result, a group of individuals possessing the necessary knowledge for a particular problem is convened. Under flexible production, these individuals tend to be multiskilled, with broad conceptual knowledge of the production system. Thus there is overlap in their expertise and experience, providing a common language for problem analysis efforts.

The GM plant is again closest to the mass production culture. The quality roles at the worker level (Quality Coordinators in the teams and Quality Analysts in the departments) are used primarily for administrative rather than analytical purposes; the former to chart quality problems and the latter to negotiate among departments to assign budget responsibility for defects. One consequence is that most of the highly visible quality improvement activities in the plant involve little or no formal problem analysis; they focus instead on problem identification and exhortations about the importance of quality. Problem-solving groups are organized on a departmental basis, thus reinforcing existing functional specialization.

The Ford plant is again in the intermediate position. While one new quality-related role (the ZIPs) is used primarily for administrative purposes, the cross-functional subsystem teams do provide a forum for problem analysis. These teams include a "vertical slice" of people, including department manager, design engineer, plant engineer, supervisors, and workers. Each of these participants is, however, quite narrowly trained.

The subsystem teams ostensibly use several analytical techniques, but, in practice, tend to rely on their (specialized) intuitions about the sources of problems (rather than collecting data) and to emphasize their implementation of a wide variety of remedies. Thus they use the Deming-derived "8D"s more for reporting purposes than for true analysis. Problems also tend to be rigidly categorized into "design", "supplier" and "plant" categories.

The Honda plant comes closest to having a holistic division of labor. Because of broad job classifications, job rotation, and lateral job movement, employees bring more conceptual knowledge about the production system to their problem-solving activities than employees in the GM and Ford plants. Managers, engineers, and manufacturing staff all work some time each week on the assembly line, keeping them close to manufacturing problems and sending a powerful signal about the importance of understanding what is happening in production.

Instead of relying on particular problem-solving methodologies and techniques, the approach to problem-solving at the Honda plant is to let the problem be the guide to what action is needed. This encourages a more holistic approach to problems. Data are gathered to assess both the extent of a problem and the effectiveness of countermeasures. Countermeasures must be justified with data and by reference to other possible remedies. Documentation is extensive and reveals the priority placed on actually seeing problem conditions, with many sketches and photos. Much emphasis is placed on the process of problem-solving, as a learning activity in its own right, as much as on the result.

Coordination

Chapter 2 describes the orientation towards coordination under mass production as replicative and under flexible production as reformative. With respect to problem-solving activity, this is primarily a distinction between efforts that reinforce organizational routines and those that lead to change in those routines.

The GM plant is the most replicative in its problem-solving efforts. This is primarily the case because of constraints at the corporate level, in terms of design changes and accounting systems. Efforts to move beyond these constraints typically took a "back-channel" form -- defining problems in a way that bypassed the corporate level, giving the plant more discretion, and authorizing "guerilla" inspections outside of the normal quality audit system. In contrast, the more direct efforts to promote learning and change, such as the plant-wide daily audit meeting, have become a ritual that reinforces the current system.

The Ford plant is similarly replicative in orientation, despite a much more elaborate structure for promoting quality improvement. Rigid problem definitions, the dominance of cost concerns, and the reluctance to move away from a fractional division of labor all exert a pull back towards traditional mass production. The move back towards the use of inspectors who catch quality problems after-the-fact, rather than moving towards the flexible production ideal of pushing inspection, problem identification, and problem-solving down to the level of the production worker (and/or work team) is the best example of this tendency.

The reformative orientation is most in evidence at the Honda plant. When a problem is found, the various quality coordinators call a group together immediately, almost spontaneously, with the membership determined by what experience and expertise is relevant to the problem. When a problem requires a longer-term effort, groups are again organized for that problem, on a time-limited basis. These problem-solving groups are constantly being formed and disbanded, with shifting membership, which facilitated communication across departments and the development of a "common language" for problem-solving. Juxtaposed against these constantly changing groups are quality circles established within departments, with relatively stable membership, that develop the social ties and shared knowledge necessary to make local "spontaneous" problem-solving efforts effective.

Summary: The Link Between Process and Structure

The discussion of these three cases suggests that structural measures are an imperfect guide to underlying processes (such as problem-solving processes) and that the latter provide the best indication of whether a mass production or flexible production "cultural logic" is present. This is particularly apparent for the GM and Ford plants, since there is a much closer link between structure and process for the Honda plant.

There are two ways to interpret this. First, it may be the case that we should reverse the implied causality between structure and process. Rather than assuming that organizational structure determines organizational processes (albeit imperfectly), perhaps we should start with the premise that structure is a consequence of process -- the structuration perspective. Accordingly, we would forego traditional structural analyses in favor of a more fine-grained look at those factors (primarily cultural, although at an organizational rather than a national level) that affect organizational processes (and hence structure in the "structuration" sense).

Second, these observations could be the consequence of a transition period between mass and flexible production. The GM and Ford plants are quite clearly in the midst of such a transition (although it is possible that they may revert to mass production rather than make the full transition). Thus the gap between structure and process at these plants may be anomalous, and temporary.

The strong association between the structural measures of production organization and manufacturing performance suggests that, on a statistical basis, the structure-process relationship may be quite strong -- based on the assumption that it is this consistency or "fit" that explains the performance results. Thus the number of anomalous cases, such as the Ford and GM plants, may be limited even at this time of transition.

Perhaps in ten or twenty years, if flexible production diffuses as widely as I would expect, a new equilibrium state will emerge, dominated by flexible production as the postwar period was dominated by mass production. In this situation, there may be a very strong consistency between structure and process, and rather than revising our view of the relationship between structure and process, we will only need to revise theories that predict that mass production is the only appropriate form of organization for the large-scale production of low cost, high quality goods. Only future research can provide the answer to these questions -- focusing both on the pace of diffusion of the structural forms of flexible production worldwide and on understanding in greater depth the processes and culture of flexible production.

CHAPTER 8

CONCLUSIONS

This dissertation presents both quantitative and qualitative data in support of the thesis that flexible production represents a new production paradigm with a unique "organizational logic" that yields economically superior performance to mass production. This chapter will summarize the data analyses reported above, but perhaps more importantly, will address the broader questions raised by these findings.

The dissertation suggests that flexible production is likely to continue to diffuse until it becomes the dominant model for automotive assembly. But there is good reason to expect this alternative model to diffuse throughout other sectors of the economy as well. Mass production, after all, diffused from Henry Ford's factories to become the dominant model for much of manufacturing, and even for such service industries as insurance and banking whose back office operations proved well-suited to becoming "paper factories".

Indeed, flexible production may prove to be, like mass production, a general organizational model applicable to many tasks. If this is the case, and flexible production has anything like the impact of mass production on organizational life, we will need to understand more about the dynamics of flexible production. What holds flexible production together? What undermines it? I will address these questions below -- in a preliminary way -- and touch on the implications for the structural and cultural logic of flexible production, as well as individual work identity, work/family boundaries, and educational and firm-based training requirements. The chapter will conclude with summary points about the diffusion of flexible production.

A. SUMMARY OF DISSERTATION FINDINGS

I will report separately on the quantitative data, drawn from the International Assembly Plant Study carried out with John Krafcik, and qualitative data, drawn from my fieldwork on problem-solving processes at three North American assembly plants.

Quantitative Data

Efforts to measure production organization, as a bundle of inter-related organizational practices, took two forms. First, a Production Organization (ProdOrg) index was formed as the average of three intercorrelated ($r > .5$) component indices -- Use of Buffers, Work Systems, and Human Resource Management (HRM) Policy -- placing plants on a continuum between the "ideal types" of mass production (MassProd) and flexible production (FlexProd). Second, the same variables used to form this index were used in a cluster analysis, with a comparison of different distance measures and clustering methods to find the clusters that were most statistically distinct. Both methods revealed a similar distribution, broadly bipolar, but with a sizeable number of plants in a "transitional" category between the two endpoints.

The Production Organization index proved to be strongly linked to manufacturing performance, accounting for over 36% of the variance in both productivity and quality outcomes. Similarly, the four-cluster solution, featuring two clusters near the "ideal types" and two transitional clusters, found statistically significant differences between adjacent clusters for both productivity and quality.

Several analyses addressed the "integration hypothesis" -- that high levels of automation within the context of flexible production yield the best manufacturing performance. One analysis found that manufacturing performance is considerably higher for plants with high levels of technology and a FlexProd organization (21 hours per vehicle, and 49 defects per 100 vehicles) than for plants with similar levels of technology and a MassProd organization (30 hours per vehicle and 79 defects per 100 vehicles). Another analysis found that the correlation between the amount of technology and performance (productivity and quality) was much stronger for the FlexProd plants than for the MassProd plants.

A third analysis looked at plants grouped by their combined performance. Plants with poor productivity and quality had low levels of technology and a MassProd organization, while intermediate performers (i.e. good productivity but poor quality) had high levels of technology with a MassProd organization. A small set of "world-class" plants with excellent productivity and quality had both high levels of automation and a FlexProd organization.

This hypothesis was also examined with a cluster analysis that used the production organization variables and the technology variables to yield five distinct technology/organization configurations. Here too, there were statistically significant differences in productivity and quality means across virtually all of these configurations.

A multivariate analysis then tested whether these relationships between technology, production organization, and performance would hold when a set of control variables (Production Scale, Model Mix Complexity, Parts Complexity, and Product Design Age) was introduced. Again, the data analysis followed two parallel tracks: one using the ProdOrg index and technology variables separately in regression analyses, and the other using dummy variables to identify the five technology/organization clusters.

These multivariate analyses upheld the integration hypothesis, with the control variables having essentially no impact on the results. Some of the control variables, most notably Product Design Age and Parts Complexity, were significant with respect to productivity, but none were significant with respect to quality.

Model Mix Complexity, which can also be viewed as a product variety measure, was not significant in any of the analyses.

Model Mix Complexity (i.e. product variety) also had virtually no correlation with the ProdOrg index. In other words, plants with flexible organizational practices do not necessarily produce high product variety, nor do plants with a mass production organization necessarily produce low product variety. An intriguing interpretation for this result emerges from an examination of FlexProd plants, for in this group are the plants with the highest product variety and lowest product variety in the world. This suggests that a "flexible production" plant is flexible because it can choose whether to produce high or low product variety, depending on market conditions and product strategy, without any appreciable sacrifice in productivity or quality.

