

Cell Production and Workplace Innovation in Japan: Toward a New Model for Japanese Manufacturing?*

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This article investigates the current trend toward cell production and other workplace innovations in Japan using a large-scale sampling survey of manufacturing firms and in-depth interviews with four leading electrical and electronic establishments. The quantitative analysis reveals the correlation between the use of cell production and the ratio of female to male workers and production strategy variables, as well as the positive effect of cell production on operating profit rates and ordinary profit rates. The case studies reveal the following points: First, processes and organizations have been decentralized to the degree that individual workshops move toward taking primary responsibility for customer relations, production decisions, and delivery. Corporate headquarters increasingly play a coordinating rather than decision-making role. Second, firms have steadily implemented make-to-order systems by tightening links to suppliers and customers and developing new inventory and cost-control systems. Third, firms have started to implement more performance-based personnel practices. However, considerable variance among firms is observed in complementary changes, particularly personnel innovations.

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Introduction

Since the burst of the “bubble economy” in 1991, Japan has suffered prolonged economic stagnation. Economic leaders and the media routinely refer to this as the nation’s worst economic crisis since World War II. Even manufacturing industries, which continue to rack up large trade surpluses, share the sense of crisis. They are plagued by the so-called three excesses—excess capacity, excess employment, and excess debt—which are forcing them to steadily cut workforces (Economic Planning Agency 1999). Further, the strong yen has undermined competitiveness and put pressure on firms to send production overseas. In contrast to high-profile American firms such as General Electric that have prospered by shifting primarily into services, Japanese manufacturing firms are determined to improve manufacturing efficiency. If anything, the sense of crisis seems only to have strengthened their determination to restructure and innovate.

Evidence is emerging that Japanese manufacturers are reversing the trend toward large-scale automation and conveyor systems, which characterized industry in the prosperous 1980s, and are starting to emphasize “human-centered” workplace systems that utilize low-cost automation (LCA)¹ and entail greater autonomy for skilled production workers (Shinohara 1996). The most important system in final assembly plants, particularly in the electrical and information technology (IT) industries, has been *cell production*.² Cell production has been promoted as a means of improving productivity and flexibility, and is often linked to broader attempts to integrate and rationalize the entire value chain from supply to retail sales points (see *Kojyo Kanri [Plant Management]*, September 1996, November 1997). The purpose of this article is to provide a quantitative and qualitative analysis of cell production and related workplace innovations in Japanese industry. The shift toward human-centered production systems began only recently, and is far from complete. Therefore, no clear statistical data can, as yet, verify the extent of the shift, although our survey data, discussed later, show that a substantial number of firms had adopted or planned to adopt cell production by 1997, and leave little doubt that an even larger number will have adopted the system by the time this article is published.

¹In this article, we use the term “LCA” as a specific concept to refer to simple automation that makes extensive use of equipment that can be produced relatively inexpensively in-house. See also Shinohara (1995).

²Because the cell-production system is a new phenomenon, systematic empirical studies, whether academic or governmental, have yet to appear. Shinohara (1995) presents case studies of important adopters of cell-production system and reports that the first major facility in Japan to adopt cell production was Nippon Electric Corporation’s (NEC) Nagano facility, around 1993.

Based on a recent large-scale survey of production systems and a set of case studies of four high-end manufacturers in the electrical and electronic industries, we examine the nature of the ongoing change. Our study supports the belief that cell production is diffusing rapidly, but also indicates that it is just one of a number of innovations that are reshaping manufacturing industries. These innovations are making it possible for high-end manufacturers to adjust more flexibly to rapid market fluctuations while using fewer, but high-skilled, workers. Furthermore, our case studies indicate that the Toyota Production System continues to exert a powerful influence on the reshaping of production systems.

The article is organized as follows: The next section uses quantitative survey data to provide an overview of the new tendencies in final assembly, focusing on cell production. Using data from field research on four companies, including in-depth interviews, the third section examines the main factors in the diffusion of cell-production systems and workplace innovations in the electrical and electronic industries. Next discussed are the implications of the case studies previously presented. We conclude with a summary of the main findings of this article and a discussion of future prospects for the Japanese manufacturing industry.

New Trends in Final Assembly Work Practices: Evidence from Survey Data

What is Cell Production? In Japan, as in many other countries, the conveyor-belt system has long been dominant at final assembly plants, despite its shortcomings (notably low flexibility); consequently, worker skills have been little utilized. A few factories tried to introduce other production systems in the early 1970s. In the late 1980s, during the bubble economy, firms with abundant cash were eager to adopt large-scale, automated production systems such as Computer-Integrated Manufacturing (CIM). However the collapse of the bubble economy in the early 1990s led Japanese manufacturers to shift to more autonomous, human-centered production systems, which rely heavily on the skills of the workers.

Cell production exemplifies the shift toward human-centered production systems. A cell-production system is a production system in which a single worker or small team of production workers (two to five members) perform multiple production jobs (multitasking) in short segment lines. Cells are, with few exceptions, arranged in U-shaped lines in which unfinished components enter at a point adjacent to the point that they leave as finished products. The cell design places a wide range of tools and equipment in

close proximity to the workers, enabling them not only to perform a wide range of production tasks, but to customize the products as well. Cell production enables workers trained to perform multiple tasks to respond more easily to rapid variations in product demand; thus it is very suitable for small-lot production. Further, the high skills of the workers and the careful design of the cells means that fewer workers are needed than in conveyor systems. Cell production has been introduced mainly in final assembly processes as a substitute for large-lot production, although it has also been introduced at a number of suppliers. The actual term used for cell production differs from firm to firm; it is called “multi-task spiral lines” at Sony EMCS’s Koda Tech factory and the “one-man production line” at Toshiba Corp. The most prominent foreign case of which we are aware is Compaq, which has reportedly implemented a similar concept in its computer assembly operations in Houston. Cell production has attracted the attention of economists as well as that of practitioners because they think it heralds an important change in production practices (e.g., Aoki, Okuno, and Okazaki 1999; Shinohara 1995).

Cell production can generate highly flexible and efficient manufacturing with relatively simple inspection tools and low-cost automation (LCA). We believe that the trend toward cell production is part of a strategic shift to LCA. We can better grasp the distinctive features of cell production by comparing it to other new or similar production practices, such as the “new assembly system” developed by Toyota Motor Kyushu Corporation at its Miyata plant (see Fujimoto 1999:ch. 7). Toyota Kyushu’s new assembly system is characterized by five to 11 complete line segments. Each segment is manned by an autonomous group of workers, and job rotation and training are conducted within the groups. The new assembly system features an ergonomics evaluation system, which measures the workload of each assembly job quantitatively, based on physiological studies. The development of the new assembly system at Toyota was prompted mainly by efforts to improve working conditions, or “humanize” assembly jobs, in order to deal with the shortage of young workers (Shimizu 1995). Cell production, in contrast, has evolved to manufacture products that have very short life-cycles. The pressures for flexibility in the electrical and electronic industries are stronger than in the auto industry because the demands for product variation and rapid production and delivery are even greater while the lots and numbers of workers are much smaller.

Cell production also shows a strong similarity to the “U-line production” methods developed by Toyota. However, Toyota’s U-lines are used mostly in machining and parts manufacturing rather than in the final assembly of vehicles. As our cases indicate, most of the firms that have implemented

cell-production systems have in fact received guidance from consultants connected directly or indirectly to Toyota. Unlike Toyota's U-line production, however, cell production has been adopted in the final assembly processes of electrical and electronic industries in which the conveyor system was long dominant. In a typical conveyor system, production workers are assigned fewer tasks and assemble a smaller variety of products than those in a cell-production system. In addition, the conveyor system generally requires higher set-up costs and thus has become less cost effective in a rapidly changing economic environment demanding high flexibility.

