Adoption of Just-in-Time Manufacturing Methods at U.S.- and Japanese-Owned Plants: Some Empirical Evidence

Masao Nakamura, Sadao Sakakibara, and Roger Schroeder

***Abstract*— Since the early 1980's, when Japanese manufacturing firms in a number of industries—including auto, electronics, and machinery—achieved high levels of international competitiveness, Japanese manufacturing practices—particularly those associated with just-in-time manufacturing (JIT)—have attracted considerable attention in North America. Transfer to the United States of JIT is characterized by special production management practices involving inventory and quality control, industrial relations, and supplier-manufacturer relationships.**

Because so many different aspects of plant operation are involved, the transfer of JIT requires a substantial effort on the part of U.S. manufacturers. Despite this barrier, anecdotal evidence suggests that substantial transfer of Japanese production methods has taken place and that this transfer has had a significant impact on the performance of U.S. manufacturing plants. However, there is little empirical evidence of this process that is based on broad samples of plants and workers from various manufacturing industries. The purpose of this paper is to help fill this gap in the literature.

Using a sample of U.S.- and Japanese-owned manufacturing plants in the United States in three different industries, we show that the implementation of JIT has improved many of the performance measures for these U.S. manufacturing plants.

***Index Terms*—Just-in-time manufacturing, manufacturing performance, production management practices.**

I. Introduction

SOME Japanese manufacturing industries, such as auto, electronics, and machinery, achieved high levels of international competitiveness in the 1980's. As a result, their manufacturing practices, particularly just-in-time (JIT) manufacturing, attracted the attention of North American manufacturers. JIT involves inventory and quality control, industrial relations, and supplier-manufacturer practices that differ from traditional North American business practices. Because of these differences, the transfer of JIT to North America in the original form developed by Toyota in Japan would have been difficult.

In comparison with North American management practices, Japanese business practices tend to emphasize long-term business relationships. This emphasis is particularly evident in employer-employee relationships and also in interfirm (for example, supplier-manufacturer) relationships. Long-term relationships are consistent with the economic incentives of firms, workers, banks, and other participants in the Japanese business system.[1] These long-term Japanese business practices have evolved as means of increasing the economic efficiency of firm and internal market operations in the specific context of the Japanese economy. Some of these practices, if transferred to the United States, would prove problematic in coping with external market issues such as individual rights, employment equity, and antitrust policies [35].

On the one hand, North American firms' difficulties in dealing with external market problems and associated legal restrictions over which they have little control may have impeded North American adoption of certain Japanese business practices, such as supplier-manufacturer relationships.

On the other hand, U.S. manufacturing firms do have control over their production methods and, to a lesser degree, the industrial relations on their own shopfloors. It is Japanese business practices in these areas that U.S. manufacturing firms spent substantial amounts of resources in the 1980's to transplant to their U.S. operations.[2] There is anecdotal evidence that the transfer of Japanese production methods has had a significant impact on the performance of U.S. manufacturing plants. There is, however, relatively little empirical evidence based on a broad sample of plants and workers from various manufacturing industries. The purpose of this paper is to help fill in this gap in the literature.[3]

In this paper, we estimate the impact of JIT practices on certain key manufacturing performance measures using a unique data set containing a sample of U.S. plants and their workers. Our sample covers three manufacturing industries and

Manuscript received June 1, 1996; revised March 2, 1997. Review of this manuscript was arranged by Guest Editors J. K. Liker and D. V. Gibson. M. Nakamura's work was supported in part by the Social Sciences and Humanities Research Council of Canada and in part by the Centre for International Business Studies at the University of British Columbia.

M. Nakamura is with the Faculty of Commerce, University of British Columbia, Vancouver, B.C. V6T 1Z2 Canada.

S. Sakakibara is with the Faculty of Business and Commerce, Keio University, Tokyo, Japan.

R. Schroeder is with the Carlson School of Management, University of Minnesota, Minneapolis, MN 55455 USA.

Publisher Item Identifier S 0018-9391(98)05251-9.

[1] See, for example, [2], [3], [35], and [40].

[2] The increasing interest in Japanese manufacturing is also reflected in the manufacturing literature, which addresses Japanese manufacturing methods. In 1982, only three authors wrote articles on JIT in English [49]. In the last half of the 1980's, more than 700 papers discussing JIT were published in English [22].

[3] The only exception is the auto-assembly industry, for which considerable empirical research has been done. (See, for example, [7], [26], and [30].) Our sample by design does not include the auto-assembly industry.

includes both U.S.-owned plants and Japanese transplants in the United States. We find that the implementation of JIT has had a statistically significant positive impact on many aspects of the performance of both U.S.- and Japanese-owned manufacturing plants in the United States.

The organization of the rest of the paper is as follows. The next section (Section II) discusses the practices that constitute JIT manufacturing as it has been adopted in the U.S. manufacturing sector. The relationships of these practices to various performance measures at the plant level are discussed from a theoretical perspective in Section III. Our model specifications and hypotheses are discussed in Section IV. Our data are described in Section V. In Section VI, we discuss our empirical results. The paper ends with concluding remarks in Section VII.

II. Japanese Manufacturing Methods

In designing its production system in the period from the late 1950's to the early 1960's, Toyota Motor Company decided that the type of mass-production system employed, for example, by General Motors (GM) could not be implemented in Japan because the small Japanese demand for automobiles would not allow the U.S.-style mass-production system to achieve the scale economies required for production efficiency. Toyota instead chose to develop a production system that minimizes the total production cost and achieves scale economies through the production of many differentiated products on the same production line.

Toyota perfected the Toyota Production System (also called the "Kanban" system or JIT system) in the early 1970's. After the first oil shock, Toyota emerged as the leading Japanese auto manufacturer. Toyota disseminated its JIT production management technology to other Japanese auto makers in the late 1970's [41]. By the end of the 1970's, all Japanese automakers had adopted JIT. In addition, JIT was widely adopted in various forms by Japanese manufacturers in other industries.

The JIT production system requires that all necessary parts and/or semifinished products be delivered to where they are needed, as they are needed, and in the quantities needed. (See, for example, [32], [41], and [51, ch. 16] for operational aspects of JIT manufacturing.)

In the Japanese context, JIT is closely tied to Japanese labor-market practices, such as long-term employment with a strong emphasis on internal labor markets,[4] and to supplier-manufacturer relationships, which involve loose but effective equity-based connections as exemplified by Japanese production-based (capital) *keiretsu* groups.

In the U.S. environment where JIT and other Japanese production management practices were adopted, there is little evidence that Japanese-style labor-market practices or capital keiretsu relationships were also introduced.[5] In transferring JIT to the United States, U.S. manufacturers as well as Japanese transplants distilled and implemented only those aspects of JIT that they deemed essential to improving their production efficiency.[6] This has led us to conclude that it is essential to identify those core practices that make JIT manufacturing work on the U.S. shopfloor. After our many plant visits and discussions with plant managers and workers, it became clear that JIT manufacturing in the United States is reasonably well characterized by the following JIT core practices:

- setup-time reduction;
- schedule flexibility;
- JIT maintenance;
- specific equipment layout configurations;
- kanban;
- pull system support;
- JIT supplier relationships.