Finally, the multivariate analysis considered alternate explanations, particularly those based on national-level variables, such as location in Japan, Japanese management, or low-wage levels. When Japan-related dummy variables were added to the regression analyses, the explanatory power of the ProdOrg variable was weakened somewhat for productivity but remained unchanged for quality.

For productivity, this suggests at least partial support for a "weak culturalist" view -- that flexible production is most strongly linked to productivity in plants that are Japan-located or Japan-managed. But in general, a reasonably strong relationship between ProdOrg and productivity still remained when the Japanese plants are removed from the analysis, providing broad support for a structuralist view -- that the structural features of flexible production are linked to better performance regardless of a plant's regional affiliation.

The addition of the Low Wage dummy variable revealed that, in terms of productivity, these plants do suffer from low levels of automation and old product designs.

Yet, in terms of quality, some plants in Low Wage countries are among the best in the world, an achievement that is most strongly associated with the partial adoption of flexible production principles.

Throughout the multivariate analyses, the use of the five technology/organization clusters, identified as dummy variables, produced essentially the same results as the use of the separate ProdOrg and technology variables.

In summary, the quantitative data analysis supports the following conclusions:

1. Plants with flexible production organization (FlexProd) achieve better manufacturing performance than plants with mass production organization (MassProd).

2. Technology contributes more effectively to manufacturing performance in a FlexProd plant than in a MassProd plant, regardless of the inherent "flexibility" of the technology.

3. Accordingly, flexibility is best understood as an organizational characteristic, rather than a technological characteristic.

4. Flexible production is a general organizational model that diffuses successfully across different social and economic contexts. Its link to manufacturing performance is not dependent on its origin in Japan, although Japan-managed plants do achieve better productivity (but not quality) performance than other flexible production plants.

5. The configurational approach used here, which measured the production system as a "bundle" or cluster of interdependent elements, has considerable value as a strategy for examining the causes of complex and possibly overdetermined outcomes such as productivity and quality.

Qualitative Data

A fieldwork-based study of problem-solving processes at three North American assembly plants -- one from General Motors, Ford, and Honda -- sought to identify differences in these processes between mass production and flexible production plants and, more generally, to examine the relationship between structure and process in these production systems.

The fieldwork showed clearly that the structural features of the production system at these plants were not determinative of underlying processes. The General Motors plant was structured as a relatively flexible plant, but demonstrated problem-solving processes more characteristic of mass production, while the Ford plant had the opposite characteristics -- a MassProd structure with FlexProd problem-solving processes. Only the Honda plant showed a close correspondence between its (flexible production) structure and process.

The fieldwork focused on problem definition, problem analysis, and solution generation and selection for a group of commonly-found production problems -- water leaks, electrical defects, and paint chips. My observations were broadly supportive of the distinctions laid out in Chapter 2 between the "cultural logic" of MassProd and FlexProd:

1. Information processing -- The MassProd orientation views production problems as an obstacle to be avoided, and guards information about such problems carefully. Data about problems are drawn primarily from in-house audits, and are used by the accounting system to affix blame and cost responsibility for problems. The FlexProd orientation is to view production problems as an opportunity for system improvement, and thus seek to make information about such problems transparent, in terms of both access and comprehensibility. Data about problems are drawn from customer-based sources and documented extensively; at Honda, a high priority is also placed on seeing problems directly. The accounting system is used to assign responsibility for problem resolution.

2. Division of Labor -- MassProd plants tend to view problem analysis as a task for managers or engineers, not workers. Problems are divided up according to specialized expertise and when a problem is multifaceted, these specialists have difficulty finding a common language to address it. Problem-solving activities are organized on department lines, reinforcing functional specialization. FlexProd plants tend to push down the responsibility for problem analysis to problem-solving groups on the shop floor. These groups are organized according to the knowledge needed for the particular problem, and are made up of multiskilled employees whose knowledge overlaps, thus facilitating the development of a common language for addressing problems. At Honda, such groups are constantly being formed and disbanded, with shifting membership, facilitating cross-functional communication.

3. Coordination -- MassProd plants carry out problem-solving in a way that reinforces organizational routines and relationships, while FlexProd plants instead approach problem-solving as a way to change routines for system improvement. MassProd plants are often constrained at the corporate level from choosing problem

solutions that lead to improvement by cost concerns or rigid design parameters. The corporate context of FlexProd plants supports the integration of production and innovation, and the plant-level pursuit of ongoing improvements in both product and process.

B. THE DYNAMICS OF FLEXIBLE PRODUCTION

What keeps flexible production in place? What potentially undermines it? These questions about the dynamics of flexible production are not directly addressed by this dissertation, with its cross-sectional data, but they are important enough to warrant some speculation. The tentative answers offered in this chapter encompass not only the organizational and environmental factors that sustain or constrain flexible production but also individual factors, such as individual work identity, work/family boundaries, and the requirements for training and education under flexible production. Finally, this preliminary examination of the dynamics of flexible production can provide considerable insight into the challenges of diffusing this approach, particularly into traditional mass production settings.

The data analyzed above suggest, first of all, that the answers to these questions involve more than the structural elements of flexible production. There are clues in both the quantitative and the qualitative data that these structural elements are not determinative of the crucial underlying processes of flexible production -- particularly those problem-solving processes that integrate innovation and production.

So these questions must be addressed to both components of the "organizational logic". What holds together (or undermines) the structural logic of flexible production? What holds together (or undermines) the cultural logic?

The Structural Logic

The structural logic of flexible production is held together by a particular relationship between technical capabilities and human capabilities. As described in Chapter 2, human capabilities are enriched, in terms of multiple skills, broad conceptual knowledge, and incentives that align individual and organizational goals, so that it is more capable of responding to problem conditions. In turn, the technical system is made "lean" through the minimization of buffers and a tighter interdependence among production steps, thus increasing its sensitivity to problem conditions and its ability to provide information that people can use for problem resolution and system improvement.

The significant dynamic factor here is the elimination of slack in the technical system. This leads either to breakdown of the production system or to an intensified reliance and renewed investment in human capabilities -- the pushing down of more responsibility to the team, the sharing of more information, more broad job rotation, more training, more effort to break down status barriers. Thus, the lean technical system provides a constant incentive to maintain and expand human capabilities, which provides the contingency-absorbing "buffer" that allows the production system to function.

Consequently, a production system with "flexible" work organization and human resource policies will only maintain its distinctive characteristics as long as it maintains its minimalist approach to the use of buffers. As buffers grow, the potential for problems to remain hidden grows, and the possibility of relying on the technical system to handle contingencies (rather than working with infinitely more complex human beings) grows -- and with these, the tendency to revert back to mass production.

A lean technical system may provide the dynamic element in flexible production. But it provides a necessary but not sufficient basis for the implementation of flexible production. Minimizing buffers alone will not bring about the development of the necessary human capabilities. A lean technical system that is unsupported by people capable of continuous learning will simply cease to function.

Thus the structural logic of flexible production is sustained by the interdependence between technical and human capabilities, and can be undermined either by the augmentation of buffers in the technical system or by the diminishing of employee skill, motivation, and adaptability.

The Cultural Logic

The cultural logic of flexible production is sustained by a norm of reciprocal obligation between the company and its employees, which encourages employees to feel that they are part of a "community of fate".

The norm of reciprocal obligation is evoked initially by company policies. The most notable policy in this regard is the commitment to employment continuity. This is best understood not as a "no layoff" contract with employees but as a commitment that management will do everything in its power to avoid layoffs, including such actions as wage freezes and reductions for managers, and "loaning" employees to suppliers and subsidiary companies. But this norm is also reflected in the high investment of the firm in employee skills and conceptual knowledge -- i.e. the willingness of the firm to "overinvest" in skills and conceptual knowledge relative to the task requirements of the technical system -- and in the elimination of status differentials.

These investments by the firm in individual employees create the conditions for a "psychological contract" to take hold, in which employees are motivated and committed partly by the design of their work (the structural logic) but partly by the sense of being part of a "community of fate". (Cole, 1979) To be part of a "community of fate" involves more than employee perceptions that their interests are closely aligned with company interests -

- it invests the workplace with a mission of broader significance.

One example of this "community of fate" notion in flexible production culture emerged during my interview with the president of NUMMI, Kan Higashi, in the summer of 1988. At that time, the fate of NUMMI beyond the twelve-year joint venture with GM was quite unclear. Toyota had not yet decided whether to use NUMMI to build trucks in the U.S., and it was unclear that GM would keep the plant open if Toyota decided to scale back its involvement.[1]

I asked Higashi about the effect of this uncertainty on plant morale. He answered: "I tell everyone that the future of the plant is not simply a Toyota or a GM decision. It's up to you. In the past, you put out a bad product and the plant was closed. No one can tell the future. But if you can keep your morale high and continue making the best quality product in the U.S., no one will want to shut this plant down."

With this statement, Higashi created a sense of drama, of this bold experiment in an old plant, perched on the West Coast far from supplier networks and corporate decision-makers, making a product (then the Chevrolet Nova -- now the Geo Prizm) that wasn't selling well, but with the opportunity, through its actions, of virtually guaranteeing its survival. He relied on neither threats nor empty praise but communicated the sense that "we're all in this together" and "together, we are masters of our fate." When statements of this kind are backed up with action that fulfill the norm of reciprocal obligation, such as the decision at NUMMI during a severe volume downturn to provide 48 hours of training for all production workers rather than laying off anyone, the result can be powerful bonds between individuals and their "community of fate".

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[1] Since that time, Toyota did decide to build trucks there, making it all but certain that the plant will stay open under Toyota management, either as an extension of the joint venture or with Toyota buying out GM's share.