There are three main types of cell production: the divided production system (*bunkatsu houshiki*), the one-man production system (*hitori houshiki*), and the chase production system (*jyunkai houshiki*) (Shinohara 1995). In the divided production system, several workers (usually four or five people) work in each cell, and each performs a limited number of specialized tasks. The work pace tends to be rapid. The divided production system is often a transition system, meaning that in many cases it is used by a company making the transition to either the one-man or the chase system. In the one-man production system, there is only one worker in each cell, and he or she performs all the operations, including inspection, thus achieving maximum line efficiency and line balance. However, the capital investment burden tends to be heavier, as each worker must be allocated a separate set of tools and machines (especially when inspection is conducted separately by each cell). The chase system consists of two to three workers who perform all the necessary operations in turn while working at roughly the same speed. Because equipment can be shared, capital investment needs are comparatively small. The disadvantage is that the cycle time is necessarily restricted to the pace of the slowest worker.

The Diffusion of Cell Production. This section uses the results of a large-scale mailed survey to provide an overview of the diffusion pattern for cell-production systems in Japan. The source of the data is a survey conducted in January and February 1997 by the Economic Research Institute of the Japan Society for the Promotion of Machine Industry for a project entitled "Research on New Trends in Production System Development and Human Resource Practices." The questionnaire was sent to 1,000 establishments in four main sectors of the machine industry. All the companies contacted are listed on the Tokyo Stock Exchange. The response rate for the survey was 22.7 percent, and was especially high among the precision instruments industry (66.7 percent). Most of the respondents were administrative employees, such as plant directors and chiefs of manufacturing departments (see Table 1).

TABLE 1
BASIC CHARACTERISTICS OF POPULATION AND SAMPLES

	Population size	Sampling rate	# of sampled establishments	# of respondents	Response rate
Total	2,252	10.1	1,000	227	22.7
General machinery	389	13.4	310	52	16.8
Electrical machinery	502	12.8	330	64	19.4
Transport equipment	452	9.5	170	43	25.3
Precision instruments	122	16.4	30	20	66.7
Other manufacturing	787	6.0	160	48	30.0

TABLE 2
ADOPTION OF CELL-PRODUCTION SYSTEM (%)

	Adopted	Plan to adopt	Do not plan to adopt
Total	23.2	25.0	51.8
Size of establishments			
–99	11.5	11.5	76.9
100–299	28.3	25.0	46.7
300–499	26.7	36.7	36.7
500–999	27.5	22.5	50.0
1000–	23.3	46.7	30.0
Industry			
General machinery	14.0	22.0	64.0
Electrical machinery	40.0	33.3	26.7
Transport equipment	25.6	28.2	46.2
Precision instruments	30.0	45.0	25.0
Other manufacturing	13.5	21.6	64.9

As Table 2 shows, 23.2 percent of the respondents had already implemented cell production in the assembly process, and 25 percent were planning to adopt it in the near future. Adoption rates and planned adoption rates were highest among electrical machinery manufacturers, followed closely by precision instrument makers. By size of establishment, adoption rates were highest among establishments with 100–299 workers, though by only a small margin compared to larger establishments. More importantly, the survey indicates that the larger the establishment, the more likely it is that it has already adopted cell production or is planning to adopt it in the near future. Not surprisingly, given the large capital outlays, few small establishments (fewer than 100 employees) have adopted or plan to adopt cell production; still, the aggregate figure, 23.2 percent, is significant.

TABLE 3
PERIOD WITHIN WHICH CELL PRODUCTION WAS ADOPTED (%)

	Previous year	1–3 years earlier	3–5 years earlier	5 or more years earlier
Total	0.0	46.0	26.0	28.0
Size of establishments				
–99	0.0	33.3	33.3	33.3
100–299	0.0	53.3	6.7	40.0
300–499	16.7	16.7	33.3	33.3
500–999	0.0	66.7	0.0	33.3
1000–	0.0	57.2	14.3	28.6
Industry				
General machinery	0.0	66.7	0.0	33.3
Electrical machinery	0.0	60.9	13.0	26.1
Transport equipment	11.1	22.2	0.0	66.7
Precision instruments	0.0	40.0	40.0	20.0
Other manufacturing	0.0	80.0	0.0	20.0

Table 3 reveals that the adoption of cell production is a new trend—in fact, an ongoing trend—as the majority of establishments using the system reported having implemented it within the previous three years. However, 28 percent of establishments already using cell production implemented it five or more years earlier. Among companies that had adopted cell production in the previous three years, the highest rates are for large establishments, those with 500–999 workers (66.7 percent) and 1,000 or more workers (57.2 percent), and for other industrial sectors (80 percent), general machinery (66.7 percent), and electrical machinery (60.9 percent). Given the response rate, the figures are not definitive, but they strongly suggest that mid-size firms (especially those with 300–499 workers) and transport equipment firms were the earliest adopters of cell production, beginning in the early 1990s, while larger firms and machinery makers stepped up the pace of adoption in 1994–1996. This may reflect the greater difficulty of implementing cell production in more complex or faster evolving product lines, and in larger establishments.

In addition, the data (not shown here) indicates that a majority of establishments surveyed have begun to eliminate their conveyor lines and plan to scrap them completely in the future. Thus the survey indicates that the cell-production system is being adopted as a substitute for the traditional conveyor system. At present over 70 percent of the establishments with cell production are presently using the divided production system, but over 60 percent plan to shift to the chase system in the future.

What about the economic effects of the cell-production system? More than 60 percent of the respondents answered that cell production has helped

decrease the number of personnel in manufacturing operations by 20–40 percent. In the open-ended survey question section, managers cited the following advantages, ranked from one to three in order of importance: (1) reducing man-hours and production lead time; (2) increasing flexibility to adjust product mixes and volumes and decrease of work-in-process inventories; and (3) reducing the number of maintenance workers and supervisors. The managers also reported, again in ranked order, the following disadvantages: (1) difficulties in responding to sudden changes in orders; (2) increased training time; and (3) difficulties in monitoring and controlling work pace within a cell.³ In sum, cell production is still a new phenomenon but it has already been introduced by a considerable number of manufacturing establishments. It makes possible much faster responses to environmental changes and greater flexibility in production but, as a new system, it presents new problems in terms of training and motivating workers.

Empirical Analysis. In this section we use statistical methods to identify the determinant factors driving the diffusion of cell-production systems as well as to examine their effects on economic performance. We work from the assumption that major gains from technological innovations in manufacturing can be realized only if appropriate complementarities are implemented.

Previous research on workplace innovations. Our theoretical and empirical framework draws heavily on previous studies of workplace innovation, particularly Osterman (1994), Dunlop and Weil (1996), and Nakamura, Sakakibara, and Schroeder (1998, 1999). These works have demonstrated the importance of “complementarity” in successfully implementing new production and business systems. Following Milgrom and Roberts (1992), we define complementarity to mean that if the simultaneous adoption of a set of various practices results in higher performance than the adoption of a single practice, then there is a complementarity among the various practices.⁴

³Analysis of variance and *t*-tests did not detect any significant difference in the average age, length of service, and period of training of employees between establishments that have adopted the cell-production system and those that have not.

⁴Following Milgrom and Roberts (1992), we define “complementarity” as follows. Let the variable *y* represent the firm’s performance and let *a, b, ...* be indicators for the adoption of various intrafirm activities, and assume that there is a functional relation $y = f(a, b, \dots)$, where *f*(*·*) is at least two-times differentiable. Then, the conditions

$$\frac{\partial^2 y}{\partial a \partial b} > \frac{\partial y}{\partial a} > 0 \text{ and } \frac{\partial^2 y}{\partial a \partial b} > \frac{\partial y}{\partial b} > 0$$

indicate the existence of “complementarity” within a firm.