Note that this list does not include any of the production management or business practices that are peculiar to the Japanese market and other circumstances in which the original Toyota system was established. The JIT manufacturing in the United States to be discussed below refers to this list of core JIT practices.

In assessing the impact of JIT manufacturing on production efficiency at either the plant or firm level in the United States, it is important to recognize that the marginal cost of implementing some of the core JIT practices is not likely to be higher than the marginal cost associated with alternative manufacturing practices (for example, material requirements planning methods). This is because the costs of JIT and the alternative manufacturing practices all depend to a large extent on the utilization of factory labor, and the total cost of labor does not vary much depending on whether JIT is used. Compared to alternative production methods, successfully implemented JIT is typically associated with more extensive utilization of labor and higher productivity.[7]

[4] Internal labor markets are emphasized in Japan via long-term employment practices, job rotations, multiskilled workers, and knowledge sharing on the shopfloor. In turn, these factors facilitate investment in firm-specific human capital. Also, Japanese production-based *keiretsu* group relationships help align the incentives of firms in these groups. For example, Toyota and its suppliers cooperate effectively in new-car development (see [40]). The Japanese implementation of JIT generally takes advantage of the presence of these practices.

[5] Considerable anecdotal evidence exists for this observation. The widespread long-term employment practice of which the Japanese implementation of JIT takes advantage, and the relative lack of active external labor markets for midcareer job seekers, have not spread to the United States. Active downsizing, massive layoffs of workers, and active hiring of experienced workers in the labor market describe the contemporary U.S. labor market. More emphasis is placed on outsourcing to cut cost by U.S. manufacturers and some U.S. assemblers in designing new products. For example, Nippon Denso participated in Chrysler's development of the Neon from the early stage of the product development. It is, nevertheless, unknown whether this is going to be a long-term pattern for Chrysler's new product development program. There is also no evidence that U.S. assemblers and their suppliers have entered Japanese capital-keiretsu style equity relationships. Such relationships may not be compatible with the U.S. antitrust regulations either.

[6] It is interesting to note that [53] explicitly recommends that Japanese firms attempt to transplant to their overseas plants only those aspects of JIT that are essential to their manufacturing operations. This is exactly what some U.S. corporations have done as well.

[7] In this sense, Japanese manufacturing methods may be viewed as methods that encourage workers to go the "one extra mile." (This is not, of course, peculiar to Japanese methods. All so-called good management methods share this property.) There are different theories that attempt to explain why workers are motivated to go one extra mile by certain management methods. These theories include the efficiency wage theory, gift exchange [1], risk sharing (as explained in [39]), and agency theory (as explained in [37]). Considerable criticism also exists regarding this speedup characteristic of JIT manufacturing as implemented in the auto industry. (See, for example, [4] and [43].)

Nevertheless, there are other sorts of costs required to implement core JIT practices: worker training, investment in research and development, and investment in capital equipment. For example, setup-time reduction and new equipment layout require a redesigning of production equipment. It is well known that significant portions of Japanese manufacturers' capital expenditures are allocated to the design and production of the machinery required for implementing new JIT production lines.

JIT manufacturing was first transferred successfully to the United States around 1980 at Kawasaki's Lincoln, NE, plant, where JIT manufacturing was applied to production of various models of motorcycles on a single line. Because the model mix was made to track the final demand approximately, this JIT-based mixed-model production resulted in reduced inventory. In motorcycle production, JIT allowed inventory turns (defined by sales/inventory) of about 20 to be achieved, compared with Figs. 3–5 for the traditional production setting [50], [51].

Since then, JIT has been widely adopted by many U.S. manufacturing firms. JIT also proved effective at New United Motor Manufacturing, Inc. (NUMMI), a 50–50 joint venture between Toyota and GM established in 1983. NUMMI took over most of the basic production equipment and the factory itself from GM's Fremont, CA, plant and implemented the Toyota Production System. The average number of labor hours needed to produce a standardized car (i.e., labor hours adjusted for the type of the car, the type of labor, and other relevant factors) went down from 29.1 h for the peak production period under GM management in 1978 to 19.6 h under NUMMI management in 1986 [26], [53]. This productivity gain at NUMMI was achieved with only a modest amount of new capital investment to complement the existing production facilities from the old GM factory. Furthermore, many of the NUMMI workers are actually former workers of GM's Fremont plant who were once among the most militant employees in the U.S. auto industry.

In addition to the Kawasaki and NUMMI cases noted above, a number of other examples of successful and unsuccessful applications of JIT to North American and European corporations have been reported (see, for example, [48]).

Early implementations of JIT in the United States were achieved despite frequently expressed concerns in the early 1980's about the applicability of JIT to U.S. manufacturing because of cultural and other country-specific obstacles (although [49] did point out the applicability of JIT to the United States). The widely publicized successful implementations of JIT in the United States, including the two examples noted above, suggest that the implementation of JIT core practices in the United States is associated with improved manufacturing performance in general. The purpose of this paper is to examine this hypothesis empirically.

III. JIT Practices and Manufacturing Performance Criteria

An important principle underlying JIT is eliminating waste throughout the production system [5], [55]. The waste can occur, for example, through excess inventories and overly large lot sizes, both of which can cause unnecessarily long customer lead times. [8], [49]. References [17] and [50] observed that simplifying manufacturing processes is an essential step in eliminating such waste.

We explain below the role of the core JIT practices in enhancing manufacturing performance.

Setup-time reduction requires the implementation of activities that facilitate the reduction of setup times. The reduction in setup time provides an economic basis for the implementation of small lot sizes, which allows plant production to more closely track customer demand[8] [19], [44].

JIT manufacturing requires scheduling of system-wide production plans based on customer-demand information that is fed into the last part of the assembly line. Such demand-driven scheduling is made possible by *pull system support* practices [20], use of a *kanban* card system [8], and *schedule flexibility* [18]. To achieve JIT manufacturing as a continuous production system in which one unit is the ideal lot size, *equipment layout* must be able to accommodate work cells,[9] and the *maintenance* of equipment must be largely delegated to shopfloor workers so that most routine repairs can be carried out immediately on site as the needs arise. Last, the system-wide nature of JIT manufacturing requires the establishment of *JIT supplier relationships* with suppliers that are able and willing to deliver the needed quantities of parts as the needs arise and without any defects.

A. Plant Manufacturing Performance Criteria

Although there are many dimensions of manufacturing plant performance, the following criteria are widely used. These are generally believed to be positively correlated with overall firm performance.

%Downtime measures the average percentage downtime of machines due to failure during a normal shift. The economic significance of this variable is that while a machine is down, there are financial losses from wages that must be paid despite the stoppage of work and from other ongoing costs. Since JIT emphasizes maintenance functions on the shopfloor, implementation of JIT is expected to improve this performance criterion.