These underpinnings of the cultural logic of flexible production can be usefully contrasted with those associated with participative management or socio-technical systems. (Figure 8-1). The flexible production culture encourages individuals to draw their identity from the "community" level, whether that be plant or company, and thereby to see themselves and their co-workers as equals, sharing in a common fate. Interaction and collaboration among individuals is emphasized, as a necessary means of achieving the community mission.[2]

Figure 8-1

Flexible Production vs. Participative Management Culture

	FlexProd	PartMgmt
Central norm	Reciprocal obligation	Participation
Employee most identifies with	"Community of fate" (plant or company)	Team
Primary emphasis of team activity	Integrated "teamwork" across groups	Autonomous work teams
Team control over personnel/admin matters	Low	High
Team control over work pace	Low	High
Team control over technical/production matters	High	Low
Level of problem-solving activity	High	Low

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[2] This can be powerfully reinforced when there is a national "mission" that is consistent with that of the company, as was the case in the postwar rebuilding of both the Japanese and German economies. Conversely, it may be more difficult to create a "community of fate" culture in a society like the U.S., where there is little agreement about the nation's political agenda, much less its "mission".

The "participative management" culture also emphasizes collective goals, but highlights the participative contribution of the individual in reaching those goals. By holding up participation as the primary means through which collective goals are reached, this culture emphasizes autonomy and discretion, as the conditions necessary to maximize the value of individual creativity.

This participative culture encourages individuals to focus on those aspects of their work experience that constrain their autonomy, either positively - when a participative culture minimizes those constraints - or more often negatively - since all organizations constrain individual autonomy in some way. A conflict is created for individuals, between the pursuit of individual autonomy and the need for direction, for interaction, for the expertise of others.

The approach to teams taken in these two cultures, also contrasted in Figure 8-1, highlights the way in which a common structural element can be interpreted differently, and serve a different function in the production system. In a participative management culture, team members tend to focus on the autonomy of the team and its freedom from supervisory oversight or technical constraints. This is particularly the case when socio-technical design principles are used to create semi-autonomous work teams, incorporating those functions that would formerly have been viewed as constraints on individual or team autonomy, e.g. supervisory tasks such as scheduling and task assignment. The emphasis on individual autonomy broadens to incorporate team autonomy.

In the flexible production culture, individual autonomy is not central. The emphasis is on "teamwork", which, unlike the "work team" focus of the participative management model, signifies the dissolving of boundaries between groups within the "community of fate." There is teamwork among members of a work team, between a supervisor and a work team, between manufacturing and engineering functions, and even between assemblers and suppliers. Teamwork in this sense involves not autonomy for the group but a dense web of connectedness across groups, manifested in overlapping knowledge, extensive information-sharing, and a high value placed on personal relationships outside one's primary team. Norms of reciprocity, applied to relationships across groups, help to maintain this network of interactions.

These differences in emphasis are reflected in the responsibilities given to work teams, or -- viewed differently -- in the functions that are integrated into the work team. Under the participative management culture, administrative and personnel tasks are assigned to the work team, and, in the most advanced cases, some control over work pace. This integrates supervisory and managerial functions into the team.

Under the flexible production culture, maintenance, inspection, and job specification tasks are assigned to the work teams, thus integrating engineering and manufacturing staff functions into the team. Teams take on these responsibilities in the context of a culture that is centered around the intrinsic cognitive challenges of operating and improving the production system. The result is high levels of team-based problem-solving activity. Cole (1990) writes about Japanese companies:

> In effect, (these) firms have created a very large cadre of lower-level technicians who make enormous contributions to fine-tuning the production system. At the same time, manufacturing engineers, while they are available to support production workers in these efforts, can have much of their valuable time freed up to work on still more difficult problems. A lot of the firefighting and job redesign that so bedevils management and engineering personnel in American plants is done in Japanese plants by production workers. (p. 10)

In contrast, participative management teams generally do much less production-related problem-solving directed at this kind of "fine-tuning". This fact, together with the inward focus on team autonomy, means that teams under a participative management culture are far more likely to view changes requiring coordination and cooperation with other teams or functional groups as a threat to their autonomy. This further limits problem-solving activities.

Thus the cultural logic of flexible production is held together by norms of reciprocal obligation and the identification of employees with the plant or company as a "community of fate". Buttressed by company policies on employment continuity, training, and status differentiation, this culture encourages integrated "teamwork" across groups and high levels of problem-solving activity.

This culture is facilitated by a sense of "sameness" among employees. While in Japan, the homogeneity of the society provides these conditions, it does not appear necessary for this "sameness" to be based on race, ethnicity, or gender. But some homogeneity in attitude, particularly the willingness to learn new skills and receptiveness to high levels of interaction and communication, is probably a requirement for this culture -- and this is undoubtedly more difficult to achieve in the absence of racial, ethnic, or sexual homogeneity.

This culture could therefore be undermined by external conditions that threaten the fulfillment of reciprocal obligation norms (such as cyclicality that threatens employment continuity) or by internal conditions that factionalize the workforce, either by creating divergent interests or by sharpening intergroup distinctions, thereby diminishing the sense of a common fate.

<u>Individual Work Identity</u>

What effect does flexible production have on individual work experience and identity? This is a question of great importance that is also quite difficult to investigate. Thus my observations in this area are mostly speculative. I will therefore organize this section by reviewing recent thinking by Piore and Sabel on this topic, as a backdrop for my own observations.

Piore (1989) uses Hannah Arendt's categories of work, labor, and action to capture what is different about work under flexible production, focusing primarily on industrial districts in Italy:

> Work and labor involve the relationship between man and the physical world.... The product of work is permanent. It achieves a durable place in the world in the sense that it outlives the creator... By contrast, labor.. is an activity associated with the biological process and desiqned to ensure basic needs.... By extension, it is closely associated with consumption.
>
> Action, unlike labor and work, involves a relationship between men and women. It is the activity through which individuals reveal themselves to other individuals, and through which they achieve meaning as persons.... The sequence of actions of an individual over his or her life constitute a story, and it is through that story remembered and retold in the community that individuals achieve immortality ...

From this perspective, craft production is "work" that yields a lasting product, thereby conferring a kind of immortality on the craftsman. Mass production converts this "work" into "labor" - a repetitive activity of no lasting effect, beyond its contribution to daily consumption (in the form of a wage) and thereby survival.

Flexible production represents not the return of "work" but the opportunity for "action". The production system becomes a "realm in which (people) reveal themselves to each other as individuals" through discourse (in a shared language) about the production process. This discourse is inherently interactive and collaborative; the substantive content of the discourse can shift from design to technology to quality to interpersonal relations, but regardless of topic, it serves as a way for individuals to express something of who they are.

The link to my emphasis on problem-solving under flexible production is clear. Problem-solving, in a context that favors the integration of innovation and production, could be viewed as a kind of "action" that provides the basis for individual identity. The problems tackled, the paths pursued, the dead ends reached, the eventual arrival at solutions, the accumulation of knowledge and experience -- all can plausibly be part of a "story" that helps build a unique work identity for an individual.

Job movement under flexible production, both through job rotation and promotion, is also consistent with this view. Once employees masters all the jobs within a team, they begin to move across teams and departments, partly according to staffing needs, but partly based on individual interests and experience. Over time, the result is a kind of unique "career path" for each employee, that both builds broad conceptual knowledge of the production system but also provides individuals with their own "learning story".

The manager of the paint department at Honda's Marysville plant, whose first job at Honda was as a production worker in the motorcycle plant, described this kind of experience:

> I trained [in Japan] for five weeks on the GL1100 engine - how to disassemble, reassemble, and troubleshoot. I returned from there to my job as a team leader in the engine area, to train my team members. But shortly after that, I was promoted to production coordinator in a part of the main line that had virtually nothing to do with the engine. Which I found very strange...
>
> The company had already spent five weeks of time and money to teach me everything that could be known about these engines. I asked a question and the answer I got was, "We recognize that you have some ability and we don't want you to only learn about engines. The more you know, the more versatile you are."
>
> I'm living proof of that, because I've been in several different areas now. It gives me a wider view of the total concept. It made me open my eyes more to see. When I moved to a new area, I could look back and assist sometimes in my old area. It just grows from there.

Piore also emphasizes that the key prerequisite for "action" is a community of equals. "Only within such a community can one differentiate one's self; if the other members of the community are not like one, they cannot appreciate one's differences." This is consistent with the efforts to minimize status differentials within flexible production, to develop overlapping conceptual knowledge in individuals that helps create a common language, and to encourage individuals to identify their common bonds with others in the "community of fate".

Sabel (1989) contrasts work under flexible production with both craft and professional notions of work. Craft involves mastery of the "secrets of working with particular materials". Nature provides physical constraints, leading to a creative tension with man's quest for individual autonomy and expression of will. "To craft something is to find the way to freedom in necessity."

Professions, in contrast, organize specialized knowledge in relation to a particular political order. "Professions are a kind of priesthood, publicly licensed to interpret and administer the mysteries of expert knowledge... less concerned with the reconciliation of freedom and necessity than with the political domestication of potentially unruly knowledge."

Sabel argues that work under flexible production is like craft in its continuous interaction with the physical properties of materials and tools, but unlike craft, there is a sense of "technological indeterminacy" resulting from technological advances that remove the constraints of nature. While this broadens the scope for creativity in problem-solving (and the range of possible solutions), it also creates "organizational vulnerability" because the relation between task and technology is no longer determinative, and as a result, the stable knowledge and work routines of the craft world disappear. Work identity under flexible production must therefore be based on (or able to tolerate) a context where knowledge and routines are always changing.

This indeterminacy about knowledge also differentiates work under flexible production from professional work, since the latter depends on agreement about the boundaries of knowledge in realms not easily regulated by either the state or the market. Professionals draw their identity, and their jurisdictional authority, from the clarity and stability of these boundaries. Since these conditions do not hold under flexible production, autonomous, specialized expertise can no longer provide the basis for individual identity.

Instead, Sabel suggests, work identity under flexible production will more likely be based on a sense of "worldmaking" -- the production system as a distinct world that employees can make and remake over time. Here Sabel's views complement Piore's -- his "worldmaking" (drawn from Goodman) describes how individuals shape their work world, while Piore's "action" (drawn from Arendt) describes how individuals shape their sense of self.