Osterman (1994), utilizing a large-scale survey, sought to identify the main factors that influence the degree of success (or failure) of innovative work practices such as teamwork and job rotation in U.S. establishments. Using logit, he showed that a "high road strategy," in which management strategy stresses worker skill formation and quality over cost (extracted by employing principal component analysis), has a positive effect on innovative work practices.

Dunlop and Weil (1996), using business-unit data, analyzed the factors driving the diffusion of modular production⁵ in the American apparel industry and estimated its effects on economic performance. Their results indicate that the diffusion of modular production is affected by "replenishment pressure" from retailers, and that the degree of adoption of modular production positively affects the operating profits ratio.

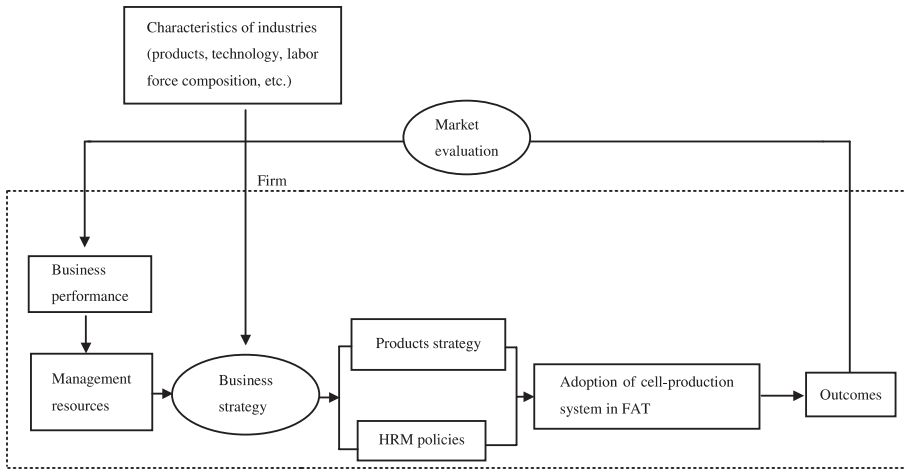
Nakamura, Sakakibara, and Schroeder (1998), using plant-level survey data in three machine industries, conducted a statistical test to see if the implementation of "core JIT" (practices such as setup reduction time central to implementing just-in-time (JIT)) and "infrastructure JIT" (manufacturing practices that supplement or support JIT such as "kaizen" activities to improve product quality) would affect manufacturing performances. Regression results showed that the implementation of core JIT alone could improve manufacturing performance, but they also suggested that the joint adoption of JIT practices and complementary practices (such as breakdown charts) could improve manufacturing performance even further. Using the same data set and employing canonical correlation analysis, Nakamura, Sakakibara, and Schroeder (1999) showed the existence of a positive and significant correlation between "core JIT" and JIT performance, as well as between the utilization of "core JIT" and "infrastructure JIT" practices.

These studies strongly indicate that management strategy and the market environment are key factors in the implementation of innovative workplace practices and production systems. More important, they strongly suggest that an improvement in business performance is most likely to result from the coordinated introduction of *complementary* innovative practices.

Determinants of the adoption of cell production. Based on our analysis of survey data as well as the existing literature, we hypothesize that certain causal relations, illustrated in Figure 1, play central roles in the adoption of cell-production systems. The figure depicts the following causal

⁵A modular system is a production system based on multitask team production and the elimination of in-process inventories in the apparel industry. It shares several characteristics with cell production.

FIGURE 1
ANTICIPATED CAUSALITY IN ADOPTION OF CELL-PRODUCTION SYSTEM



Notes: Observable variables in boxes, and unobservable variables in ellipses.
FAT means “Final Assembly and Test.”

relationships. According to management resources and various external factors, firms first determine overall business strategies, including product strategy and HRM policies. Then they decide whether to adopt cell production in final assembly and test (FAT) lines affected by characteristics of each industry (products, technology, composition of labor forces, etc.). Later, market performance either validates or invalidates the outcomes and is the most important factor in determining whether cell production will be continued.

Using this logical flow, we have designed a simple qualitative response model with the cell production adoption dummy set to 1. The explanatory variables used are management resource variables (the attitude toward automation, the ratio of female workers employed in the manufacturing process, market share, market status of the main product, number of workers), environmental variables (growth of sales), and controls (industry dummy,⁶ production-related variables).⁷ The definitions of the variables and summary statistics are reported in Table 4 (sales volumes and other indexes are in millions of yen). We use a weighted estimation. Since there is little difference between the results of logit and probit estimation, only the results of the logit analysis are shown.

⁶The general machinery industry is the base dummy.

⁷The correlation matrix for explanatory variables is available from the authors upon request.

TABLE 4
SUMMARY STATISTICS

Variable name	Obs	Mean	SD	Definition of variables
Cell adoption	220	0.23	0.42	1 = Cell-production system adopted
Electric	64	1	0	1 = Electrical machinery (base: general machinery industry)
Transportation	41	1	0	1 = Transportation equipment industry
Precision	19	1	0	1 = Precision instruments industry
Others	43	1	0	1 = Other manufacturing industries
Present stage of automation	212	2.67	1.19	Stage of automation of the whole process (present) takes the following six levels: 1 = not automated at all, 2 = individually automated machines, 3 = FMC, 4 = FMS, 5 = FA system, 6 = CIM
Future stage of automation	203	3.96	1.53	Stage of automation of the whole process (five years later) (takes the same levels as above)
Attitude toward automation	203	1.31	1.26	Difference between present and future stages of automation
Number of workers	205	581.35	690.53	Number of workers
Ratio of female workers	193	0.15	0.13	Ratio of female workers
Mass production	213	0.60	0.49	1 = Mass production
Production to stock	53	1	0	1 = Production to stock
Production to order	155	1	0	1 = Production to order
Machining	59	1	0	1 = Machining as the main type of production
Assembly	102	1	0	1 = Assembly as the main type of production
Status of main product	210	1.90	0.60	Market stage of main product takes the following three levels: 1 = growing, 2 = mature, 3 = contracting
Share of main product	209	1.80	0.93	Market share of the main product takes the following five levels: 1 = less than 20%, 2 = 20–40%, 3 = 40–60%, 4 = 60–80%, 5 = more than 80%
Main product	210	60.78	27.25	Ratio of main product over total sales
New product	208	4.14	1.13	Willingness to make inroads into new product markets takes the following five levels: 1 = not strong at all, 2 = not strong, 3 = neither, 4 = strong, 5 = very strong
Retreat	204	0.85	1.20	Willingness to retreat from the main product market
Overseas	209	3.77	1.33	Willingness to build plants overseas
Model change	204	3.17	1.65	Willingness to shorten the period for model change
Lot down	206	3.53	1.49	Willingness to make lot size smaller
Product variety	205	3.14	1.30	Willingness to increase variety of products
Principal Component 1	197	−0.03	1.34	Principal Component 1, see text
Principal Component 2	197	−0.03	1.07	Principal Component 2, see text
Principal Component 3	197	−0.01	0.95	Principal Component 3, see text
Operating profit rate	174	0.02	0.06	Operating profit rate over sales in 1996
Ordinary profit rate	174	0.02	0.06	Ordinary profit rate over sales in 1996
Growth of sales	174	0.04	0.11	Growth rate of sales over 1995–96 (in log difference)