%Passed measures the percentage of products that pass final inspection without rework. The cost of rework, which is an indication of quality problems somewhere in the manufacturing process, can be significant. Rework often requires a separate production line, which must be staffed and must be linked to inventories of parts and products associated with the rework function. As discussed below, implementation of JIT is not possible without achieving a high level of quality management. In fact, the level of quality usually aspired to with JIT implementation is zero defects.

[8] Toyota reduced its setup time for an 800-ton punch press for the hood and fender from 2–3 h in 1954 to 15 min in 1965 and then to 3 min in 1970. In 1970, the usual setup time for this type of press machine was thought to be several hours to a day in the United States.

[9] It is of interest to note that the idea of the work cell, which is an indispensable part of JIT manufacturing, was proposed by an American engineer, R. E. Flanders, in 1925 [11].

The following three criteria measure the time performance of manufacturing. This measure indirectly reflects a company's ability to manage quality and other essential functions such as orders and production runs.

%Shipped measures the percentage of orders that are shipped on time and hence the degree of customer satisfaction with on-time product delivery. Poor performance for this measure may well be associated with dissatisfied customers who may easily be lost to competitors. Such losses are reflected in declining sales. Because of the pull property of JIT manufacturing, propagation of a random shock to one part of a JIT system is less likely to be magnified into a major disturbance in other parts of the system. However, implementation of a JIT system also requires more predictable time estimates for the delivery of orders.

Cycle time measures the average total time in days from the receipt of raw materials until a customer receives the product, and hence reflects the overall efficiency of the production system, including inventory management and supplier and delivery operations. JIT manufacturing practices generally reduce the waiting (idle) time for raw materials and for semifinished and finished products in the production system. Such waiting time arises because of, for example, inventory and poor quality. For this reason, JIT manufacturing practices are thought to be effective for reducing cycle time.

Lead time measures the average time in days from the receipt of each order until the product is shipped, and hence measures the effectiveness of the production system in responding to a new order as well as in managing the production time. The pull nature as well as other characteristics of the JIT system are considered effective for reducing lead time.

Inv, defined as the ratio between total inventory and sales, measures the dollar amount of capital tied to inventories relative to the amount of sales. A reduction in inventory, if achieved without adversely affecting other performance criteria, is tantamount to freeing up capital tied up without a productive purpose, and hence is a very appealing goal. JIT practices are consistent with maintaining low plant inventory levels.

For manufacturing industries with significant numbers of repetitive operations, plant performance is likely to have a direct impact on these plant manufacturing performance criteria.[10] However, it is not likely that all of these performance criteria will receive equal priority from firm management. In fact, it is most likely that the weights attached to these criteria will vary from one manufacturing plant to another within the same company. This sort of variation in the degree of importance attached to different performance criteria often reflects differing strategic objectives. Given this sort of variation in the weights attached to different plant-performance criteria, the portion of the variation in the performance criteria that can be explained by systematic factors such as JIT manufacturing is expected to be small. (Note that our sample of plants in this study does not contain multiple plants from the same firm, and hence does not capture intrafirm variations.)

IV. Our Model Specifications and Hypotheses

The objective of this study is to obtain numerical estimates for the impact of JIT and some other production management policy variables on the plant-level manufacturing performance measures discussed above. The most important policy variables in this study are the following dummy variables representing the state of JIT practice at a plant: 1) a dummy variable set equal to one if core JIT practices are implemented with limited scope (limited JIT) in a plant and 2) a dummy set equal to one if core JIT practices are implemented on a plant-wide basis (full JIT). More specifically, limited JIT describes a situation in which all core JIT practices are implemented for some but not all operations and/or products produced in the plant. On the other hand, full JIT describes a situation in which the plant has implemented all core JIT practices for all relevant operations and product lines. As discussed above, these JIT dummy variables are believed to be positively related to plant-performance criteria. Therefore, our primary hypothesis to be tested in this study is the following.

Hypothesis: JIT practices improve manufacturing performance.

Even though we have *a priori* reasons to believe that the introduction of a limited JIT operation will improve plant performance, this hypothesis must be verified empirically. Since most plants start their JIT manufacturing with a limited scope (i.e., limited JIT) before moving to a full JIT operation, it is of considerable practical interest to verify empirically that limited JIT improves plant performance even before full JIT operation is introduced. For this reason, we include both limited and full JIT dummies in our specifications.

In addition to the JIT policy dummies, there are some other production management policy variables that may affect the performance criteria. Even though our primary interest in this study is to measure the effects of the JIT policy dummies, it is important to control for the effects of other measurable factors that may have important effects on plant performance. There are theoretical reasons to believe that these plant policy variables are correlated with the implementation of JIT. Thus, omitting these variables would result in biased coefficients estimates because the regression error term would include the effects of these (omitted) variables.[11]

We include the policy control variables for quality management practices, worker training for multitasks, implementation of machine breakdown charts, and a team approach. These variables are discussed below.

1) Quality Practices and JIT: The importance of quality management (QM) practices for the successful implementation of JIT has been recognized since the outset of the introduction of JIT to the United States in the early 1980's. QM is defined as an integrated approach to achieving and sustaining high-quality output, focusing on the maintenance and continuous

[10] Cycle time is also an important performance measure for new-product development. For example, [21] finds that, on average, companies lose 33% of after-tax profit when they ship new products six months late, as compared with losses of 3.5% when they overspend 50% on product development.

[11] We thank a referee for pointing out the omitted variable issue in the context of our model. See [33] and [34] for the econometric issues related to this type of specification error.

improvement of processes and defect prevention at all levels and in all functions of the organization, in order to meet or exceed customer expectations [13].

There is extensive literature on the importance of QM to JIT manufacturing (for example, [32] and [49]). Reference [21] notes that QM practices provide support for JIT by establishing control over the manufacturing process. This control facilitates the unhampered flow of goods through the production process and allows buffer inventory reduction [56]. The JIT focus on inventory reduction readily exposes QM problems that are due to manufacturing process problems [9], [57]. Also, QM provides accurate and timely feedback about the manufacturing process, permitting shopfloor personnel to detect, diagnose, and remedy process problems as they occur. Both JIT and QM require the cooperation, coordination, and integration of many different functions within the organization [49].

Yet, the empirical evidence for the relationships between manufacturing performance and JIT and QM practices is scarce. We discuss below how, within our research framework, QM practices enter our empirical specifications for manufacturing performance.

We note that there is a fundamental conceptual difference between JIT and QM practices. On the one hand, JIT practices, as originally proposed, explicitly strive to reduce total direct and indirect production cost, as well as the opportunity costs attributable to the loss of customers due to poor product or delivery quality. JIT inventory control, for example, aims to maintain the inventory level at close to zero, with an immediate objective of reducing the capital tied to the inventories.