Sabel also touches on the idea of reciprocal obligation -- although he sees this as more important to the employer than to the employee. Employees under flexible production are expected to be loyal to the work group or corporation. But "loyalty is just the willingness to acquire through experience and education the mixture of general knowledge and intimacy with their work and workplace which permits them to execute concepts while reconceptualizing them." In other words, the most prized contribution from individuals is their willingness to contribute their understanding of the production process and the effort to reconceptualize the production process during problem-solving activities.

But with the blurring of boundaries, both intra-organizationally and inter-organizationally, Sabel argues that it is difficult for this loyalty to cohere around any specific entity, such as the firm. The firm, on the other hand, needing to win this contribution, "owes employees <u>its</u> loyalty. Why else would they accept the uncertainty of permanent reorganization?" From this perspective, the norms of employment security, the high investment in skill development, the elimination of status differentials are all attempts to win employee loyalty in this crucial area of making a cognitive contribution to the production process.

My observations of flexible production plants suggest that employees are bound more closely to the firm than Sabel suggests -- and not just by their involvement in the daily challenges of keeping the production system functioning. In my visits to the

Japanese transplants, I found that the non-Japanese employees in these plants definitely have a story to tell -- of their own learning process and that of the plant as a whole, of influential ideas, of key events charged with both symbolic and emotional meaning. Workers interviewed at NUMMI, for example, spoke in terms that echoed Higashi's statement (above) about the plant's prospective future. This is closer to Piore's notion of "action" and is quite consistent with the "community of fate" culture.

Work/Family Boundaries

The attachment of the individual to the firm has clear advantages to the operation of flexible production, but raises dilemmas about the boundaries between work and family. One American team leader at NUMMI raised this issue when commenting on his training experience in Japan.

> We used to have discussions with the Japanese: 'In Japan, your job is number 1 and your family is number 2. It will never be like that in America. Our families are number 1.' We had lengthy discussions about this. They said that without a secure job, you do not have a family, you can't feed them and support them. We said that without a strong family structure, what good is your work? They were truly dedicated to the Toyota Motor Company and were grateful for working there. For us Americans, I don't care how much I enjoy work, I'll never be wholly grateful. It's not my whole life.

This comment can be interpreted in two ways. First, that cultural differences will prevent Americans working under flexible production from making the same commitment to their work as the Japanese. Second, that this employee's remarks reflect traditional American norms on the balance between work and family, but that over time, the experience of working under flexible production will produce among American employees the same involvement and commitment to work as among Japanese employees.

On the whole, I tend to agree with the latter interpretation, although I think there may be some persistent cultural differences in work ethic. But in Japan, as Lotte Bailyn

(1990) has pointed out, the intense involvement in work under flexible production is only possible because of a social system in which women carry out practically all responsibilities related to household matters and child-rearing, and rarely work outside the home. What then are the long-term implications of efforts to diffuse flexible production to societies with less traditional sex roles and higher participation of women in the workforce?

In keeping with my view that flexible production is well-suited to coping with problem conditions of all kinds, I believe that these work/family boundary issues can be addressed without undermining its "organizational logic". But a distinction must be made between the effects of work on family that result from time conflicts and those that result from high involvement.

The structural and cultural logic of flexible production do, I believe, result in both high involvement and high stress, because of the greater cognitive demands of the job. Thus the psychological distress most associated with flexible production is likely to be "burnout" rather than alienation -- a state which can certainly affect family relationships, both in terms of energy levels and the capacity for empathy. But this statement could also be made for upper-level managerial work under mass production. Perhaps what is significant about flexible production is that this stress and risk of "burnout" applies to the entire workforce, and not just senior management.

With regard to time, however, I see no inherent reason that, in a context in which high value is placed on giving employees more time for family responsibilities, flexible production couldn't be organized accordingly, with reduced working hours or "flextime" arrangements. This "contingency" would be addressed through ongoing problem-solving activities, to accomplish any necessary changes in job design, scheduling, or compensation policy. There are some recent signs of change in this area in Japan, in response to a campaign by the Japanese government to reduce working hours. Toyota, for example, has recently announced a four-day work week (organized in shifts that support five-day factory operations) in selected supplier plants.

However, until such time that the freeing of employee time for family responsibilities becomes a corporate (or national) priority, there is no doubt that flexible production tends to draw managers and workers alike into deeper psychological involvement in their work and longer working hours. Furthermore, the cultural meaning of time in a production system that relentlessly reduces buffers may preclude the adoption of a larger "buffer" of family or personal time. It is no surprise that calls for change to boost U.S. competitiveness often advocate a move in the direction of greater effort and involvement at the workplace, without acknowledging the contradiction with other social goals that require greater effort and involvement in the family.

Education and Training

If flexible production makes greater cognitive demands on the workforce, what are the implications for education and training? Some useful observations can be made based on a comparison of Japanese plants in Japan and the Japanese transplants in the U.S.

The high level of educational achievement in Japan is well-known. High school graduates in Japan achieve considerably higher scores in reading and math skills than Americans with equal years of education. In Japan, companies hire recent high school and college graduates for production, engineering, and managerial jobs. There is little screening prior to hiring; rather, the educational system provides this function, both in terms of assuring a certain level of basic skills and in directing particular students towards particular employers.

In the transplants, recruitment practices have drawn considerable public attention for their scale, complexity, and departure from American industry tradition. While a basic physical capability has sufficed as the traditional qualification for U.S. production jobs, the transplants have carried out a highly selective recruiting process involving written tests of reading and math skills, interviews, group exercises, and a rigorous simulation of actual production operations. This elaborate process is best understood first, as screening for the basic reading, math, and interpersonal skills that, unlike Japan, can not be assumed to be provided through the U.S. educational system and second, as an attempt to identify a homogeneity of attitude about learning that is crucial to the culture of flexible production.

Following hiring, the transplants typically provide one to three weeks of classroom training, primarily as an orientation to the different principles of flexible production. But in both Japanese plants and in the transplants, the primary mode of training for most employees is a lengthy period of "on the job training" or OJT. This term means something quite different from the customary American usage, where a job with OJT is one for which a new hire is given fifteen minutes of instruction from a co-worker and then "learns the ropes" through unstructured observation and imitation.

Japanese OJT (perhaps more correctly described as on-the-job learning (Ford, 1986)) involves trainers (usually employees experienced in those positions) who work intensively with new hires, at first demonstrating the job, describing its idiosyncracies, and eventually coaching. These trainers remain on the shop floor after initial training is completed, and intervene to show workers how to handle non-routine problem conditions. The team leader then assumes this training/coaching role over time. In the transplants, prospective team leaders were prepared for this role by being sent to Japan for up to six weeks of intensive OJT in all the operations of their team -- during which time, team leaders in Japan modeled the appropriate training/coaching behavior.

This "learning by doing" approach is known, from research on adult learning, to lead to greater comprehension and retention than classroom teaching methods. Furthermore, it is the best way to convey "tacit knowledge" (Polanyi, 1962) -- those skills embodied in physical activity and rarely verbalized that are crucial to effective job performance.

OJT is not only for new hires, but continues as employees move across jobs through job rotation or promotion. Only after employees reach a relatively high level of skill does off-the-job classroom training, focused on specific technical skills, take place -- in the transplants, typically one to two years after a plant opens. In Japan, this is generally provided through company-run technical institutes that can match the training closely to company technology, work organization, and existing skill base. Japanese companies tend to develop much more of their process technology in-house, so this expertise is readily available. This is important, since the increased use of microprocessor-based manufacturing technology requires the integration of mechanical and microelectronic engineering knowledge -- areas that the external educational system, even in Japan, still approaches as separate specialties.

Cole (1990) describes a training strategy among Japanese firms that emphasizes the integration of old and new skills throughout the workforce. Thus rather than training only younger or newly hired workers in new skills, Japanese firms expose employees of all ages and experience levels to new technologies, and require all to participate in job rotation and training for multiskilling -- the ability to do multiple jobs, as well as the ability to perform multiple functions, such as maintenance and reprogramming. This not only yields the broad, overlapping knowledge that supports problem-solving activities, but provides employees with "equal access" to new knowledge, avoiding the polarization between those who have new skills and those who don't that can often be found in American plants.

The implications of these educational and training practices are as follows. First, flexible production relies on the educational system for basic reading, math, reasoning, and communication skills, rather than for technical skills of any kind. Thus efforts in the U.S. to forecast skill requirements of the future and to devise vocational curricula accordingly are much less likely to support the diffusion of flexible production than a broad effort to raise these basic skills to a higher level, one that is uniform across the student population.

Second, the firm under flexible production provides practically all job-related training, for several reasons. On-the-job training is a very effective way to convey tacit knowledge about jobs, and leads to high retention of knowledge, both because of its experiential approach and because individuals acquire skills very close to the time when they will need to use them. Advanced technical training is provided to all rather than some, and matched to the existing skill base of the individual -- a customized process that the firm is in a much better position to carry out than outside institutions because of its proximity to task requirements and employee needs, and its generally superior technical expertise.

Three, training aims to teach not only substantive knowledge but also processes of problem-solving and learning. This is best conveyed through the modeling behavior of employees who already thoroughly understand these processes, and the broader production system. Furthermore, on-the-job participation in these processes helps to reinforce the norms of reciprocal obligation and to build individual work identity. Thus carrying out most training within the firm crucially supports the culture of flexible production.

Finally, it makes less sense under flexible production to speak of training and education as separate, almost detachable from the production process itself. Flexible production is flexible because of organizational characteristics that promote continuous problem-solving and learning. Knowledge creation is fundamental to its operation. Education and training policy, at the local, state, and national levels, can certainly help bolster the human capabilities required by flexible production. But it is a mistake to expect all, or even most of the skills required by flexible production to be gained outside the firm. More valuable is to reconceptualize the factory under flexible production as a kind of school, and then to develop an integrated learning strategy that spans the pre-work and workplace "schools".

The Diffusion of Flexible Production

My colleagues at the International Motor Vehicle Program (Womack et al., 1990) use the phrase "confusion about diffusion" to describe the current situation in the automotive industry. This confusion, deriving from misunderstandings of flexible production and its significance, is increasingly mixed with tension as larger competitive gaps emerge between traditional mass producers and those that have made (or begun to make) the transition to flexible production. These tensions are likely to slow the diffusion process -- something that will hurt both producers and consumers, managers and workers, and mass and flexible companies.