TABLE 5
DETERMINANTS OF INTRODUCTION OF CELL PRODUCTION (LOGIT)

	(1) Basic model	(2) Principal component model
Attitude toward automation	-0.131 (-0.631)	-0.346 (-1.283)
Electric	0.750 (0.922)	0.448 (0.588)
Transportation	0.902 (1.046)	1.024 (1.185)
Precision	0.123 (0.119)	-0.038 (-0.041)
Others	-1.250 (-1.366)	-1.782* (-1.806)
Principal Component 1	—	0.395* (1.783)
Principal Component 2	—	0.381 (1.383)
Principal Component 3	—	0.469* (1.783)
Mass production	0.127 (0.219)	-0.151 (-0.241)
Production to order	-0.360 (-0.615)	-0.595 (-0.982)
Machining	0.630 (1.008)	0.811 (1.103)
Number of workers	0.0003 (0.799)	0.0003 (0.665)
Ratio of female workers	4.477** (2.087)	5.273*** (2.820)
Growth of sales	0.655 (0.246)	2.021 (0.870)
Share of main product	0.302 (1.190)	0.319 (1.247)
Status of main product	-0.719 (-1.536)	-0.822 (-1.521)
Intercept	-1.404 (-1.060)	-0.755 (-0.591)
Sum of weight	1.4064E+003	1.3389E+003
Log likelihood	-55.883	-48.514
Pseudo R ²	0.1890	0.2491

Numbers in parentheses are z-statistics.

***Significant at 1% level.

**Significant at 5% level.

*Significant at 10% level.

Estimated results are presented in Table 5. In the first column, we estimate a basic model without product strategy variables. Only the ratio of female workers shows a positive effect. To capture the effect of product strategy on cell adoption, we estimate an extended model. In our data, six variables on the key product strategy are available. Following Osterman's

(1994) approach, we add these to the list of explanatory variables. We first perform principal component analysis on these variables, and then conduct a logit and probit estimation using the newly created composite variables (principal components). More specifically, we select three out of the original six components, based on the magnitude of their contribution rates (labeling is based on the absolute values and/or signs of the eigenvectors on the original six variables). These variables are: Principal Component 1 to represent wide product variety (positive toward model changes, small-batch production, and widening product variety); Principal Component 2 to represent new product markets (retreating from the current product market, but positive toward entry into new product markets); and Principal Component 3 to represent domestic production activities (retreating from the current product market, and unwillingness to move production overseas). We performed a logit estimation using these components as independent variables.⁸

Estimated results in Column 2 indicate the positive effect of Principal Component 1 (composite variable to represent wide product variety) and Principal Component 3 (composite variable to represent maintaining production in Japan) on the adoption of cell production at the 10 percent significant level.⁹ Moreover, the ratio of female workers is positively significant, while the industry dummy for other manufacturing is negatively significant.

Economic effects of the adoption of cell production. Cell-production systems are expected to exercise positive effects on business performance. However, our survey data does not contain business performance variables such as sales, operating profits, and ordinary profits. To complement our data, we use business performance data on Japanese firms provided by the Japan Development Bank.¹⁰ As our data is compiled at the establishment level and that of the Japan Development Bank is at the enterprise level, there may be some inaccuracies.

We estimated our model by OLS. Variables included are management resource variables (management's attitude toward automation, market share, market status of main product, number of workers), environmental variables (growth of sales), controls (industry dummies and production-

⁸The eigenvalues of Principle Components 1, 2, and 3 are 1.816, 1.150, and 0.897, respectively. They account for approximately 64.4 percent of the variance of the original six variables. It should be emphasized that it is not tautological to include as a variable "small batch production" because principal Component 1 is a composite variable, as defined in the text.

⁹A likelihood-ratio test shows that these principal components are significant at the 1 percent level.

¹⁰We are grateful to the Hitotsubashi Computer Center for making the Japan Development Bank data available to us.

TABLE 6
PERFORMANCE EFFECTS OF CELL-PRODUCTION SYSTEM

	(1) Operating profit rate over sales (1996)		(2) Ordinary profit rate over sales (1996)	
	OLS	Qreg	OLS	Qreg
Cell adoption	0.015 (1.378)	0.004 (0.434)	0.021** (1.995)	0.013* (1.839)
Attitude toward automation	0.005 (1.634)	0.007** (1.989)	0.006* (1.780)	0.004 (1.584)
Number of workers	-3.18E-06 (-0.408)	-6.62E-06 (-0.853)	-3.35E-06 (-0.417)	-2.40E-06 (-0.523)
Share of main product	0.003 (0.763)	-0.0009 (-0.195)	0.005 (0.979)	0.0004 (0.153)
Growth of sales	0.164*** (3.856)	0.054 (1.139)	0.146*** (3.322)	0.077*** (2.768)
Mass production	0.0006 (0.068)	0.004 (0.379)	0.001 (0.403)	0.012** (2.135)
Production to order	-0.009 (-0.968)	0.002 (0.202)	-0.011 (-1.091)	0.002 (0.321)
Machining	-0.019** (-2.046)	-0.019** (-2.046)	-0.018* (-1.854)	-0.018*** (-2.875)
Electric	-1.46E-06 (0.000)	0.00003 (0.002)	-0.004 (-0.261)	-0.015* (-1.932)
Transportation	0.011 (0.785)	0.005 (0.371)	0.008 (0.587)	0.008 (0.587)
Precision	-0.036** (-2.073)	-0.026 (-1.644)	-0.033* (-1.845)	-0.031*** (-3.304)
Others	0.033*** (2.857)	0.021* (1.733)	0.033*** (2.791)	0.008 (1.007)
Intercept	0.0008 (0.517)	0.011 (0.671)	0.005 (0.317)	0.011 (1.122)
Number of jobs	143	143	143	143
Adj R ²	0.1634	0.0873	0.1521	0.0803

Quantile regression (Qreg) models are estimated at 0.4 quantile.

Numbers in parentheses are *t*-statistics.

***Significant at 1% level.

**Significant at 5% level.

*Significant at 10% level.

related variables), and a cell adoption dummy. Using these variables, we tested the effect of cell adoption on business performance.

The results are shown in the first and third columns of Table 6. They suggest that cell production has a significant and positive effect on ordinary profit rates. However, the OLS regression is sensitive to outliers. To deal with this problem, we estimate our model by quantile regression. The results are indicated in the second and forth columns of Table 6. When we remove

the effects of outliers, the coefficient of the cell adoption dummy becomes smaller or insignificant.¹¹

Summary. All the results presented above indicate that higher proportions of female workers increase the likelihood that cell production will be adopted. To explain this relationship, we suggest the following interpretation. To begin with, the ratio of women to men is high in the electric machinery industry, where the adoption rate of cell production is also high. In addition, the correlation may reflect company policies, regardless of industry, to tap the skills and motivation of female workers. Indeed, the ratio of female workers has an even larger effect after controlling for the type of industry. The presumed reason is that female workers tend to accept drastic workplace changes such as shifts in production systems while male workers (or male managers) prefer to stick to the status quo and resist changing the pace of work or workplace practices (Yamakawa and Ito 1996; Institute of Labor Administration 1998). Finally, in establishments where the proportion of women workers (either regular or part time) is high, the redesign of line work may be intended in part to help relatively unskilled female workers achieve higher skill levels. Consequently, according to this interpretation, cell production is adopted in part to enhance the multiskilling of women.

Further, it should be reiterated that the production strategies of firms as a response to the environmental changes in the product market also play an important role in the adoption of cell production. The estimation result implies that pursuing small-lot production of a wide variety of products leads to the adoption of flexible production systems such as cell systems, which is consistent with the findings of the previous studies discussed above (Dunlop and Weil 1996).