On the other hand, at least some QM practices are implemented by firms without considering their effects on cost. For example, there is anecdotal evidence that some firms have focused excessively on quality product design and customer satisfaction, both of which are important QM practices, to the extent that the total financial cost of their activities has become a concern to firm management. Although certain statistical quality-control methods such as sampling inspection, sequential tests, and Taguchi methods [51] account for cost explicitly, the connection between modern QM practices of the sort we discuss here and plant or firm performance is not well established. Reference [24] states:

> A vigorous debate centers on a fundamental question of corporate management: Is total quality management a fad, or a fundamentally better way of managing economic resources and competing globally? The problem is that the obvious response is "yes" nearly as often as it is "no." Both sides tend to refer to the debate as though the data have been collected and analyzed, and their view supported . . . we have been unable to uncover a single piece of research that we could describe as empirical. There are lots of anecdotal stories and case studies, but no empirical studies.

Using their own estimates, Jarrell and Easton [24] conclude that firm market value is not worsened by adoption of total quality management.

QM involves a few relatively simple concepts and an amorphous array of peripheral associated practices [9]. Following the analysis of our data and discussions with the managers of the plants we visited, we concluded that the following three quality management practices generally constitute the core of QM at U.S. plants: *statistical process control*, *product design*, and *customer focus*. These core QM practices are briefly discussed below.

To operate a production process reliably, regardless of a fluctuating manufacturing environment, process quality control requires mechanisms for statistical process control as well as foolproof and self-inspection. The use of statistical process control by employees would provide them with incentives to deal with early signals of potentially damaging equipment failure. (Previous research shows that self-provided information is positively related to performance [23], [52].) Early detection of equipment failure would allow preventive maintenance to take place [15]. Designing quality into the product, rather than inspecting defects out, is a primary tool of QM. As much as 80% of all product failure is estimated to result from product design defects [10]. Customers, as the ultimate judge of a plant's quality performance, can provide valuable inputs into product design by expressing what they need and want. They can also provide feedback about the quality performance of the plant's production process. This customer focus can be achieved, for example, by including customers as members of product design teams [50] and by setting up a customer review board to test and evaluate products from the customers' perspective [16].

We define a plant policy variable, quality, representing the state of QM implementation at a plant. This dummy variable is set equal to one if all three core QM practices are implemented for all product/operation lines, and set equal to zero otherwise. We hypothesize that, after controlling for the effects of the JIT practices on manufacturing performance, the quality dummy may have at most limited power for explaining the plant manufacturing performance. This is because, for the reasons discussed above, the JIT practices by definition are likely to be more closely (and positively) correlated with overall manufacturing performance than the QM practices.[12]

2) Other Shopfloor Practices: Successful JIT implementation is also thought to require the implementation of certain shopfloor practices that facilitate the JIT practices. In this category, we include the following variables for which we have data: multitask training, a team approach, and the presence of machine breakdown charts.

JIT emphasizes workers' multitask abilities. For example, JIT production often utilizes work cells requiring multiskilled workers. Preventive maintenance of equipment by production staff also requires workers to become familiar with both production and maintenance tasks.

Teamwork and group problem solving are an integral part of JIT manufacturing. The aim is to achieve decentralized

[12] Using the same data base as ours, Flynn *et al.* [13] empirically analyze the statistical relationship between the core JIT and QM practices. Their results, based on canonical correlations, show positive correlation between these two sets of practices and some evidence of the direction of (statistical) causality from JIT to QM practices. For example, setup and lot size reductions, among other JIT practices, may force quality levels to improve, after controlling for performance. This implies that JIT cannot succeed without QM.

decision making. Among other things, decentralization is believed to be useful for dealing with certain types of uncertainty [6], [14].

One of the innovative aspects of JIT manufacturing is the associated information flow pattern: a horizontal flow rather than the vertical (hierarchical) flow typical of traditional material requirements planning systems [2]. One of the implications of this horizontal flow is that process as well as quality information is collected at the source, where immediate problem-solving action can be taken [28]. Breakdown charts, which display information on machine breakdown frequency, are often a part of this sort of setup.

3) Transplant and Industry Dummies: There is interest in how the national identity of a firm (U.S. versus Japanese in this paper) and industry affects the results of JIT adoption. Therefore, we include Japanese transplant and industry dummies in our specifications. In contrast to our research, most published research on the comparison between Japanese transplants and U.S. plants focuses on the Japanese-style shopfloor practices themselves and does not relate them to plant performance. Furthermore, many studies are based on case studies of some selected firms, limiting the general applicability of the research findings.

In this study, we focus on three industries: machinery, electronics, and auto parts (but not auto assembly because considerable empirical research already exists for that industry). Using a broad sample of manufacturing plants, our objective is to test whether JIT manufacturing has improved U.S. manufacturing performance.

Some studies suggest more successful implementation of JIT and other Japanese manufacturing practices at Japanese transplants compared to U.S.-owned plants. In the empirical section of this paper, we pay special attention to this issue.

In summary, the specification of our model is as follows. Multiple manufacturing performance measures are the dependent variables. The explanatory variables of primary interest are the JIT policy dummies. QM and other shopfloor practice variables are included as control variables. It should be pointed out that we do not deal with the interactions among different types of policy variables such as JIT, QM, and other industrial relations variables.[13] Nor do we deal with the directions of causality among these different types of plant manufacturing policies.

V. DATA

Our sample consists of 40 plants that were operational in 1989 in the U.S. machinery, electronics, and auto parts industries. No large integrated or diversified assembler firms (such as the Big Three auto makers, General Electric, and IBM) are included. Of the 40 sampled plants, 27 are U.S. owned, while 13 are owned by Japanese firms. Of the U.S.-owned plants in our sample, 15 are viewed as being progressive and world class (as defined by [50]), while the remaining 12 plants are regarded as traditional U.S.-owned manufacturing plants. All plants were selected at random from master lists of plants with at least 100 employees. The master lists for U.S. traditional and world-class plants, and for Japanese transplants, were created using, respectively, *Dun's Industrial Guide: the Metalworking Directory, Schonberger's Honor Roll,* and a Japan External Trade organization list of Japanese transplants in the United States.[14] In the estimated equations, we do not distinguish between U.S. owned plants that are classified as traditional and those that are classified as world class. However, having these different types of U.S. plants (as well as the Japanese transplants) represented in our sample should contribute to the generality of the results obtained.

The manager of each plant in our sample appointed a plant research coordinator who became responsible for selecting workers and supervisors at random from the entire plant, distributing the managerial questionnaires to the appropriate respondents, and collecting the questionnaires. The questionnaires for managers contain questions about the plant itself, including plant performance. The data for our performance measures and the plant policy variables (limited JIT, full JIT, and QM dummies) were acquired in this way.[15]

The questionnaires distributed to workers and supervisors also include perception variables. Workers' perception variables are scaled as follows: one for "I strongly disagree" to five for "I strongly agree." In this study, three perception variables are included as explanatory variables. The data for these variables are the ratings given by the randomly selected workers and supervisors to the following statements: 1) employees in this plant receive training to perform multiple tasks (multitask), 2) promotion implies team participation and experiences with the firm (team), and 3) charts plotting the frequency of machine breakdowns are posted on the shopfloor (breakdown charts). Though plant management usually has stated policies regarding these issues, workers and supervisory personnel may not necessarily perceive these policies to be effectively implemented on the shopfloor. Our perception variables allow for possible differences in perspective between workers and management. Tables II and III in the Appendix give descriptive statistics for our data as well as the number of usable questionnaires returned. (See [12], [13], and [46] for further details on our data and their use in empirical operations management research.)