A book could certainly be written on the issues involved in diffusing flexible production. I will confine myself here to a few summary comments, drawn from the preceding discussion.

The most important requirement for the diffusion of flexible production is understanding its distinctive "organizational logic". This is not a simple matter, for many of the differences in philosophy and practice between mass and flexible production are "invisible", in that they are lodged in interaction patterns and ways of thinking that cannot be readily observed. Indeed, we heard from many GM employees that had visited NUMMI that "they do things the same as we do". (Krafcik, 1986) Furthermore, the systemic interdependence of elements of flexible production is not readily grasped by Western-trained minds accustomed to analyzing phenomena by breaking them down into distinct component parts.

Equally important is understanding the distinction between the "structural logic" and the "cultural logic" of flexible production. The key to flexible production are its underlying organizational processes, and the "structural logic" is only germane to the extent that it helps create those processes. In fact, an implementation emphasis on the structural features of flexible production, such as teams or quality circles, can be detrimental, because the cultural factors sustaining traditional thinking will prompt tireless struggles to subvert these structures until they are nothing but superfluous overlays on a fundamentally mass production system. But a emphasis on cultural change, while perhaps a better starting point, will ultimately be constrained in the absence of accompanying structural change.

The premise of flexible production that, in my experience, is most difficult for Western managers to accept is that it is a "fragile" system -- vulnerable because of its dependence on its suppliers and its employees. This dependency is doubly disturbing to these managers, for it upsets the stability of familiar hierarchical arrangements, and it contravenes management instincts about managing risk. Thus managers will state their willingness to develop the human resource system and rely on people more fully, but will want some safeguards in the technical system, "just in case" something goes awry. Or they will show their resolve to minimize buffers and force production problems to the surface, while insisting on centralized control of efforts to deal with the resulting contingencies.

In my experience, the idea of becoming "lean" is far more intuitively appealing to these managers than the idea of investing in human capabilities. Their sense of how one achieves efficiency is offended by the notion of training for broad conceptual knowledge or sharing information widely -- both well beyond what specific jobs require. These practices have always constituted "waste" in their universe, and they turn instinctively to make cuts in these areas when the call for "waste minimization" is made.

For overlapping knowledge to be reconceptualized as a resource for learning rather than wasteful "slack", these managers need to understand how differently information processing, the division of labor, and the coordination process are approached under flexible production. Exhortations about the value of a new human resource strategy, on their own, are unlikely to have much lasting effect.

This understanding is not easily obtained, but is best gained through access by managers and union officials to a learning example -- a flexible production plant -- through joint ventures (or some other form of strategic alliance) or just geographical proximity that allows informal access. The transplants have provided such examples in the U.S., while European companies have remained mostly insulated.

Flexible production companies can benefit by allowing such access, I believe, because they benefit from the diffusion of flexible production principles, which helps create a social, political, and economic environment more conducive to sustaining this approach over time.

Furthermore, while flexible production is an important source of competitive advantage, these companies have little to fear from allowing observers to learn from them. Understanding the logic of flexible production may be the crucial first step, but implementing this logic in another setting is still tremendously difficult, requiring skills and perseverance that cannot be acquired from observation alone. Conversely, the risk of a political backlash if flexible production is not well understood, as tensions rise in regions where mass producers still dominate, is high.

The entire thrust of this dissertation has been to sharpen the distinction between mass and flexible production. While this can contribute to better understanding of the "logic" of these systems, it is somewhat misleading with respect to diffusion. In fact, there is not likely to be any "one best way" to implement flexible production, and new variants are likely to evolve over time.

For example, Toyota and Honda are both outstanding companies, but their approach to flexible production is quite different -- in culture and implementation, if not in fundamental principles. Toyota's emphasis on the "Toyota production system" reflects its thorough systematizing of such organizational innovations as just-in-time inventory and kanban into books, procedural manuals, and production routines that are readily accessible to an outside observer. Honda's emphasis on the "Honda Way" reflects the company's reliance on a strong company culture to hold the production system together, and its inclination to avoid organizational routines of any kind. Viewed in terms of specific practices, Honda thus often appears to be "breaking the rules" of flexible production. But on closer examination, Honda's actions can be seen as quite consistent with the flexible organizational logic.

Similarly, just as flexible production has evolved to reach its current state, so it will continue to evolve. Thus the key for companies attempting the transition from mass production is not to imitate some ideal model that may be outdated by the time it is understood, but to adopt the <u>principles</u> of flexible production while allowing the <u>methods</u> to vary. Companies that build on their unique assets -- which are likely to be unique knowledge and experience among their employees rather than unique technology -- will have a much better chance to devise methods that provide some sustainable competitive advantage. Only such an approach can be true to the spirit of creative problem-solving and continuous improvement that flexible production embodies.

APPENDIX A

SURVEY FORM FOR THE

INTERNATIONAL ASSEMBLY PLANT STUDY

INTERNATIONAL AUTOMOTIVE ASSEMBLY PLANT STUDY

International Motor Vehicle Program
Massachusetts Institute of Technology
Cambridge, Massachusetts

Summer 1988

Revised January 1989

INSTRUCTIONS

1) Please record your name, title, address, phone number and fax number in the spaces provided:

Name: ______________________________
Title: ______________________________
Address: ______________________________
____
____
Phone number: ______________________________
Fax number: ______________________________

2) Please answer all questions by either checking the appropriate box (✓ symbol), circling the appropriate response (① symbol), or writing in the blank space provided (✎ symbol).

3) For certain plants, we have answered some of the questions in pencil with information you have already supplied us. You may leave these responses intact if the information is still valid. Otherwise, please provide a new response.

4) Please call either John Krafcik (1 713 796-8542) or John Paul MacDuffie (1 617 253-0008) should you have any questions about this survey.

5) Return the completed questionnaire in the enclosed, addressed envelope by September 15, 1988.

Pledge of Confidentiality

Information shall not be presented or published in any way that would identify any individual, plant, or company.

Section A. Production System Data

The questions in this section cover basic information about the production system in your plant -- the rate of production, working hours, and staffing levels.

A1. For your plant, please indicate the:

- number of units produced per standard, non-overtime shift ________ units/shift
- number of shifts of production worked per day ________ shifts/day
- average number of hours the plant operates per standard, non-overtime week ________ hours/week
- capacity in units per standard, non-overtime shift with current equipment ________ capacity/shift

A2. Please fill in the simple worksheet below concerning the schedule for hourly workers. *(If this schedule varies by department, please use a typical schedule.)*

	Example	Your Plant
• Number of minutes average worker is in plant during an average shift, excluding overtime:	510	______
• Subtract:		
• Minutes of meal times:	30	______
• Minutes of "mass" break time: (all workers break together)	40	______
• Minutes of "personal" break time: (workers break individually)	10	______
• Miscellaneous non-working time: Explain purpose:________________	0	______
• Total available working minutes per shift, per worker:	430	______

A3. Please indicate the production activities that occur in your plant and the number of employees performing them.

(Here we identify certain "Standard Activities". This allows us to accurately compare plants of different scope. For this study, we ignore workers involved in stamping, plastics molding, knock-down kit production, seat sub-assembly, and various other sub-assemblies. The breakdown of Standard and non-Standard Activities is defined below. Please follow the instructions on the following page so that we may determine the activities you perform in-house.)

Assembly Plant Standard Activities

✓ *Check any Standard Activities that your plant __does not__ perform.*

Welding
- ❒ Main body panels

Painting
- ❒ Body cleaning
- ❒ Joint sealing
- ❒ Top coat
- ❒ Electrolytic dip
- ❒ At least 1 primer coat
- ❒ Cavity waxing

Sub-Assemblies
- ❒ Bumpers
- ❒ Front & rear strut
- ❒ Bumper painting
- ❒ Instrument panel
- ❒ Tire/wheel assembly and balancing
- ❒ Clutch & brake pedal sub-assembly

Assembly
- ❒ Seat installation
- ❒ Glass installation
- ❒ Interior and exterior trim application
- ❒ Full engine dress (installing hoses, belts, etc.)

Indirect Activities
- ❒ Production control
- ❒ Parts delivery to line
- ❒ Product repair and inspection
- ❒ Maintenance

Administrative and Support Tasks
- ❒ Direct supervision
- ❒ Plant management
- ❒ Manufacturing and facilities engineering

Assembly Plant Non-Standard Activities

✓ *Check any Non-Standard Activities that your plant __does__ perform.*

Welding
- ❒ Welded sub-assemblies shipped to other plants as kits

Painting
- ❒ A second coat of primer

Sub-Assemblies
- ❒ Steering column
- ❒ Exhaust pipe bending
- ❒ Fan-to-fan shroud
- ❒ RWD rear axle
- ❒ Engine mounts
- ❒ Drive shaft(s)
- ❒ Lift rail-to-window
- ❒ Door trim panel
- ❒ Fuel & brake tube
- ❒ Steering column painting
- ❒ Fuel & brake tube bending
- ❒ Seats
- ❒ FWD rear axle
- ❒ Window regulator
- ❒ Steering gear
- ❒ AC compressor
- ❒ Wire harness
- ❒ Fuel pump

Indirect Activities
- ❒ Customs workers
- ❒ Security personnel
- ❒ Water purification
- ❒ Dedicated fire workers
- ❒ Lease car maintenance
- ❒ Vehicle delivery
- ❒ Indirect labor to support any of the above non-standard activities your plant performs*

Administrative and Support Tasks
- ❒ Engineering design
- ❒ Component purchasing

With these activities in mind, carefully fill in one of the tables below.

Direct Employees

Do not include in either table those employees performing the non-Standard Activities listed above. Count only the direct employees performing Standard Activities for each department.

Indirect Employees*

☛ For indirect employees such as material handlers, inspectors, and supervisors, subtract a proportional number based on the percentage of direct, non-Standard Activities employees in your total workforce. For example, suppose your plant had 5000 total employees, 4000 direct, 1000 indirect. Now suppose that 3000 of your direct employees are involved in Standard Activities. Since 3000/4000 = 75% of your direct employees are involved with Standard Activities, we assume that 75% X 1000 = 750 of your indirect employees are Standard Activities related.

