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We consider Just-in-Time (JIT) to be an overall organizational phenomenon. Accordingly, we developed and tested a model that includes both JIT practices and the infrastructure practices hypothesized to provide an environment in which JIT practices perform more effectively. Canonical correlation analysis was used to test five hypotheses. The results indicated that: (1) there was not a significant relationship between the use of JIT practices, alone, and manufacturing performance, (2) there was a very strong relationship between JIT practices and infrastructure practices; (3) the combination of JIT management and infrastructure practice was related to manufacturing performance; (4) infrastructure, by itself, is sufficient to explain manufacturing performance; and (5) manufacturing performance was related to competitive advantage. These findings provide support for the notion that JIT is an overall organizational phenomenon, rather than limited to strictly shop floor practices, and that at least part of its effect on manufacturing performance may be through providing a set of improvement targets and discipline for the entire organization. In addition, the analysis highlights the areas of infrastructure practice most relevant for future research

(*Empirical Study; Just-in-Time Manufacturing; Manufacturing Performance*)

1. Introduction

The purpose of this paper is to present an empirical analysis of Just-in-Time (JIT) manufacturing which moves beyond description and focuses on the impact of both JIT practices and their supporting infrastructure practices on manufacturing performance. It is based on a framework developed from a review of the relevant literature, as well as discussions with managers.

Recognition of the importance of JIT is exemplified by the fact that over 700 JIT-related articles were published between 1985 and 1990 (Inman and Mehra 1990). Various dimensions of JIT practice have been proposed by many researchers, but a consistent set of dimensions has not emerged. We will add to the research on JIT by investigating whether JIT is affected by various aspects of organizational infrastructure, including manufacturing strategy, human resource management, and quality management.

In the next section the literature is reviewed, and a framework for JIT research is developed. Dimensions of JIT practices and infrastructure practices are described, and hypotheses are presented. This is followed by a methodology section, which describes variable measurement, sampling methods, and data collection procedures. The results of our analysis, using canonical correlation, are then presented and discussed, and conclusions are drawn.

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2. A Framework for Research on JIT

2.1. JIT Practices

In order to articulate a set of relevant JIT practices, we considered several sources. The conceptual literature on JIT is extensive, and we searched both the early literature, which introduced the concept to English-speaking audiences, and significant bodies of more recent literature. The empirical literature is limited, but was useful in providing verification of the importance of these practices. We also visited plants that use JIT, to refine the list of important JIT practices.

Conceptual Literature. Monden (1983, 1989) is credited with introducing the JIT concept to a broad audience in the United States. His early work focused primarily on a limited set of JIT practices related to shop floor activities. His series of articles described the philosophy of JIT (1981a), the Kanban system (1981b), production smoothing in JIT (1981c), and set-up time reduction (1981d). He also emphasized the importance of small lot sizes, mixed model production, multifunction workers, preventive maintenance, and JIT delivery by suppliers.

Along with Monden, Schonberger is considered to be one of the pioneers in JIT research in the United States. Probably his greatest contribution was his description of the applicability of JIT in the United States, despite early doubts which centered on cultural obstacles. Schonberger's early work (1982) stressed many of the same shop floor JIT practices as Monden, while his later work (1986) included employee involvement, preventive maintenance, and quality. The book edited by Ohno and Monden (1983) showed how JIT fits with other manufacturing concepts, including Flexible Manufacturing Systems (FMS) and Material Requirement Planning (MRP) and the relationship of the Kanban system with the computer. Lee and Ebrahimpour's (1984) literature survey identified similar practices. They concluded that management's understanding and support of the JIT system, management and labor cooperation, long-term planning, the redesign of department functions, and supplier management were all critical practices in implementing a successful JIT system.

Empirical Literature. Although JIT has been discussed heavily in the conceptual literature for the past decade, empirical research is only just beginning to be reported in the academic literature. The topics of these studies are diverse, including JIT practices in the United States (Celley et al. 1987, Crawford et al. 1988, Im and Lee 1989), JIT practices in the United Kingdom (Voss and Robinson 1987), and a comparison of JIT practices between large and small firms (Inman and Mehra 1990). Im and Lee (1989) surveyed 33 organizations in the United States and found that the use of JIT practices was reflected in almost every aspect of the organization, particularly in the production planning and control system, including inventory control, shop floor control, production planning, purchasing, capacity planning, and distribution planning. Voss and Robinson's (1987) study of firms in the United Kingdom supported this finding. Thus, empirical studies have tended to confirm the definitions and scope of JIT practices found in the earlier conceptual studies.