[13] Such interactions are discussed, for example, in [47].

[14] The selected plants were directly contacted, and those that agreed to be surveyed were included in the sample. The few plants that declined to be surveyed were replaced by plants of the same type that agreed to be surveyed. A significant amount of time was spent explaining our questionnaires to managers of the sample plants during our visits to many plants in the sample and also by telephone conversations for a few sample plants that we did not visit. Hence, we have not experienced the problem of low response rate.

[15] In this paper, managers' understanding of QM and JIT practices determines the quality of our dummy variables representing the status of quality management and JIT practices. Our QM dummy is set equal to one if the core QM practices (statistical process control, product design, and customer focus) are all practiced for all plant product lines. Full JIT dummy is set equal to one if the core JIT practices are all implemented for all the products being produced at the plant. Limited JIT dummy is set equal to one if the core JIT practices are all implemented for some but not all of the products being produced at the plant. We spent a considerable amount of time explaining the definition of each of the QM and JIT practices to plant managers. It is our estimate that the majority of the sample plant managers have understood these definitions in responding to our questionnaires.

TABLE I
THE EFFECTS OF JIT AND OTHER VARIABLES ON PLANT PERFORMANCE MEASURES

	%downtime (-)[c]	%passed (+)	%shipment (+)	cycle time (-)	lead time (-)	inv (-)
constant	18.8***[b] (9.79)	89.0*** (19.9)	61.7*** (5.30)	159.3*** (5.08)	100.9*** (2.68)	.135** (2.00)
JIT:limited	-11.4*** (7.04)	2.71 (1.06)	10.4* (1.65)	-60.1*** (3.87)	-65.0** (1.92)	-.111*** (2.90)
JIT:full	-12.0*** (7.71)	4.93** (2.44)	5.89 (.84)	-90.3*** (5.73)	-82.8*** (2.99)	.056 (1.20)
quality	-1.70** (2.38)	-.164 (.08)	25.7*** (2.65)	17.9 (1.12)	-16.9 (.68)	.064 (1.42)
multitask	-.156 (.44)	.468 (.509)	1.23 (0.55)	8.31 (1.43)	-6.48 (.95)	.066 (.54)
team	.064 (.310)	-1.43 (1.35)	-2.40 (.95)	-0.94 (.127)	12.4 (1.36)	-.012 (.72)
breakdown charts	-.288 (.982)	1.85*** (2.72)	2.64* (1.78)	-13.1*** (2.64)	-1.09 (.20)	.014 (.90)
J-transplant	-.914 (.896)	-1.07 (.547)	2.02 (.34)	6.81 (.53)	-.81 (.04)	-.054** (1.99)
U.S. owned	--	--	--	--	--	--
machinery	1.08 (1.30)	-7.09*** (3.49)	-9.28** (2.19)	-6.01 (.45)	16.4 (1.00)	.108* (1.81)
auto parts	2.48*** (4.69)	.834 (.49)	-16.33** (3.53)	-24.2** (2.51)	-9.75 (.66)	.009 (.32)
electronics	--	--	--	--	--	--
R^2 (R^2adj)	.38(.36)	.36(.29)	.32(.24)	.42(.26)	.25(.18)	.21(.12)
N	93	102	99	102	102	97

[a] See the text for the definitions of the performance measures and included explanatory variables.
[b] Numbers in parentheses are heteroscedasticity-corrected t ratios. One, two and three asterisks imply 10%, 5% and 1% significance levels, respectively.
[c] The signs in parentheses indicate the desired directions for the respective performance measures to move.

VI. EMPIRICAL RESULTS

A. Determinants of Plant Performance

Our performance measures for assessing a plant's manufacturing operations are:

1) average percentage downtime of machines due to failure during normal shifts (%downtime);
2) percentage of products that pass final inspection without rework (%passed);
3) percentage of orders that are shipped on time (%shipped);
4) average total cycle time measured in days from the receipt of raw materials until a customer receives the product (cycle time);
5) average lead time measured in days from the receipt of each order until the product is shipped (lead time);
6) ratio of total inventory to sales (inv) (as described in Section III).

For the types of manufacturing industries where Japanese manufacturing methods are thought to be effective, these plant performance measures are important indicators of overall firm performance. (In this paper, economic tradeoffs associated with these performance measures considering firms' overall optimization processes are not discussed. The variation in weights attached to different performance measures among firms is likely to add noise to our estimation task.)

The plant performance measures defined above are regressed on a plant manufacturing policy variable, plant dummies, and industry dummies.

The plant manufacturing policy dummy variables that are included are: 1) a dummy variable equal to one if JIT is implemented on a limited scope (limited JIT), 2) a dummy variable equal to one if plant-wide JIT is implemented (full JIT) (as described in Section IX), and 3) a dummy variable equal to one if quality management practices are implemented (QM) (as described in Section IX).

Our estimation results are presented in Table I. The policy variables of primary interest, full JIT and limited JIT, are often statistically significant and have the expected signs. This result suggests that the implementation of JIT generally leads to significant improvements in various plant performance measures. In the equations where both limited and full JIT are significant (the equations for %downtime, cycle time, and lead time), the coefficients of full JIT are consistently larger in magnitude than the coefficients for limited JIT. This is what might be expected if JIT improves plant performance.[16]

Implementation of quality management is found to decrease %downtime and increase %shipment. In fact, the estimated effect of QM on the latter is larger in magnitude and more significant than the effects of both limited and full JIT. (Implementing QM increases %shipment by 25.7%, while implementing limited JIT increases %shipment by 10.4%, and the associated coefficient for full JIT is not significantly different from zero. The quality dummy is significant at a 1% level, while limited JIT is significant only at a 10% level.) One possible reason for the importance of QM for %shipment is that %shipment (%orders that are shipped on time) affects customer satisfaction, which is also closely related to QM. (In fact, a customer focus is necessary for the QM dummy to be one.) In contrast, the primary connection of the core JIT practices to customers is via the demand for the plant's final product, which is attributable to product performance. Thus, the quality dummy seems to contain certain information that is not contained by the JIT practice dummies.[17]

Neither the multitask nor the team variables seem to have statistically significant effects on the performance measures after controlling for JIT and quality management. On the other hand, having breakdown charts seems to significantly increase %passed and %shipped and seems to significantly reduce cycle time. However, the improvements for the breakdown charts are smaller than the improvements for the JIT dummies. The breakdown charts are used for inducing workers' cooperation in improving quality by providing them with relevant and easy-to-understand information on the existing quality problems. The high value of this variable is believed to reflect success in inducing workers' cooperation on the shopfloor. While this cooperation is thought to be important for successful implementation of JIT, our JIT dummies are not expected to fully capture the effects of workers' perceptions and the success of information exchange mechanisms. We believe that this omission is the reason why our breakdown chart variable is such an important determinant of some of our performance measures even after controlling for JIT practices.