Keep in mind that we only want data for on-roll Standard Activities employees, carefully fill in one of the tables below.

DIRECT EMPLOYEES

☞☞ ***DO NOT INCLUDE IN EITHER TABLE THOSE EMPLOYEES PERFORMING THE NON-STANDARD ACTIVITIES LISTED ON PAGE 2.***

These must be on-roll, not "required-to-operate" numbers. Count only employees performing Standard Activities for each department, ***including all those on the payroll, even those that are absent at any given time*** (see p. 19, question I11). With this information we can accurately compare plants around the world that perform different operations, adjusting later for differing levels of absenteeism.

INDIRECT EMPLOYEES

☞ For indirect employees such as material handlers, inspectors, and supervisors, subtract a proportional number based on the percentage of direct, non-Standard Activities employees in your total workforce. For example, suppose your plant had 5000 total employees, 4000 direct, 1000 indirect. Now suppose that 3000 of your direct employees are involved in Standard Activities. Since 3000/4000 = 75% of your direct employees are involved with Standard Activities, we assume that 75% X 1000 = 750 of your indirect employees are Standard Activities related.

Option #1: Detailed Information

If you have the data readily available, please indicate the number of employees in the following categories, using these abbreviations: **Prod**=Direct production related; **MH**=Material Handling; **QC**=Quality Control; **Maint**=Maintenance; **Sal** = Managers (including 1st line supervisors) and Staff; **Other**=all others. If you do not have the data in this detail, please fill out the table under Option #2.

✎

	Prod	MH	QC	Maint	Sal	Other	Total
Welding	____	____	____	____	____	____	____
Painting	____	____	____	____	____	____	____
Assembly	____	____	____	____	____	____	____
Administrative/Support	XX	____	____	____	____	____	____
TOTAL →	____	____	____	____	____	____	____

Option #2: Simplified Information

If the breakdown among various indirect employee categories is too difficult to determine, then fill out the simplified table below, where **Direct** = Production-related employees; **Indirect** = Material Handling + Quality Control + Maintenance + all other non-salaried positions; and **Salaried** = Managers (including 1st line supervisors) and Staff.

✎

	Direct	Indirect	Salaried	Total
Welding	____	____	____	____
Painting	____	____	____	____
Assembly	____	____	____	____
Administrative/Support	XX	____	____	____
TOTAL →	____	____	____	____

Section B: Human Resource Policies

The questions in this section concern recruitment, training, compensation, promotion, and employee participation policies in this plant.

B1. When you hire new production workers, does your recruitment process include:
✓

	Yes	No
Physical tests of skill	❐	❐
Written tests of reading or math	❐	❐
A review of previous work records	❐	❐
Individual interview	❐	❐
Group interview or exercise	❐	❐

B2. When you most recently hired new production workers, how many positions did you fill? ________ positions filled

How many total applications did you receive for these positions? ________ applications

B3. How would you describe the importance of the following hiring criteria for each of the positions listed below? *Please circle the appropriate number.*
①

For Production Workers:

	Not very important				Very important
Previous experience in a similar job	1	2	3	4	5
Educational level	1	2	3	4	5
Specific technical expertise	1	2	3	4	5
Willingness to learn new skills	1	2	3	4	5
Ability to work with others	1	2	3	4	5

For First Line Supervisors:

	Not very important				Very important
Previous experience in a similar job	1	2	3	4	5
Educational level	1	2	3	4	5
Specific technical expertise	1	2	3	4	5
Willingness to learn new skills	1	2	3	4	5
Ability to work with others	1	2	3	4	5

For Manufacturing Engineers:

	Not very important				Very important
Previous experience in a similar job	1	2	3	4	5
Educational level	1	2	3	4	5
Specific technical expertise	1	2	3	4	5
Willingness to learn new skills	1	2	3	4	5
Ability to work with others	1	2	3	4	5

B4. How many hours of training would a newly-hired employee in the following positions receive in the first six months? Approximately what percent of these hours would occur off-the-job (before taking up regular job duties) and what percent would be on-the-job training?

	Total training hrs per person (first 6 months)	%Off-the-job		%On-the-job	
Newly-hired production worker	______	______	+	______	=100%
Newly-hired first line supervisor	______	______	+	______	=100%
Newly-hired manufacturing engineer	______	______	+	______	=100%

B5. How many hours of training did **each** employee with at least one year of experience in the following positions receive in 1988? Approximately what percent of these hours occurred off-the-job (away from regular job duties) and what percent occurred on the job?

	Total training hrs per person (in 1988)	%Off-the-job		%On-the-job	
Experienced production worker	______	______	+	______	=100%
Experienced first line supervisor	______	______	+	______	=100%
Experienced manufacturing engineer	______	______	+	______	=100%

B6a. What was the total number of training hours received by employees in your plant in 1988? __________ total training hours

B6b. List the five most important training topics at your plant. Also, check off (✓) in the boxes on the right which group was primarily responsible for providing the training.

Training Topic	Company Staff	Equip. Vendors	Consultants
1. __________	☐	☐	☐
2. __________	☐	☐	☐
3. __________	☐	☐	☐
4. __________	☐	☐	☐
5. __________	☐	☐	☐

B7. Which of the following compensation plans apply to these categories of employees?
✔ *Please place a checkmark (✔) in all appropriate boxes.*

Compensation Plan	Production workers	First line supervisors	Engineers
Hourly pay based on job class	☐	☐	☐
Hourly pay based on skills learned	☐	☐	☐
Salary	☐	☐	☐
Bonus based on corporate/plant performance	☐	☐	☐
Bonus based on work group performance	☐	☐	☐
Bonus based on individual performance	☐	☐	☐
Bonus based on seniority	☐	☐	☐
Merit increase in salary based on individual performance	☐	☐	☐

B8. Please indicate whether you agree or disagree with the following statements about
① promotion policies in this plant. *Please circle the appropriate number.*

	Strongly Disagree				Strongly Agree
This plant has a "promote from within the company" policy.	1	2	3	4	5
Most of the top managers here held other jobs in this plant before taking their current position.	1	2	3	4	5
Most first line supervisors were promoted from production worker positions	1	2	3	4	5
Most skilled trade workers in this plant first worked here as production workers	1	2	3	4	5
All in all, the majority of employees in non-entry level positions in this plant were promoted from within	1	2	3	4	5

B9. Are any of the following practices followed in this plant:
✔

	Yes	No
Common uniform for all employees?	☐	☐
Common cafeteria for all employees?	☐	☐
Common parking for all employees?	☐	☐
No ties for managers?	☐	☐

B10. Is there an official suggestion plan in use at your plant in which employees can offer written suggestions to improve plant operations?

Yes ☐ No ☐

If Yes, do you keep records of the number of suggestions submitted?

Yes ☐ No ☐

If Yes, how many suggestions were submitted during 1987? ________ suggestions

How many of the suggestions were accepted by management? ________ accepted

B11. Does your plant have Quality Circles, Employee Involvement groups, or other problem solving activities?

Yes ☐ No ☐

If Yes, how many formal groups meet on a regular basis? ________ groups

How many total employees are involved in these activities? ________ employees

Section C: Work Organization

The questions in this section focus on how tasks and responsibilities are divided, how decisions are made, and how work is organized in this plant.

C1. Which group do you rely on most to perform each of the following production tasks? *Check only one group per task.*

	Production Worker	Skilled Trades	First Line Supervisor	Engineering Staff	Quality Control Staff	Noone performs this task
Machine set-up	☐	☐	☐	☐	☐	☐
Routine maintenance	☐	☐	☐	☐	☐	☐
Inspection of incoming parts	☐	☐	☐	☐	☐	☐
Inspection of work-in-progress	☐	☐	☐	☐	☐	☐
Inspection of finished products	☐	☐	☐	☐	☐	☐
Statistical Process Control - gathering and charting data	☐	☐	☐	☐	☐	☐

C2. ✔ Which group do you rely on most to perform each of the following functions? *Check only one group for each function.*

	Plant Staff who only perform this function (Specialists)	Specialists provided by parent company	Outside consultants	Managers, engineers who perform other duties as well	Skilled trades or production workers	Noone performs this function
Development of quality control methods	❒	❒	❒	❒	❒	❒
Setting of production standards and methods	❒	❒	❒	❒	❒	❒
Programming robots and other programmable automation	❒	❒	❒	❒	❒	❒
Installation of new equipment	❒	❒	❒	❒	❒	❒
Technical training	❒	❒	❒	❒	❒	❒

C3. ✔ For each of the following issues, please indicate the level that has the formal authority to approve decisions?

	Production worker	First line supervisor	Middle manager	Department head	Plant manager	Company official above plant manager
Staffing requirements	❒	❒	❒	❒	❒	❒
Promotion of production workers	❒	❒	❒	❒	❒	❒
Promotion of supervisory staff	❒	❒	❒	❒	❒	❒
Overtime to be worked	❒	❒	❒	❒	❒	❒
Inspection; i.e. what items or processes will be inspected	❒	❒	❒	❒	❒	❒
Methods of recruitment	❒	❒	❒	❒	❒	❒
Training methods	❒	❒	❒	❒	❒	❒
Methods of work to use (how to do a job)	❒	❒	❒	❒	❒	❒

Machinery or equipment to be used for a job	☐	☐	☐	☐	☐	☐
Allocation of work among available workers	☐	☐	☐	☐	☐	☐

C4. ✔ For the same list, what is the level at which, in everyday practice, each of these decisions is actually made?

	Production worker	First line supervisor	Middle manager	Department head	Plant manager	Company official above plant manager
Staffing requirements	☐	☐	☐	☐	☐	☐
Promotion of production workers	☐	☐	☐	☐	☐	☐
Promotion of supervisory staff	☐	☐	☐	☐	☐	☐
Overtime to be worked	☐	☐	☐	☐	☐	☐
Inspection; i.e. what items or processes will be inspected	☐	☐	☐	☐	☐	☐
Methods of recruitment	☐	☐	☐	☐	☐	☐
Training methods	☐	☐	☐	☐	☐	☐
Methods of work to use (how to do a job)	☐	☐	☐	☐	☐	☐
Machinery or equipment to be used for a job	☐	☐	☐	☐	☐	☐
Allocation of work among available workers	☐	☐	☐	☐	☐	☐

C5. ✔ Does the line shut down during break periods ("mass relief") or is there a system of "tag relief", where someone substitutes for the worker taking a break, so the line can run continuously?