Although the results suggest, by and large, that cell production has a positive effect on business performance, this finding should be interpreted with caution. The effect of the introduction of cell production on business performance may not be immediate. Because of data restrictions, however, we cannot conduct a more detailed analysis at this point. For this purpose, panel data indicating the time lag from the point of adoption to the point when cell production begins to influence business performance is required.

In addition, it must be emphasized that cell production does not exist independently of other workplace practices. Rather, it should be considered

¹¹As to why the adoption of cell production raises ordinary profit rates, but not operating profit rates, we suggest the following hypothesis. If a reduction in inventory is realized, it leads to savings in opportunity costs and therefore does not appear on the firm's balance sheet. However, if the savings are invested in securities, it increases earned interest, leading to an increase in ordinary rather than operating profits.

as a subsystem of the broader manufacturing system of an enterprise or operational unit. Our statistical analysis suggests that cell production has a positive effect on business performance but our model lacks numerous variables affecting business performance, such as the use of information networks and changes in relations with affiliated companies. Moreover, some firms have implemented even more comprehensive redesigns of production systems in which cell production is just one element among many (*Kojoyo Kanri* [*Plant Management*] November 1997). In the following section, we discuss four case studies to explore the connections between variables not included in our survey data.

Workplace Innovations: Evidence from Case Studies

In this section, the term “workplace innovation” refers to various organizational initiatives aimed at achieving higher levels of business performance as well as customer and employee satisfaction. Workplace innovation typically involves a fundamental transformation of work and production organizations. The introduction of cell production, which represents a means of organizing manufacturing activities fundamentally different from other systems, matches this definition. However, many firms have comprehensively reorganized production systems by adopting manufacturing practices other than cell production.

To understand the broader nature of ongoing change in the Japanese manufacturing industry, we examined two establishments that have adopted cell production and two that have opted for other workplace innovations. The first two establishments are final assembly plants that produce digital electronics products, including DVD players and cellular phones, while the latter two establishments manufacture key components and parts that are incorporated in those digital products. The interviews covered the following topics: (1) general information about the company or the factory (this information is summarized in Table 7), (2) how the firms implemented cell production or other new workplace practices, (3) what changes (such as personnel system innovations) accompanied the introduction of the practices, and (4) key principles (such as the Toyota Production System) underlying the practices. Respondents included plant managers and chiefs of production management departments.

We selected these four establishments because they are located in the electrical and electronics industries, which have established themselves since the late 1980s as Japan’s most important manufacturing sectors. In the 1970s, the auto industry emerged as Japan’s leading innovator of production

TABLE 7
BASIC CHARACTERISTICS OF ESTABLISHMENTS

	# of workers	Female ratio	Type of production	Main products	Market share	Automation rate
Company <i>A</i> Factory <i>O</i>	1,350	17%	Final assembly	DVD player, etc.	50%	—
Company <i>B</i> Factory <i>P</i>	756	Less than 1%	Final assembly	Cellular phone, etc.	Less than 80%	30%
Company <i>C</i> Factory <i>Q</i>	582	42%	Parts machining & assembly	Chemical condenser	25.9%	90%
Company <i>D</i> Factory <i>R</i>	222	26%	Parts machining & assembly	Resistor	23.1%	42%

processes. Now the electronics industry, using cell production and other manufacturing innovations, is probably playing the leading role in the continued development of the Toyota Production System (TPS). This is because, as noted earlier, this industry faces the strongest pressure to customize production and respond quickly to customer demand.

The four cases show how the transformation of production systems, while itself generated by environmental factors and broader business strategies, has encouraged the increasing decentralization of corporate organizations along with the corresponding tightening of production-sales linkages. The cases explain why the companies have adopted cell production or other new technologies, describe the resources that contributed to the establishment of the new systems, and show what complementary innovations have accompanied the adoption of new production systems. The nature and intensity of the innovations, particularly the personnel practices, vary considerably from firm to firm. Interestingly, the last case examined, Company *D* Factory *R*, has not implemented cell production, but has probably instituted the most complete range of new innovations.

Workplace Innovation Practices

Company A Factory *O*.¹² Factory *O* manufactures primarily audio-video products. It employs 1,350 regular workers, of which 17 percent are women.

¹²Company *A* is an audio-system manufacturer established in the late 1930s. The sales growth rate is especially high for car electronics production. Factory *O* was established in 1960. The emphasis of the manufacturing strategy recently shifted from audio to video production. The ratio of indirect workers is relatively high given the absence of any machining lines. Company *A*'s national share of the DVD market is said to be over 50 percent, although it is difficult to obtain detailed data due to the recent introduction of this product.

The adoption of cell production was related to the increasing rate of overseas production, which exceeded 60 percent of Company *A*'s total output in fiscal 1996. The remaining operations in Japan are focused on small-lot production and new products requiring a highly flexible production system capable of accommodating frequent changes in equipment and layout. In 1993, when the cell-production system was introduced, company managers attended a lecture given by a local trade association on the Toyota Production System. They also visited the NEC Nagano factory, which is believed to be the first major facility in Japan to have adopted cell production. No consultants were involved. In 1991, the company began to develop small-group production practices and undertook various labor-saving activities focused on LCA, and by 1993 it had initiated a number of kaizen activities focusing on manufacturing operations. Beginning in 1994, cell production was adopted on a gradual basis.

Cells were divided into four groups according to product size and delivery requirements. Job rotation was organized in response to production needs, and the cell layouts were changed approximately every two weeks. Employees engaged in special work such as inspection and soldering received more extensive training. There was a degree of division of labor on the line according to sex: Male workers were responsible for coordination; female workers were mainly engaged in assembly wiring, soldering, and other basic operations.

Company *A* introduced a special system to manage parts logistics in 1996. Under this system, parts delivered by the supplier are first registered on a sheet along with information about the manufacturing line, type of equipment, production process, lot, number of parts, and so on. After going through parts delivery reception and parts inspection, the parts are classified, according to the manufacturing process, into three groups: mass production, individual unit production, or storage. Parts for individual production proceed to a parts storage bin, called a refrigerator,¹³ from which operators take only the parts necessary for the following manufacturing process.

In 1996, the company introduced a comprehensive cost-control system that it developed in-house. The keys to the new system are a special kanban (inventory control method) called a "zaiko kanban" and a cost-recording system called a "rain kakei-bo" (literally, a household account book for production lines). First, the production and marketing departments jointly

¹³A "refrigerator" is a storage shelf for parts located next to workers between the "store" and the lines in order to facilitate "visual control." The refrigerator is not described in standard TPS textbooks such as Monden (1993).

determine the volume of monthly and weekly production. This production plan is revised ex-post at the factory level by the chief of the manufacturing line who conducts a highly detailed breakdown of inventory using the zaiko kanban.¹⁴ Next, the cost-recording system, which records cost information in far greater detail than any other system we know of, is used to determine production costs to the level of individual lines. One of its tasks is to calculate monthly profit levels for particular lines. For example, when a worker is temporarily transferred to a different cell, such "assistance" is also registered as a cost. Perhaps the most important contribution of the new record-keeping system is that it heightens the cost consciousness of both managers and workers. Further, the detailed inventory and cost breakdowns have made it possible for the factory to make decisions largely independently of the corporate headquarters. Company *A* did not implement a just-in-time system (with zero in-process inventories) but is planning to do so, and is currently negotiating this matter with parts suppliers and affiliated companies.