The Japanese transplant dummy is significant in the equation for INV. Specifically, the inventory-to-sales ratios are 5.4% less for Japanese transplants than for U.S.-owned plants. This difference may reflect Japanese firms' emphasis on carrying as little inventory as possible and is consistent with earlier findings that Japanese manufacturers tend to carry less inventory than U.S. manufacturers [38].

For the remaining performance measures, we have found little evidence that Japanese transplants are superior to U.S.-owned plants. The finding that, on average, the Japanese transplants are not superior to the U.S.-owned plants in several of our performance measures is new. Also, there is little existing empirical evidence comparing transplants and U.S.-owned plants on a broad range of performance measures such as the ones being considered here.[18] This is particularly true for manufacturing industries. The exception is the auto-assembly industry, for which there is empirical evidence of this sort. Since our sample does not include auto-assembly plants, our results complement the existing empirical evidence for that industry.

The behavior of the transplant dummy in our regression equations is also consistent with the descriptive statistics for our sample. Our descriptive statistics show that the performance measures for the Japanese transplants are not better than those for the U.S.-owned plants in our sample that satisfy Schonberger's [50] criteria for world-class manufacturers. [See Table II for mean values for our performance measures for all the transplants as well as world-class plants á la Schonberger, and for the rest of U.S.-owned ("traditional") plants].

It is also interesting to note that the average after-tax profitability of Japanese manufacturing transplants in manufacturing industries located in the United States has been low (close to zero) compared to Japanese transplants in other parts of the world, particularly Asia (see [36] and [40]). Furthermore, a U.S. government study confirms that the profitability of Japanese transplants in the United States is low compared to domestic U.S. firms' profitability [27]. Our performance measures for Japanese transplants seem consistent with these existing findings.[19] There is considerable variation in plant performance measures for the three industries included in our sample: machinery, electronics parts (omitted category in Table I), and auto parts. The industry dummies account for these industry differences. In particular, these dummies account for intrinsic differences among the three industries, which lead to different industry standards. Compared to the U.S. electronics industry, the machinery industry performs poorly in the areas of %passed, %shipped, and inv, while the auto parts industry performs better in cycle time but poorly in %downtime and %shipment.

While our results suggest that JIT practices are effective in improving a wide range of performance measures for

[16] Regressions were also run without limited JIT dummy. The results were similar with full JIT dummy absorbing some of the effects of the limited JIT dummy variable. This underscores the importance of controlling for limited JIT practice in our specifications. In particular, our specifications allow us to observe the degree of usefulness of implementing limited JIT.

[17] We also ran regressions with interaction terms between full JIT and QM dummies. The interaction terms are often significant with expected signs but do not increase the explanatory power of the regressions significantly. More research is clearly needed to identify the mechanisms by which JIT and QM practices interact.

[18] The auto-assembly industry is the only exception where there is both anecdotal and some systematic empirical evidence suggesting an improvement in the manufacturing performance for the Big Three in such areas as development time, quality, labor hours, and cost of production as a result of adopting JIT and other Japanese practices [26] and [29].

[19] One potentially important practical issue yet to be investigated is why Japanese transplants' low inventory levels compared to those of U.S. plants do not lead to better plant performance by transplants. One possible reason may be that their first-tier suppliers carry more than optimal inventories. This is possible given the difficulty Japanese firms are having in establishing their supplier networks. We thank a referee for bringing this issue up to us.

TABLE II
DESCRIPTIVE STATISTICS

	All[b]	US	US-WC	US-T	J
%downtime[c]	5.25 (6.4)	4.98(5.9)	3.93 (3.0)	6.08 (8.3)	6.00 (7.4)
%passed[c]	80.0 (32)	80.9(29)	76.6 (33)	85.0 (28)	79.3 (36)
%shipment[c]	75.7 (35)	72.5(35)	66.9 (42)	79.0 (24)	82.8 (35)
cycle time[c]	57.2 (64)	54.5(51)	31.1 (35)	84.1 (55)	62.7 (86)
lead time[c]	49.3 (79)	46.3(88)	16.3 (16)	82.4 (125)	56.5 (56)
inv[c]	.19 (.18)	.22(.19)	.21 (.30)	.22 (.10)	.15 (.11)
JIT:limited[c]	.32	.45	.40	.50	.08
JIT:full[c]	.47	.40	.60	.17	.62
quality[c]	.80	.81	1.00	.58	.77
multitask[d]	2.45 (.99)	2.45(.98)	2.37 (.99)	2.59 (.98)	2.43 (1.01)
breakdown chart[d]	3.63 (1.07)	3.71(1.02)	3.50 (1.10)	3.85 (.90)	3.55 (1.16)
team[d]	2.43 (.85)	2.42(.88)	2.67 (.89)	2.28 (.88)	2.29 (.77)
worker	.47	.47	.46	.48	.47
plant type	1.00	.68	.38	.30	.32
machinery	.33	.32	.27	.42	.31
electronics	.40	.43	.47	.42	.31
auto parts	.27	.25	.26	.17	.38

[a] See the text for the definitions of these variables.
[b] Plant types (defined in the text) are: U.S. owned world class (WC), U.S. owned traditional (T) and Japanese owned (J).
[c] These variables are defined at the plant level.
[d] These variables represent workers' responses to questions in our questionnaires.

TABLE III
NUMBER OF USABLE QUESTIONNAIRES RETURNED

	Machinery		Electronics		Transportation Components	
	Mgmt	Workers	Mgmt	Workers	Mgmt	Workers
U.S. owned						
	95	90	138	117	76	66
Japanese transplants						
	43	45	32	30	52	38
Total	138	135	170	147	128	104

manufacturing plants in the United States, they also raise some interesting questions regarding the different roles JIT, quality management, and breakdown charts play in determining U.S. manufacturing performance.

VII. Concluding Remarks

Toyota disseminated its just-in-time production system to other Japanese firms in the late 1970's [41]. JIT was quickly adopted by Japanese manufacturers, not just in the auto industry but in other manufacturing industries as well. Starting in the early 1980's, there was a massive transfer of JIT production methods from Japanese to U.S. manufacturers. This transfer took place in various forms. It began with Japanese transplants and joint ventures involving U.S. and Japanese firms. Then, many U.S. firms independently began adopting JIT.

It is particularly noteworthy that U.S. firms expressed relatively little concern about potentially country-culture-specific aspects of JIT while pouring massive efforts into establishing their own JIT production systems. This strategy may have resulted from the relatively transparent nature of the JIT approach, which made it more feasible for corporations outside of Japan to develop their own custom-fit JIT systems.

There is considerable anecdotal evidence that adoption of JIT has improved certain measures of manufacturing performance in the auto-assembly industry in the United States. This does not imply, however, that JIT has improved performance in other U.S. manufacturing industries; and empirical evidence on this issue has been lacking.