Mass relief ☐ Tag relief ☐

C6. Check the statement which best describes the job rotation policies in this plant.
✓

- ☐ Workers are trained to do one job and do not rotate to other jobs
- ☐ Workers are capable of doing other work tasks within their work group, but generally do not rotate jobs
- ☐ Workers rotate jobs frequently within their work group, but not outside the group
- ☐ Workers rotate jobs within their work group and across work groups in the same department, but not across departments
- ☐ Workers rotate jobs within the work group, across work groups, and across departments

C7. Do the following departments in this plant use work teams? *(formally designated groups of production workers that rotate jobs, and hold regular meetings)* If Yes, please list the number of groups in each department and indicate whether they have a formally designated team leader. If there are any work teams in this plant, please answer Questions C8 and C9 as well. Otherwise skip to Question C10.
✓
✎

	Work teams?			Team leaders?	
Department	**Yes**	**No**	**# of teams**	**Yes**	**No**
Stamping (if located in plant)	☐	☐	______	☐	☐
Welding	☐	☐	______	☐	☐
Painting	☐	☐	______	☐	☐
Assembly	☐	☐	______	☐	☐
Repair/Inspection	☐	☐	______	☐	☐

C8. What is the typical size of a work team (excluding the team leader)? ______ people
✎

C9. To what extent do teams influence decisions in each of the following areas? *Please circle the appropriate number.*
①

Area of Influence	**Not at all**				**To a very great extent**
The use of new technology on the job	1	2	3	4	5
Who should do what job	1	2	3	4	5
The way the work is done - revising methods	1	2	3	4	5
Who should be brought into the team	1	2	3	4	5
Who should be dismissed from the team	1	2	3	4	5
Performance evaluations	1	2	3	4	5
Settling grievances or complaints	1	2	3	4	5
How fast the work should be done	1	2	3	4	5
How much work should be done in a day	1	2	3	4	5
Selection of a team leader	1	2	3	4	5

C10. Whether or not there are formal work teams, are any of the following activities carried out?

✔ Work groups meet regularly, to receive information from their supervisor or to carry out problem-solving activities

Yes ☐ No ☐

✔ An employee is assigned to help work groups with gathering and charting Statistical Process Control data

Yes ☐ No ☐

✔ An employee is assigned to help work groups with on-the-job training, job rotation scheduling, and other job-related matters

Yes ☐ No ☐

The next three sections pose specific questions concerning technical aspects of your plant's operations.

Section D: Body Welding Process Data

Please fill in the table below.

D1. Average number of welds applied in your body welding shop per vehicle.
D2. Percentage of these welds which are *manually applied.*
D3. Percentage of these welds *applied by robot.*
D4. Percentage of these welds *applied by hard automation* (not robot, but automatic).

	Name	D1. # of welds	D2. % Manual	D3. % Robot	D4. % Hard
Model 1:	________	________	________	________	________
Model 2:	________	________	________	________	________
Model 3:	________	________	________	________	________
Model 4:	________	________	________	________	________

D5. Total number of body shop robots in your facility: ________ robots
(Robot defined as programmable, with at least three axes of motion.)

D6. Do you have laser guided body inspection capability? Yes ☐ No ☐
✔

D7. If arc, MIG, or laser welding is performed in your body welding shop, indicate the total length of this type of weld on an average vehicle in your plant: ________ meters

D8. Percentage of arc, MIG, or laser welding done by machine: ________ % by machine

Section E: Paint Shop Process Data

E1. Please describe the paint process in your facility. (For example, phosphate wash --> ELPO dip --> joint sealer --> sealer coat --> primer coat -->interior color --> top coat one --> top coat two --> clear coat --> striping)

____________ --> ____________ --> ____________ -->____________ -->____________ -->
____________ --> ____________ --> ____________ -->____________ --> ____________

E2. Please provide information on the level of automation of the following paint shop processes: primer application, joint sealer application, interior color application, top coat application. Please use the table below to record this information.

Level of Paint Shop Automation (%)*

	Name	Primer	Joint Sealer	Interior	Top Coat
Model 1:	________	______	______	______	______
Model 2:	________	______	______	______	______
Model 3:	________	______	______	______	______
Model 4:	________	______	______	______	______

* Note: These percentage figures should be based on the *proportion of the surface area of the body (or joints in the case of joint sealer) coated automatically as opposed to by hand.*

E3. Number of paint shop robots performing sealing operations: ______ sealing robots

E4. Number of paint robots performing prime/paint application: ______ prime/paint robots

E5. Total length of joint sealer applied to the average vehicle: ______ meters

E6. What is the capacity of the paint bank (the storage area between the paint and assembly departments)? ______ vehicles

E7. What was the average number of cars held in the paint bank during the past week? ______ vehicles

Section F: Assembly Area Process Data

Here we define the assembly area as everything after the paint shop and paint bank, including trim, chassis, final assembly, inspection and repair.

F1. How many assembly lines are there in your facility? ________ lines

F2. Which products are built on which assembly lines?
(For example, Line 1: Model 1, 2 dr; Model 2, 5 dr; Line 2: Model 3, 2 dr)

Line 1: ________________________________

Line 2: ________________________________

Line 3: ________________________________

Line 4: ________________________________

F3. Is there any automation in the assembly process? ☐ Yes ☐ No

✓

If Yes, which steps are automated? (For example, wheel installation, front windscreen installation, door mounting, battery placement, etc.)

____

____

____

____

F4. How many robots are operating in the assembly area? ________ assembly robots

F5. What percentage of steps are automated in the assembly area? ________ % automated
(Base your response on direct production steps only.)

F6. What is the total number of part numbers used in the assembly area?
(Exclude paint stripes and standard parts like hardware and fasteners. Ignore color variations for trim parts. Use this definition of part number throughout the survey.) ________ part numbers

F7. How many different suppliers furnish parts to the assembly area? ________ suppliers

F8. How many of the part numbers supplied to the assembly area of this plant are single-sourced (i.e. provided by only one supplier)?
________ single-sourced part numbers to the assembly area

F9. Inventory Levels: What are the average operating stock levels located in your plant (either at line side or in a warehouse area) of the following parts?
(For example: Seat sets: 3.5; 2 => 3.5 days of stock in-house, delivered to line two to four times a shift)

Part Name	Average Stock Level (in days)	Frequency of Delivery to Line (1=hourly; 2=two to four times a shift; 3=once a shift; 4=once a day; 5=less often than once a day)
Seat sets	______	______
Wheels	______	______
Wire harnesses	______	______
Steering wheels	______	______
Tires	______	______
Instrument clusters	______	______
Headlights	______	______
Interior carpet sets	______	______
Batteries	______	______

F10. Does this plant use any Just-in-Time (JIT) inventory techniques in the assembly area:

✓ a. With external suppliers? Yes ☐ No ☐

If Yes, about what percentage of *assembly area* part numbers are received from external suppliers on a JIT basis? (JIT is defined here as deliveries **more frequent than once per shift.**)
☐ 0-10% ☐ 11-20% ☐ 21-40% ☐ 41-60% ☐ 61%-80% ☐ 80%+

✓ b. Between parts storage and the assembly line? Yes ☐ No ☐

If Yes, about what percentage of *assembly area* part numbers are received from in-house parts storage areas on a JIT basis? (JIT is defined here as **deliveries within the plant at least 4 times per shift.**)
☐ 0-10% ☐ 11-20% ☐ 21-40% ☐ 41-60% ☐ 61%-80% ☐ 80%+

F11. Is the unscheduled stopping of the assembly line permitted in the assembly area?
✓ Yes ☐ No ☐

	Yes	No
Who has the authority to stop the assembly line:		
✓ Production workers?	☐	☐
First line supervisors?	☐	☐
Manufacturing engineers?	☐	☐
Production managers?	☐	☐
Which of the following occurs when the line stop cord is pulled?		
✓ Light comes on to signal problem?	☐	☐
Line stops at end of next cycle?	☐	☐
Line stops immediately?	☐	☐

Approximately how many times was the assembly line stopped in the last month? ______ times

Section G: Plant Layout

Please provide a small (11 x 17 inches or B4 size) floor plan. We use this to determine space utilization. Please fill in (very approximate) floor space by functional area in the table below.

Welding (excluding knockdown (KD) and KD kitting)	________	square meters (or feet)
Painting	________	
Assembly (standard activities only)	________	
Final Assembly Repair (all area after the end of the assembly line dedicated to repair/reinspection)	________	
Total Production Floor Area (for Standard Activities)---->	________	

Section H: Product Characteristics and Mix Complexity

H1. Please provide the percentage each model contributes to your current production schedule.

	Name	Percentage
Model #1	________	________
Model #2	________	________
Model #3	________	________
Model #4	________	________

H2. Please provide the percentage by body style of each of the models built in your plant.

	Name	2 door	3 door	4 door	5 door
Model #1	________	_____	_____	_____	_____
Model #2	________	_____	_____	_____	_____
Model #3	________	_____	_____	_____	_____
Model #4	________	_____	_____	_____	_____

H3. Do you produce vehicles with both right hand and left hand steering? Yes ☐ No ☐

H4. Please fill in the table below regarding the percentage of options installed for each model built in your facility. (e.g. Air conditioning is installed on 22% of Model 1's, 18% of Model 2's, etc.)

Option	Model 1	Model 2	Model 3	Model 4
Air Conditioning	______	______	______	______
Power Steering	______	______	______	______
Power Windows	______	______	______	______
Power Seats	______	______	______	______
Power Door Locks	______	______	______	______
Cruise Control	______	______	______	______
Remote LH Mirror (electric or manual)	______	______	______	______
Remote RH Mirror (electric or manual)	______	______	______	______
Sun Roof/T-roof	______	______	______	______
Four-Wheel Drive	______	______	______	______
Anti-Lock Braking System	______	______	______	______

H5. Which of the following statements best describes the **optional equipment availability strategy** your company uses in your plant?