The company introduced various changes in its personnel practices in April 1998, aiming to make them more responsive to interworker differences in skills. According to company managers, however, these changes are not related to the introduction of the cell-production system. The revised methods of encouraging productivity include pay raises and bonuses for individuals, as well as a system of monetary rewards to motivate kaizen activities.

*Company B Factory P.*¹⁵ Company *B*, a member of the keiretsu network of a major electrical machinery manufacturer, makes a variety of communications, information, and other electronic products, including mobile phones and related equipment. Managers instituted cell production in order to achieve higher flexibility with regard to demand fluctuations.¹⁶ Before making the shift, company managers received guidance from Hino Motors, a Toyota-affiliated truck manufacturer, and visited NEC and

¹⁴Zaiko means inventory. The zaiko kanban includes a record of standard stock sizes, stock sizes for the latter part of the month, expected stock sizes for the latter part of the month, and volume of expected sales and production for the entire month. This information is divided into two separate sections for overseas and domestic markets.

¹⁵Company *B*, established in the late 1940s, employs roughly 2,300 workers. It produces goods for both the consumer market and the public sector. Factory *P* was established in mid 1960s, mainly to manufacture information equipment for the public sector. There are 756 employees, and fewer than 1 percent are women. The firm presently produces mobile telephones, but has less than 8 percent of the Japanese market.

¹⁶The following data was obtained during our visit to Company *B* on August 21, 1997. Subsequently, all production lines were transferred to a factory in Hokkaido specializing in development and prototypes. The cell-production system used in the Hokkaido factory is similar to the one we describe.

Hitachi factories. In 1995 and 1996, with the help of consultants, Company *B* implemented a cell-production system first in mass production lines and later in nonmass production lines.

Factory *P* manufactures mainly information equipment for the public sector. Cell production at the factory now covers 35 percent of manufacturing operations for mobile phone systems, 50 percent of digital base stations for cellular and car telephones, and 15 percent of other production lines. In addition to improving productivity and responsiveness to customer demand, the implementation of cell production has lowered the cost of routine workplace improvements such as changing line layouts. One of the initial disadvantages was the considerable amount of standing work, but the introduction of adjustable tools and shock absorption mats has mitigated this problem. There is still a lot of room for improving jigs and tools, increasing the speed of operations, and reducing equipment set-up time. Therefore, the factory can count on continued significant improvements in efficiency. Personnel training is based on OJT and job rotation. Previously, rotation was limited to surrounding workstations only, but workers are now rotated throughout the plant.

Although Company *B* is not planning to implement a made-to-order production system, the head office is connected to other factories, including Factory *P*, and affiliated companies by a WAN using ISDN lines. At present, Company *B* manufactures mobile telephones, digital base stations, and pagers according to a "semi-manufactured production forecast." In other words, modules are made based on forecast and stocked, while final assembly is performed strictly to order. Every cell has a parts "store" where the modules are stocked. Production planning is conducted in three stages. Production plans like those used in the auto industry, where production is based on information about yesterday's sales, are deemed unfeasible. Supplier relations have undergone substantial changes due to the new production system, as the frequency of deliveries has been increased and the production plans are revised every day instead of monthly.

*Company C Factory Q.*¹⁷ In the case of Company *C*, which produces condensers, the main reason for the introduction of workplace innovations was that in 1993 the company suffered its first operating deficit since its registration on the Tokyo Stock Exchange. In the same year, under the

¹⁷Company *C* was established in the early 1930s to manufacture condensers. Its main product is aluminum condensers, which constitute 74 percent of its total sales. The company ranks second in the world in the production of aluminum electrolytic condensers, with a global market share of 25.9 percent in 1996. Factory *Q* started operations in the mid 1960s. There are roughly 600 workers; 42 percent are women, most of them part time.

guidance of Mr. *X*, from a private consulting firm, Company *C* started to implement workplace innovations under a program called CPS (for Company *C* Production System). In 1993–1994, the company scrapped its factory automation (FA) systems, automatic warehouses, and automatic guided vehicles (AGV), which had collectively cost close to 400 million yen (about 3.2 million dollars), before the period of their amortization was over because they reduced the company's flexibility in changing production strategies.

Since Company *C* mass produces parts, cell production was not a viable option. However, it shifted the position of the equipment in production lines from "job shops" to "flow shops" as part of its CPS program. In a job shop, inputs and unfinished products proceed along a discrete manufacturing line organized by related processes, or stages, in which different operations are performed. In most cases goods-in-process are stocked as inventories at the end of each stage of production before moving to the next stage. In a flow shop, by contrast, inputs and unfinished products proceed along a more fully integrated manufacturing line. Whereas the layout of job-shop-type lines is determined by process (or stage of production), the layout of flow-shop-type lines is determined by product, and, in principle, no goods-in-process are stocked as inventories (Hirano 1990). After setting up a flow-shop system, the company reorganized the factory as well, laying it out by products instead of by processes. Although the new system is still under development, it has already exhibited higher levels of productivity than the previously used batch-production system. Among other problems in the former system was the difficulty of controlling operations and seeing the connection between separate production processes. The new system greatly enhances visual control. In addition, Company *C*, like Companies *A* and *B*, has begun to use refrigerators and stores.

The company has also been seeking ways to raise productivity through improvements in personnel practices and employee incentives. The company has promoted joint improvement activities conducted by female staff from the head office in cooperation with female team leaders from the factory. One personnel innovation did not work out. At first, the factory initiated a system where each cell took charge of profit control as part of a transfer of responsibility to the shop floor, but it had to cease this practice because differences in demand for the various products and other external factors undermined the performance of certain cells. To help "smooth" (*heijunka*) production levels, the company is planning to involve the sales department in factory operations.

Another means of improving efficiency was to reorganize production control by subdividing it into separate sections. Five years ago production

technicians were transferred from the head office to three branches of Factory *Q*. The engineering department of the head office now focuses on basic research and development, a change that has reportedly speeded the pace of equipment improvement. Moreover, the distribution center of the head office was closed and the factories began sending products directly to the customers. Now orders received from customers through a VAN network are registered in the host computer of the head office. After receiving instructions from the head office, the factory starts manufacturing as soon as the materials are delivered from the affiliated companies, which provide them through means of a just-in-time system. The product is then delivered directly to the customer without passing through any distribution centers. As contact between customers and the factory is conducted through the head office, this is not yet a “direct order” system.

*Company D Factory R.*¹⁸ Company *D* has implemented the most comprehensive innovations of the four firms examined here, largely because it redesigned its entire organization and order-and-delivery system as well as its production system. In 1987, following an unsuccessful attempt at diversification, the company faced an operating deficit, prompting the managers to seek outside advice from the above-mentioned Mr. *X*. On his advice, Company *D* introduced DPS (Company *D* Production System). Previously, Company *D* had ambitiously planned to completely automate its production lines using FA, automatic warehouses, automatic racks, AGV, and materials resource planning (MRP). In 1984 it even won a prize for FA (factory automation) from a business newspaper. However, these systems were completely scrapped after four to five years, before their costs could be amortized, because of low efficiency.

Company *D* reduced the degree of automation and, like Company *C*, introduced a flow-shop system. The production control method was changed from computer-controlled, large-lot production to visually controlled, small-lot production. These changes brought several major improvements in efficiency, including reductions in manufacturing cycle time and in various forms of waste. In addition, the company flattened its organization in accordance with the “workshop” concept, meaning that small business units operated to produce and promote individual products. Responsibility was transferred to the managers of workshops. The company

¹⁸Company *D* is a resistor manufacturer established in the early 1940s. It employs roughly 800 workers. Its main product is metal film resistors. Company *D* ranks second in the world for metal film resistors and had a 23.1 percent market share in 1996. Factory *R* was established in the early 1990s for the manufacture of chip resistors. Women account for 26 percent of regular employees; they are mainly engaged in inspection and office work, including production control.

also transformed the entry-order system so that orders go directly from customers to workshops and the finished products are delivered from workshops directly to customers.