In this paper, we provide empirical evidence based on a broad sample of U.S. manufacturing plants in the machinery, electronics, and auto parts industries that JIT can indeed improve six measures of manufacturing plant performance. These six measures capture different aspects of manufacturing performance, and there is no *a priori* reason why adoption of JIT would necessarily be effective in improving any one of them.

JIT practices, however, are not uniformly effective in improving our six performance measures. In particular, JIT is only marginally effective in improving the percentage of orders that are shipped on time (%shipment). Quality management practices are much more effective in improving this performance measure than JIT. We have argued that the customer focus aspects (for example, achieving customer satisfaction) of QM may be the relevant QM factors for improving %shipment.

The dummy variable for breakdown charts, interpreted as a worker perception variable representing the voluntary transmission of equipment repair requirement information on the shopfloor, is also found to be related to improved values for three of the six performance measures, after controlling for JIT, QM, and other variables.

The findings of this study suggest that while JIT practices play an integral role in improving manufacturing performance, JIT alone will not result in optimal plant performance. QM practices emphasizing customer focus and satisfaction, and mechanisms for facilitating workers' shopfloor communication, such as breakdown charts, are also necessary.

We have found significant differences in performance by industry, but we are unable to provide consistent explanations for the observed industry differences.

Last, we have found that Japanese transplants are not generally superior to U.S.-owned plants with respect to our performance measures. That is, Japanese transplants have no discernible performance advantage over U.S. plants, controlling for JIT preparation. This finding is consistent with the existing evidence that Japanese transplants in the United States are not profitable compared to U.S. domestic firms. However, inventory levels for the transplants are better than those for U.S.-owned plants.

APPENDIX

See Tables II and III.

REFERENCES

[1] G. A. Akerlof, "Gift exchange and efficiency-wage theory: Four views," in *Proc. Amer. Econ. Rev.*, vol. 74, pp. 79–83, 1984.

[2] M. Aoki, *Information, Incentives, and Bargaining in the Japanese Economy*. New York: Cambridge Univ. Press, 1988.

[3] ——, "Toward an economic model of the Japanese firm," *J. Econ. Lit.*, vol. 28, pp. 1–27, 1990.

[4] S. Babson, "Lean production and labor: Empowerment and exploitation," in *Lean Work: Empowerment and Exploitation in the Global Auto Industry*, S. Babson, Ed. Detroit, MI: Wayne State Univ. Press, 1995, pp. 1–37.

[5] K. A. Brown and T. R. Mitchell, "A comparison of just-in-time and batch manufacturing," *Academy of Management Journal*, vol. 34, pp. 906–917, 1991.

[6] P. Collins, G. Hage, and F. Hull, "Organizational and technological predictors of change in automaticity," *Acad. Manage. J.*. vol. 31, pp. 512–543, 1988.

[7] J. Cutcher-Gershenfeld, M. Nitta, B. Barrett, N. Belhedi, J. Bullard, C. Coutchie, T. Inaba, I. Ishino, S. Lee, W.-J. Lin, W. Mothersell, S. Rabine, S. Ramanand, M. Strolle, and A. Wheaton, "Japanese team-based work systems in North America: Explaining the diversity," *Calif. Manage. Rev.*, vol. 37, pp. 42–64, Fall 1994.

[8] J. A. Davy, R. E. White, N. J. Merritt, and K. Gritzmacher, "A derivation of the underlying constructs of just-in-time management system," *Acad. Manage. J.*, vol. 35, pp. 653–670, 1992.

[9] J. W. Dean and S. A. Snell, "Integrated manufacturing and job design," *Acad. Manage. J.*, vol. 34, pp. 776–804, 1991.

[10] S. E. Fawcett, "The Japanese challenge," *Oper. Manage. Rev.*, vol. 7, pp. 46–52, 1989.

[11] R. E. Flanders, "Design manufacturer and production control of a standard machine," *Trans. ASME*, vol. 46, pp. 28–37, 1925.

[12] B. B. Flynn, S. Sakakibara, R. G. Schroeder, K. A. Hates, and E. J. Flynn, "Empirical research methods in operations management," *J. Oper. Manage.*, vol. 9, pp. 250–284, 1990.

[13] B. B. Flynn, R. G. Schroeder, and S. Sakakibara, "A framework for quality management research and an associated measurement instrument," *J. Oper. Manage.*, vol. 11, pp. 339–366, 1994.

[14] J. Galbraith, *Designing Complex Organizations*. Reading, MA: Addison-Wesley, 1973.

[15] D. A. Garvin, "Quality on line," *Harvard Bus. Rev.*, vol. 61, pp. 64–75, 1983.

[16] ——, "Japanese quality management," *Columbia J. World Bus.*, vol. 19, pp. 3–12, 1984.

[17] R. W. Hall, *Zero Inventories*. Homewood, IL: Dow Jones-Iewin, 1983.

[18] ——, *Attaining Manufacturing Excellence*. Homewood, IL: Business One Irwin, 1988.

[19] R. L. Harmon and L. D. Peterson, *Reinventing the Factory: Productivity Breakthroughs in Manufacturing Today*. New York: Free Press, 1990.

[20] R. H. Hayes, "Why Japanese factories work," *Harvard Bus. Rev.*, vol. 59, pp. 56–66, 1981.

[21] C. H. House and R. L. Price, "The return Map: Tracking product teams," *Harvard Bus. Rev.*, Jan.–Feb. 1991, pp. 92–100.

[22] R. A. Inman and S. Mehra, "The transferability of just-in-time concepts to American small businesses," *Interfaces*, vol. 20, pp. 30–37, 1990.

[23] S. Jackson and S. Zedeck, "Explaining performance variation: Contribution of goal setting, Task Characteristics and Evaluative Contexts," *J. Appl. Psychol.*, vol. 67, pp. 759–768, 1982.

[24] S. L. Jarrell and G. S. Easton, "An exploratory empirical investigation of the effects of total quality management performance," presented at the Field Studies in Quality Conference, University of Rochester, Rochester, NY, Mar. 1993.

[25] K. Koike, "Skill formation systems in the U.S. and Japan: A comparative study," in *The Economic Analysis of the Japanese Firm*, M. Aoki, Ed. Amsterdam, The Netherlands: North-Holland, 1984, pp. 47–75.

[26] J. F. Krafcik, "Triumph of the lean production system," *Sloan Manage. Rev.*, pp. 41–52, Fall 1988.

[27] S. Landefld, A. M. Lawson, and D. B. Weinberg, "Rates of return on direct investment," *Survey Current Bus.*, Aug. 1992, pp. 79–86.

[28] S. M. Lee and M. Ebrahimpour, "An analysis of Japanese quality control systems: Implications for American manufacturing firms," *SAM Advanced Manage. J.*, pp. 24–31, Spring 1985.

[29] J. K. Liker, R. R. Kamath, S. N. Wasti, and M. Nagamachi, "Integrating suppliers into fast-cycle development," in *Engineered in Japan: Japanese Technology Management Practices*, J. K. Liker, J. E. Ettlie, and J. C. Campbell, Eds. New York: Oxford Univ. Press, 1995.