- ❐ Most equipment is available only as part of an option or trim package.
- ❐ Most optional equipment in our plant can be ordered as part of a package, but many "stand-alone" options remain.
- ❐ Most of our optional equipment can be ordered as a "stand-alone" option -- packaging is not used for most options.

H6 Please determine the **number of different bodies** (bodies-in-white) in your plant, measured at the end of the body welding shop just before they go to the paint shop. Record this number for each of the major models built in your plant. Please include all **major variation such as number of doors, sun roof, right or left drive, US side door beams, etc.** Ignore minor variation such as differing hole configurations for trim pieces and baoges, etc.

	Name	Approximate Number of Major Body Variants			
Model 1	____________	❐ 1-10	❐ 11-50	❐ 51-200	❐ 200+
Model 2	____________	❐ 1-10	❐ 11-50	❐ 51-200	❐ 200+
Model 3	____________	❐ 1-10	❐ 11-50	❐ 51-200	❐ 200+
Model 4	____________	❐ 1-10	❐ 11-50	❐ 51-200	❐ 200+

H7. How many different **exterior colors** are available for the products built in your plant?332

✎ ______________ different exterior colors

H8. How many different **main body wiring harness part numbers** are used in your plant? *Do not include engine harness and accessory harness part numbers.*

✓

☐ 1-5 ☐ 6-10 ☐ 10-15 ☐ 15-20 ☐ 20-50 ☐ 50+

H9. How many different **engine assemblies/types** (based on part number counts) are delivered to your plant? *Count these before your plant begins engine "dressing" activities.*

✓

☐ 1-5 ☐ 6-10 ☐ 10-15 ☐ 15-20 ☐ 20-50 ☐ 50+

H10. How many different **combinations of engine/transmissions** are possible in your plant? *Include all forms of variation such as emissions equipment, power steering, air conditioning, etc. Measure this just before the unit is installed in the vehicle.*

✓

☐ 1-10 ☐ 11-20 ☐ 21-50 ☐ 51-100 ☐ 101-500 ☐ 500+

H11. What percentage of your part numbers can be used in all the products built in your plant? *Exclude paint stripes and standard parts like nuts and bolts. Ignore color variations.*

✓

☐ <5% ☐ 6-10% ☐ 11-20% ☐ 21-40% ☐ 41-60% ☐ 60%+

H12. What sequencing pattern is used on assembly lines in your plant that produce multiple product lines or body styles? *Consider the assembly area only.*

✓

☐ No set pattern ☐ A set sequence like 1-2-1-2-1-2 ☐ Batches like 1-1-1-1-1-1-1-1-2-2-2-2

H13. Can your plant add a body style (e.g. a 4 door sedan) while operating at standard volume?

✓ Yes ☐ No ☐

H14. How much time did your plant take for its most recent complete model changeover?

- Number of days assembly plant production was stopped: ____________ days of no production
- Number of days from the resumption of production to the achievement of full rated output: ______________ days to return to full output

H15. What is the base price in the country in which your plant is located of each of the models built in your plant?

✎

	Model Name	Base Price	(in local currency, but exclude all taxes such as VAT, engine taxes, and sales taxes)
Model 1	________	________	
Model 2	________	________	
Model 3	________	________	
Model 4	________	________	

Section I: General Information

In this section, we ask for some basic information about the overall operations of this plant.

I1. What is the **total** number of employees at this plant now? ________ current employees
(If you perform any Non-Standard Activities in your plant, this number should be higher than the total given for Standard Activities only on page 3.)

I2. What was the **total** number employed at this plant in 1983? ________ employees in 1983

I3. What is the **total** number now employed in managerial jobs in this plant? ________ managerial employees
(Managers include anyone who supervises other employees, e.g. first line supervisors, area or department heads, etc.)

I4. What is the **total** number now employed in non-supervisory direct and indirect production jobs in this plant? ________ shop floor workers

I5. How many organizational levels are there in this plant? ______ organizational levels
(Count the number of levels in the longest line from production workers to plant manager -- including both of these levels.)

I6. How many different job classifications are there for production workers in this plant? _______ production classifications
(Job classifications are defined as having different job responsibilities; two identical jobs that pay differently would be counted as one job class.)

I7. How many different job classifications are there for skilled, non-production workers in this plant? _______ skilled classifications
(Same definition as above in question I6.)

I8. Does this plant have a labor union? Yes ☐ No ☐

If there is more than one union, list the total number here: ________ unions

I9. What percentage of production workers (included skilled trades) are represented by the union(s)? ________ % production workers

I10. What percentage of non-production workers (excluding skilled trades but including technical and clerical staff) are represented by the union(s)? _______ % non-production workers 334

I11. What was the total (scheduled and unscheduled) absenteeism rate for employees at your plant in 1987? _______ % total absenteeism

(Total absenteeism includes individual scheduled vacations (but not plant shutdowns), and all other absences related to short-term sickness, bereavement, jury duty, education leave (but not including short-term training programs) special leave, work care/health programs etc. Workers included in the total absenteeism figures here must be included in the employee totals on page 3.)

I12. What was the **unscheduled** absenteeism rate for employees at your plant in 1987? _______ % unscheduled absenteeism

(Unscheduled absenteeism is total absenteeism minus any absences scheduled in advance such as individual vacations, special leaves, etc.)

I13. What was the labor turnover or attrition rate for your plant in 1987? _______ % turnover

I14. What percentage of employees are in each of the following age categories?

Age	**%**
18-24	_______
25-34	_______
35-44	_______
45-54	_______
55-64	_______
65+	_______
	100%

I15. What percentage of employees are in each of the following education categories?

Equivalent US education level	**Typical age education stopped**	**% of employees**
No secondary school	less than 14 years	_______
Some secondary school	14-18	_______
Secondary school degree	18	_______
Some college	18-22	_______
College degree	22	_______
		100%

I16. How many employees are not citizens of the country in which the plant is located? _______ non-citizens

117. Is there anything else you'd like to tell us about operations at your plant or about the issues raised in this questionnaire?

____

____

____

____

____

____

____

____

____

Thank you very much for your co-operation. We will call you within a few weeks of your receipt of this survey to answer any questions you may have. Should you require immediate assistance, please call (or fax) the researchers listed below.

John F. Krafcik
International Motor Vehicle Program
2120 El Paseo #3101
Houston, TX, USA 77054
☎ 1 713 796-8542

John Paul MacDuffie
International Motor Vehicle Program
MIT, E40-213
Cambridge, MA, USA 02139
☎ 1 617 253-0008

FAX: 1 617 253-7140

When you have completed the survey form, please place it in the self-addressed mailing envelope and return it to us. Updated information on your plant's comparative performance will be sent to you as soon as possible.

APPENDIX B

CODING OF VARIABLES FOR PRODUCTION ORGANIZATION INDEX

Production Organization

The ***Production Organization*** measure is the average of three more specific indices: Use of Buffers, Work System, and Human Resource Management (HRM) Policy. The Production Organization score places each plant on a continuum between Mass Production (MassProd) and Flexible Production (FlexProd). Use of Buffers, Work System, and HRM Policy are scored in the same direction, on a scale from 0 to 100, to facilitate their combination. When combined into the Production Organization measure, a low score indicates a MassProd organization and a high score indicates a FlexProd organization.

(A) The ***Use of Buffers*** variable measures a set of production practices that are indicative of overall production philosophy, with a low score signifying a "lean" system and a high score signifying a "buffered" system. It is the sum of four items:

- the percentage of assembly area floor space dedicated to final assembly repair ;
- the capacity of the in-process buffer between the paint and assembly areas as a percentage of one-shift production;
- the level of inventory stocks *(in days for a sample of eight key parts)*;
- the frequency of parts delivery to the line from in-house storage *(a score of 1=hourly delivery, 2=two to four times a shift, 3=once a shift, 4=once a day, 5=less often than once a day).*

(B) The ***Work System*** variable captures how work is organized, in terms of both formal work structures and the allocation of work responsibilities, and the participation of employees in production-related problem-solving activity. A low score for this variable indicates a work system that is "specializing" in orientation while a high score indicates a "multiskilling" orientation. It is the sum of six items:

- the percentage of the workforce involved in formal work teams;
- the percentage of the workforce involved in employee involvement groups;
- the number of production-related suggestions received;
- the percentage of production-related suggestions implemented;
- the extent of job rotation within and across teams *(0=no job rotation, 1=infrequent rotation within teams, 2=frequent rotation within teams, 3=frequent rotation within teams and across teams of the same department, 4=frequent rotation within teams, across teams, and across departments)*;
- the degree to which production workers carry out quality-related tasks *(0=functional specialists responsible for all quality responsibilities; 1,2,3,4 = production workers responsible for 1,2,3, or 4 of the following: inspection of incoming parts, work-in-process; finished products; and gathering SPC data)*;

(C) The ***HRM Policy*** variable measures a set of policies which affects the "psychological contract" between the employee and the organization, and hence employee motivation and commitment. A low score for this variable indicates a "low commitment" set of HRM policies and a high score indicates "high commitment" policies. It is the sum of four items:

- recruitment practices and hiring criteria used in selecting the workforce *(0 = traditional recruitment (individual interviews and review of previous work records) and hiring criteria (previous experience); and 5 = highly selective recruitment (written tests and group exercises) and hiring criteria (a willingness to learn new skills and ability to work with others)*;
- the extent to which the compensation system is contingent upon performance *(0 = no contingent compensation; 1 = contingent compensation, corporate performance; 2 = contingent compensation, plant-level, managers only; 3 = contingent compensation, plant-level, production employees only; 4 = contingent compensation, plant-level, all employees)*;
- the extent to which status barriers between managers and workers are present *(0 = no implementation of policies that break down status barriers and 1,2,3,4 = implementation of 1,2,3 or 4 of these policies: common uniform, common cafeteria, common parking, no ties)*;
- the level of ongoing training offered to experienced production workers, supervisors, and engineers *(0 = 0-20 hours of training for experienced (over 1 year of service) production workers, first line supervisors, and engineers per year (either 1987 or 1988); 1 = 21-40 hours of training per year for all 3 groups; 2 = 41-80 hours of training/year; and 3 = over 80 hours of training/year).*

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