The transfer of responsibility to the shop floor made it possible to give each shop specific performance targets (e.g., delivery achievement rate, gross profit). Performance is reflected in personnel evaluation. The ratio of performance-based pay in basic wages is 30 percent for workers and 50–60 percent for managers. Thus the performance of production groups is much more closely reflected in individual pay in this company than in the other three companies.

Company *D* organizes its make-to-order system as follows. First, customers place their orders through EDI (electronic data interchange) using a VAN. As orders come in different formats, the host computer must transform them into a standard format. Second, the orders are sent from the head office host computer directly to the shop floor; the sales department and production control sections do not participate in this process, and all operators have access to the information. Third, shop leaders manage stocks autonomously, estimating the quantity of needed parts and sending orders directly to affiliated suppliers. As in the case of Company *C*, manufactured goods are delivered directly to customers without passing through a distribution center.

Summary. As summarized in Table 8, two establishments (Company *A* Factory *O* and Company *B* Factory *P*) adopted cell production in order to increase flexibility and speed adjustment to business conditions. In the other two establishments (Company *C* Factory *Q* and Company *D* Factory *R*), the introduction of innovative practices was aimed at improving performance by shifting from costly high-automation strategies to variegated approaches making greater use of worker skills. Company *D* began

TABLE 8
BACKGROUND AND DETAILS OF WORKPLACE INNOVATIONS

	Type of activity	Reason for introduction	Year of introduction	Use of consultant
Company <i>A</i> Factory <i>O</i>	Workplace innovations with cells	To cope with various efficiency losses in the production lines	1994	No
Company <i>B</i> Factory <i>P</i>	Workplace innovations with cells	To cope with increasing demand	1995–1996	Yes
Company <i>C</i> Factory <i>Q</i>	Workplace innovations without cells	Poor business performance	1993	Yes
Company <i>D</i> Factory <i>R</i>	Workplace innovations without cells	Poor business performance	1987	Yes

TABLE 9
REVISIONS IN OTHER DEPARTMENTS ASSOCIATED WITH WORKPLACE INNOVATIONS

	Use of kanban	Transfer of responsibility to shopfloor	Make to order	Revision of personnel system
Company <i>A</i> Factory <i>O</i>	Yes	Yes	No	No
Company <i>B</i> Factory <i>P</i>	No	—	No	No
Company <i>C</i> Factory <i>Q</i>	Yes	Yes	Yes	No
Company <i>D</i> Factory <i>R</i>	Yes	Yes	Yes	Yes

implementing workplace innovations in 1987 after suffering an operating loss, and the other three companies began to do so soon after the collapse of the bubble economy. In addition, we observed that three of the four establishments requested the help of consultants, who invariably transferred elements of TPS.

Table 9 illustrates how the introduction of cell production and other workplace innovations made possible the implementation of just-in-time and transfers of responsibility to the shop floor. The companies have not yet instituted, or attempted to institute, the full range of possible complementary changes, so the workplace innovations have had relatively little effect on human resource management practices. In addition, there are significant gaps among the companies in capability for made-to-order production. These gaps reflect different levels of implementation of information networks and information sharing between manufacturing and sales divisions. Of the four establishments under study, Company *D* Factory *R* appears to be the most advanced in the implementation of complementary innovative practices. Unfortunately, we were unable to gather much information on workforce policies, but it is clear that Factory *R* now takes close account of performance in personnel evaluations, whereas Company *C* was forced to scrap a similar plan, and Company *A* uses relatively simple pay incentives.

Economic Effects of Workplace Innovations. In Table 10 we compare standardized indexes obtained from each company regarding reductions in production-sales lead time and inventories before and after the introduction of innovative practices. Reducing lead time makes possible quicker responses to customer demand and therefore helps strengthen the customers' ties to the production firms. Inventory reduction raises the inventory

TABLE 10
ECONOMIC PERFORMANCE OF WORKPLACE INNOVATIONS

	Reduction rate in lead time	Reduction rate in inventory
Company <i>A</i>	50–80%	45–60%
Factory <i>O</i>		
Company <i>B</i>	50%	60%
Factory <i>P</i>		
Company <i>C</i>	27–35%	62.5%
Factory <i>Q</i>		
Company <i>D</i>	83%	84%
Factory <i>R</i>		

turnover ratio and increases capital efficiency. As can be seen, Company *D* Factory *R* showed the highest rate of business performance improvement.¹⁹

The Continuing Influence of the Toyota Production System. As emphasized by several interviewees, cell production and other current workplace innovations originated within the Toyota Production System. The continuing influence of TPS is clearly indicated by the use of kanban systems and U-shaped lines, as well as by the steady diffusion of less well-known TPS elements such as refrigerators and stores. The adoption of TPS in the electrical industry firms is a relatively recent phenomenon; three out of the four establishments studied here, for example, adopted it after the collapse of the bubble economy.

It appears that the steady—and apparently quite successful—diffusion of TPS practices is made possible in large part by the contributions of experienced consultants. Three of the four companies studied here received guidance from consultants (Company *C* and Company *D* received guidance from the same consulting company; for information on this company see Isa 1998). Our interviewees at Company *C* stated that without the guidance of Mr. *X*, they could not have understood the essence of TPS. Existing manuals concentrating on the kanban system are difficult to understand. The representative of Company *D* noted that the elimination of useless operations is a key point of TPS, and acknowledged that the company's first attempt to implement a kanban system was unsuccessful. These experiences suggest that the efforts by Ohno (1978) and Monden (1989) to systematize TPS principles may not have been very useful to actual practitioners.

TPS (or parts of it) has been successfully adopted by non-auto-manufacturing firms and plants such as Nippon Sheet Glass, Daikin Industries,

¹⁹Of course, they could be influenced by factors other than workplace innovations. But, because some key data is regarded as confidential by the firms, further analysis could not be conducted.

Hitachi, and Kawasaki Heavy Industries' motorcycle factory, and even service sector companies such as Seven Eleven Japan (Monden 1989; Hashimoto, Hasegawa, and Miyajima 1998). The system has also been introduced in America and other foreign countries where it is better known as lean production (Womack, Jones, and Roos 1990). However, our questionnaire survey and the case studies suggest that the extent and nature of TPS diffusion vary significantly from one industry to another. It is therefore necessary to reconsider the commonly held notion that TPS (or lean production) is the dominant production system in Japanese industry. At the same time, it is important to note that TPS is an important element in the new manufacturing systems being developed primarily in the electronics industry.

There are several possible reasons why the electronics industry has been slow to introduce TPS. First, the seminal TPS textbooks mentioned above are too abstract for those in the non-auto industries to master. Second, electronics firms such as Company *A* have placed more emphasis on new product development than on process innovations. Third, engineers were excessively confident about the marketability of high-quality products. Further, the auto industry has had intra-industry study groups such as "jishuken" (voluntary study meeting) to discuss and disseminate information (Sako 1996), but there have been few interindustry study groups until recently. Those interindustry study groups that have convened have typically been assisted by experienced industrial consultants.

Discussion

The innovations discussed in this article indicate an important trend of change in Japanese manufacturing practices, especially in the electrical and electronic industries. The evidence is preliminary, but suggests that firms are seeking to use more human-centered and flexible production systems. Further, they are seeking to decentralize operations, particularly in terms of tightening production-sales linkages, and to ensure the success of their redesigned production systems through complementary changes in personnel practices. The adoption of new production systems and complementary innovations has in turn encouraged organizational restructuring.