[30] J. P. MacDuffie and T. A. Kochan, "Do U.S. firms invest less in human resources? Training in the world auto industry," *Ind. Rel.*, vol. 34, pp. 147–168, Apr. 1995.

[31] I. Majima, *The Shift to JIT (JIT Kakumei)*. Tokyo: Nikkan Kogyo Shimbun, 1988.
[32] Y. Monden, "Adaptable Kanban system helps Toyota maintain just-in-time production," *Ind. Eng.*, pp. 29–46, May 1981.
[33] A. Nakamura and M. Nakamura, "On the relationships among several specification error tests by Durbin, Wu and Hausman," *Econometrica*, vol. 49, pp. 1583–1588, 1981.
[34] ——, "On the performance of tests by Wu and Hausman for detecting the ordinary least squares bias problem," *J. Econometrics*, vol. 29, pp. 213–223, 1985.
[35] M. Nakamura, "Japanese industrial relations in an international business environment," *North Amer. J. Econ. Finance*, pp. 225–251, 1993.
[36] M. Nakamura, "Japanese direct investment in Asia-Pacific and other regions: Empirical analysis using MITI survey data," *Int. J. Prod. Econ.*, vol. 25, pp. 219–229, 1991.
[37] M. Nakamura and O. Hubler, "Determinants of bonus share of pay in Germany, Japan and the U.S.," *Jpn. World Econ.*, vol. 10, pp. 221–232, 1998.
[38] M. Nakamura and A. Nakamura, "Inventory management behavior of American and Japanese firms," *J. Jpn. Int. Econ.*, vol. 3, pp. 270–291, 1989.
[39] ——, "Risk behavior and the determinants of bonus versus regular pay in Japan," *J. Jpn. Int. Econ.*, vol. 5, pp. 140–159, 1991.
[40] M. Nakamura and I. Vertinsky, *Japanese Economic Policies and Growth: Implications for Businesses in Canada and North America*. Edmonton, Canada: University of Alberta Press, 1994.
[41] T. Ohno, *Toyota Production System: Beyond Large-Scale Production (Toyota Seisan Hoshiki-Datsu kibo no keiei o mezashite)*. Tokyo, Japan: Diamond Publishing, 1978.
[42] P. Osterman, "Supervision, discretion, and work organization," in *Proc. Amer. Econ. Rev. Papers*, 1994, vol. 84, pp. 380–384.
[43] M. Parker and J. Slaughter, "Union and management by stress," in *Lean Work: Empowerment and Exploitation in the Global Auto Industry*, S. Babson, Ed. Detroit, MI: Wayne State Univ. Press, 1995, pp. 41–53.
[44] E. L. Porteus,, "Optimal lot sizing, process quality improvement and setup cost reduction," *Oper. Res.*, vol. 34, pp. 137–144, 1986.
[45] S. Sakakibara, B. B. Flynn, R. G. Schroeder, and W. T. Morris, "The impact of just-in-time manufacturing and its infrastructure on manufacturing performance," Working Paper, Carlson School of Management, University of Minnesota, 1993.
[46] S. Sakakibara, B. B. Flynn, and R. G. Schroeder, "A framework and measurement instrument for just-in-time manufacturing," *Prod. Oper. Manage.*, 1994, forthcoming.
[47] S. Sakakibara, B. B. Flynn, R. G. Schroeder, and W. T. Morris, "The impact of just-in-time manufacturing and its infrastructure on manufacturing performance," *Manage. Sci.*, to be published.
[48] A. Satir, Ed., *Just-in-Time Manufacturing Systems*. Amsterdam, The Netherlands: Elsevier, 1991.
[49] R. J. Schonberger, *Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity*. New York: Free Press, 1982.
[50] ——, *World Class Manufacturing*. New York: Free Press, 1986.
[51] R. G. Schroeder, *Operations Management: Decision Making in the Operations Function*, 4th ed. New York: McGraw-Hill, 1993.
[52] C. Shalley, G. Oldham, and J. Porac, "Effects of goal difficulty, goal setting method and expected external evaluation on intrinsic motivation," *Acad. Manage. J.*, vol. 30, pp. 553–566, 1987.
[53] H. Shimada, *The Economics of Humanware: Japanese Corporations in the U.S. (Human ware no keizai gaku: america no naka no nihon kigyo)*. Tokyo, Japan: Iwanami, 1988.
[54] H. Shimada and J. P. Macduffie, "Industrial relations and 'humanware,'" Working Paper, Sloan School of Management, Massachusetts Institute of Technology, Cambridge, 1986.
[55] Y. Suginori, K. Kusunoki, F. Cho, and S. Uchikawa, "Toyota production system and Kanban system," *Int. J. Prod. Res.*, vol. 15, pp. 553–564, 1977.
[56] H. Takeuchi and J. A. Quelch, "Quality is more than making a good product," *Harvard Bus. Rev.*, vol. 61, pp. 139–145, 1983.
[57] B. Wilkinson and N. Oliver, "Power, control and the Kanban," *J. Manage. Studies*, vol. 26, pp. 47–58, 1989.

Masao Nakamura received the B.S. degree and the M.S. degree in industrial engineering from Keio University, Tokyo, Japan, in 1967 and 1969, respectively, and the Ph.D. degree in operations research and industrial engineering from The Johns Hopkins University, Baltimore, MD, in 1972.

His was a Systems Engineer with Toshiba Corporation, a Consultant for a number of government agencies, and a Professor at the University of Alberta, Canada. Currently, he holds joint appointments at the University of British Columbia, where he is a Professor of applied science (Electrical and Computer Engineering) and of commerce and business administration and the Konwakai Japan Research Chair Professor in the Institute of Asian Research. His current research interests include technology transfer in international business, firm, and household behavior and econometrics. He has published extensively in major economics and management journals.

Dr. Nakamura is a member of the Institute for Operations Research and the Management Sciences, Econometric Society, American Economic Association, American Finance Association, and Canadian Economics Association.

Sadao Sakakibara received the M.S. degree in operations research, the M.A. degree in statistics, the Professional Engineer degree in industrial engineering, and the doctor's degree in management systems from Columbia University, New York.

He taught at University of Minnesota. Presently, he is an Adjunct Faculty Member at Keio and Gakushuin Universities in Tokyo, Japan. His current research interests are comparative evaluation of manufacturing practices between Japanese and U.S. manufacturing firms in topics related to just-in-time manufacturing, quality management, technology management, and manufacturing strategy. His has published recently in *Management Science* and the *Academy of Management Journal*.

Roger Schroeder received the B.S. degree in industrial engineering with high distinction and the M.S.I.E. degree from the University of Minnesota, Minneapolis St. Paul, and the Ph.D. degree from Northwestern University, Evanston, IL.

He is the Frank A. Donaldson Professor of Operations Management and the Codirector of the Quality Leadership Center, Carlson School of Management, at the University of Minnesota. He has received research grants from the Ford Foundation, Exxon Education Foundation, National Science Foundation and American Production and Inventory Council Society. He has published more than 100 research articles on the subjects of strategy in operations, management of technology, and quality management.