Decentralization. The redesign of production in Japanese manufacturing industries, particularly the electrical and electronic industries, along with complementary innovations, has generated important organizational changes at all levels. The basic trend is toward decentralization. The redesign of production on the basis of flow shops has made it possible to

change the layout of production lines quickly. For example, in Company *A* Factory *O*, the department of production management used to determine the volume of output. Now, the recently introduced production cells are divided into several categories according to the size of the product and line managers determine the weekly or monthly volume of production. Thus, the comprehensive inventory and cost-control systems have increased the autonomy of the workplace, and production workers have been given greater responsibility. These changes expedite rapid responses to fluctuations in demand. Some workplaces, such as Company *D* Factory *R*, are also receiving orders directly from customers, although this trend is not as advanced.

Companies *C* and *D*, though they have not introduced cell production, have redesigned equipment layouts and the organizational structure of manufacturing, in effect going from a “job shop” to a “flow shop” type organization. They reorganized their entire factories by products instead of processes. Company *D* presents the most advanced example of a transfer of responsibilities to the shop floor. The autonomous activities of workers or teams now go well beyond kaizen—incrementally improving production work and processes. In other words, companies are seeking to make each manufacturing workplace into a virtual “mini-factory” capable of autonomous adjustment to environmental changes. This is a major change from the previous assumption that company headquarters would determine responses to environmental change.

The trend toward decentralization is largely a consequence of greater diversity in consumer demand. This demand has intensified competition for scarce managerial resources among operational units within an organization, and consequently has decreased the importance of integrated operations such as batch manufacturing based on large-scale automation. Moreover, it is also possible to observe that Japanese electronic firms’ recent trend toward “unbundling”—divesting themselves of noncore business units—is stimulating parallel changes at the enterprise level.

The Transition to Make-to-Order. From the mid-1980s until the beginning of the 1990s, computer integrated manufacturing (CIM) was widely seen as the best means of achieving high degrees of integration between production and sales. CIM, based on centralized control of workplace information, did not achieve the productivity gains anticipated. However, the ongoing manufacturing innovations appear to be helping to create a much closer linkage of production and sales.

Many problems remain to be solved before such linkage can be fully realized. The innovations implemented in Company *D*, the most advanced

of our four cases, enable shop-floor workers and managers to have direct access to information about customers through the head office's host computer. In Company C, on the other hand, the factory receives customer information only after it has been processed by the sales office. According to a Company C manager, the main problem is that monthly demand fluctuations are too wide and need to be smoothed out. Consequently, the factory must continue to produce to forecasts to meet high demand at the beginning of every month. It is possible that achieving higher levels of make-to-order capability will require overcoming department-specific interests. The company's American branch, for instance, locates its sales department in the factory, and such an arrangement might help Factory Q to achieve closer linkages to customers.

In other words, transition to make-to-order is not only a matter of implementing a new management system, but also of making sure that business objectives and incentives are properly aligned and that both manufacturers and retailers see benefits in pursuing the matter. The same conclusion applies to single organizations—in this case between manufacturing divisions and sales divisions. To achieve closer interaction between divisions, it may be necessary to implement measures such as Company D's policy of providing shop-floor staff with direct access to client information, or Company C's decision to transfer part of the sales department to the factory and to promote daily information sharing between manufacturing and sales personnel.

Complementarities with Personnel Practices. A consequence of the current evolution in production systems from conveyor-based line systems toward cell production and other human-centered production practices is that individual worker performance is becoming easier to assess. This is because the manufacturing units are smaller, output can be better monitored, and, as a result, the free-riding problem is attenuated. This will generate both pressures and opportunities to develop new human resource practices, such as pay-for-performance compensation systems, that can match reward more closely to individual or group performance. So far, however, there seems to have been relatively little effort in Japan to link the two. That there are opportunities for doing so suggests that the new production systems offer substantial opportunities for further raising productivity.

The personnel policies examined here appear to lag behind the use of other innovative workplace practices, and the situation seems to be similar in the United States. Based on a review of empirical research conducted before the mid-1990s, Ichniowski et al. (1996) found that innovative

workplace practices can increase productivity improvements primarily through the introduction of multiple and mutually related practices (e.g., employee involvement, flexible work design). Firms that introduce such practices as a system have seen better results than other manufacturers, but few have done so. The main barriers to further diffusion appear to be the cost of organizational change, labor-management distrust, resistance from employees, particularly older workers and foremen, and inadequate public policies. The reasons for the failure of most Japanese firms to adopt complete systems of related workplace practices seem to be different. Many managers may be unaware of the importance of complementarity in organizational restructuring. In addition, there has often been a lack of enthusiasm for individual-based evaluation due to the relative “collectivism” of Japanese factory personnel (Tsuru, Morishima, and Okunishi 1999).

Conclusion

This article has analyzed the current trend toward cell production and other workplace innovations in Japanese industry, based on a large-scale survey of manufacturing industries and in-depth interviews in the electrical and electronic industries. The survey revealed a correlation between the use of cell production and the ratio of female to male workers and production strategy variables, as well as a positive effect of cell production on operating profit rates and ordinary profit rates.

The field studies revealed the following points. First, in response to financial difficulties and perceptions of a deeper economic crisis, firms have introduced workplace innovations that have greatly reduced lead times and inventory stocks. Second, processes and organizations have decentralized as individual workshops move toward taking primary responsibility for customer relations, production decisions, and delivery. Corporate headquarters increasingly perform coordinating rather than decision-making functions. Third, firms have steadily implemented make-to-order systems by tightening links to suppliers and customers and developing new inventory and cost-control systems. Fourth, firms have started to implement more performance-oriented personnel policies. Given the ongoing development of the production practices, it is not surprising to find considerable variance among firms in their achievement of complementarities. In particular, we noted substantial differences in personnel practices. Yet these factors also indicate that the new systems offer great potential for continued significant improvements in productivity.

Our study suggests that Japanese production systems are engaged in what could be termed a third stage of historical evolution. The steel and shipbuilding industries led a first stage of development in the 1950s and 1960s, as heavy investment and rapid technological transformation of workplaces altered the nature of worker skills to make them more knowledge intensive. At the same time, managers redesigned the social organization of work, redesigning pay and promotion systems to strengthen the productivity consciousness of workers. The automobile industry, led by Toyota, led the second stage by intensifying the development of work teams to take full advantage of production technology innovations. For various reasons, the electrical and electronic industry firms did not adopt the full range of new work practices but continued to use conveyor systems until the 1980s, when they tended to opt for the (ultimately disappointing) CIM methods. However, the electrical and electronic firms are now leading the third stage of evolution by applying TPS methods in a new generation of higher-value-added production, and some firms have already achieved major improvements in performance. Each stage of development is, of course, related to the principal product. The new model of manufacturing features a wide variety of electronic-intensive, relatively small components that must increasingly be custom-produced in small lots and delivered as quickly as possible. Further, each stage of development utilizes fewer workers at the final stage of assembly or production, and necessitates—or makes possible—further innovations in personnel management with their own potentials for reducing costs and improving efficiency.

Finally, the evidence also suggests that the conventional wisdom that TPS, or lean production, is widely used in Japanese industry is incorrect. In fact, the diffusion of TPS has just begun outside the auto industry in Japan, though in modified forms exemplified by cell production and related workplace innovations. Despite this misunderstanding, the importance of TPS would be difficult to overestimate. Its central contribution in the ongoing third stage of manufacturing indicates that its principles will continue to influence management methods in manufacturing and related areas—notably human resource management—for years to come.

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