Plant Visit Observations. To further refine and analyze our list of important JIT practices, 12 plants that had implemented JIT were visited by the authors. The plants were in three industries, and were located throughout the United States. Plant visits typically included a plant tour, as well as a series of structured interviews with production workers, production supervisors, and managers from all parts of the plants

The literature review and plant visits led us to identify six "key" JIT practices: set-up time reduction, scheduling flexibility, maintenance, equipment layout, Kanban, and JIT supplier relationships. These are referred to as the "JIT practices" in our model and subsequent analysis.

2.2. Infrastructure

An area often neglected in the literature is the linkage between JIT practices and other activities that provide support for the use of JIT practices. Even in the early JIT literature, there was an awareness of the vital contribution of a supportive infrastructure to the success of JIT. For instance, one of the earliest English language discussions of JIT, Sugimori et al. (1977), described it as having two components, working hand-in-hand. The first was the Just-in-Time production system, described as "only the necessary products, at the necessary time, in the necessary quantity" The second component, described as equally important, was Toyota's "respect-for-human" system, which focused on active employee participation, elimination of wasted movement by workers, consideration for worker's safety, and self-display of workers' capabilities by entrusting them with greater responsibility and authority. Kimura and Terada (1981) included as one of the goals of a pull system raising the level of shop control through decentralization, by giving shop supervisors and foremen the function of production control, as well as inventory control.

These early articles about JIT are significant in several respects. First, they indicate that the essential practices of JIT were developed, refined, and implemented prior to 1977. The approach they described is not substantially different from JIT as it is used today. Second, both sets of authors include infrastructure, as well as JIT practices, and they described infrastructure as being on an equal footing with JIT practices.

This early attention to infrastructure has been deemphasized as more recent JIT researchers have concentrated their discussions primarily on JIT practices. However, Rehder (1989) and others have called for an approach built upon synergies between the strategy, structure, culture, and human resources subsystems We have followed a similar direction by synthesizing the infrastructure practices, suggested by the literature and our plant visits, into the model we propose.

In the area of *product design*, the concepts of design for manufacturability (Hartley 1992) and reliability engineering (Garvin 1983) are important to JIT. Design for manufacturability incorporates ease of fabrication and assembly into product design, through such techniques as parts reduction and avoidance of separate fasteners. Reliability engineering is based on the notion that, all else being equal, the fewer the parts in an assembly, the lower its failure rate. Designing products with fewer, more reliable parts permits the reduction of inventory buffers, as well as speeding up the manufacturing cycle through improved throughput time.

Work force practices related to JIT include selection and compensation policies that develop team players who contribute to group problem-solving efforts. Training programs and personnel policies are important in developing flexible workers who are capable of shifting to the place in the process where they are most needed to facilitate a smooth production flow (Curington et al. 1986, Luthans and Fox 1989). Small-group problem-solving activities often provide solutions to production-related problems, leading to improvements in waste reduction and manufacturing cycle time.

Organizational characteristics related to JIT involve the reallocation of decision rights within the organization. For example, a decentralized structure facilitates on-the-spot decision making by the people who are most involved in the outcome of the decision (Collins et al. 1988). Coordination of decision making between various parts of the organization facilitates informed and efficient decisions to resolve problems as they arise (Hrebiniak and Joyce 1984). These characteristics combine to help in the development of a flexible, informed, and participative workforce capable of solving problems as they arise.

The linkage between *quality management* and JIT is well understood. Quality management activities provide support for JIT through establishment of a process that is in control (Hayes 1981) This facilitates the development of an unhampered flow of goods through the process, and allows buffer inventory reduction (Takeuchi and Quelch 1981). The provision of accurate and timely feedback about the manufacturing process permits shop floor personnel to detect, diagnose, and remedy process problems as they occur.

The connection between *manufacturing strategy* and JIT is rarely discussed in the literature. To the extent that JIT becomes an important part of the business strategy or that business strategy is built on the capabilities offered by JIT, there should be a strong linkage between Wheelwright and Hayes' (1985) Stages 3 and 4 and JIT practices. According to this framework, in Stage 1 organizations, the manufacturing function is considered to be a detriment, in need of tight internal controls or, at best, neutral. In Stage 2 organizations, manufacturing is also perceived as neutral, at best; however, firms seek parity with major competitors, rather than using internal controls to minimize the potential negative impact of the manufacturing function. However, Stage 3 and 4 organizations progressively incorporate the capabilities of manufacturing into their corporate strategy or even consider manufacturing to be the driver of their corporate strategy. Manufacturing strategy also includes a long-term orientation and integration of strategic and functional decisions.

2.3. JIT Framework and Hypotheses

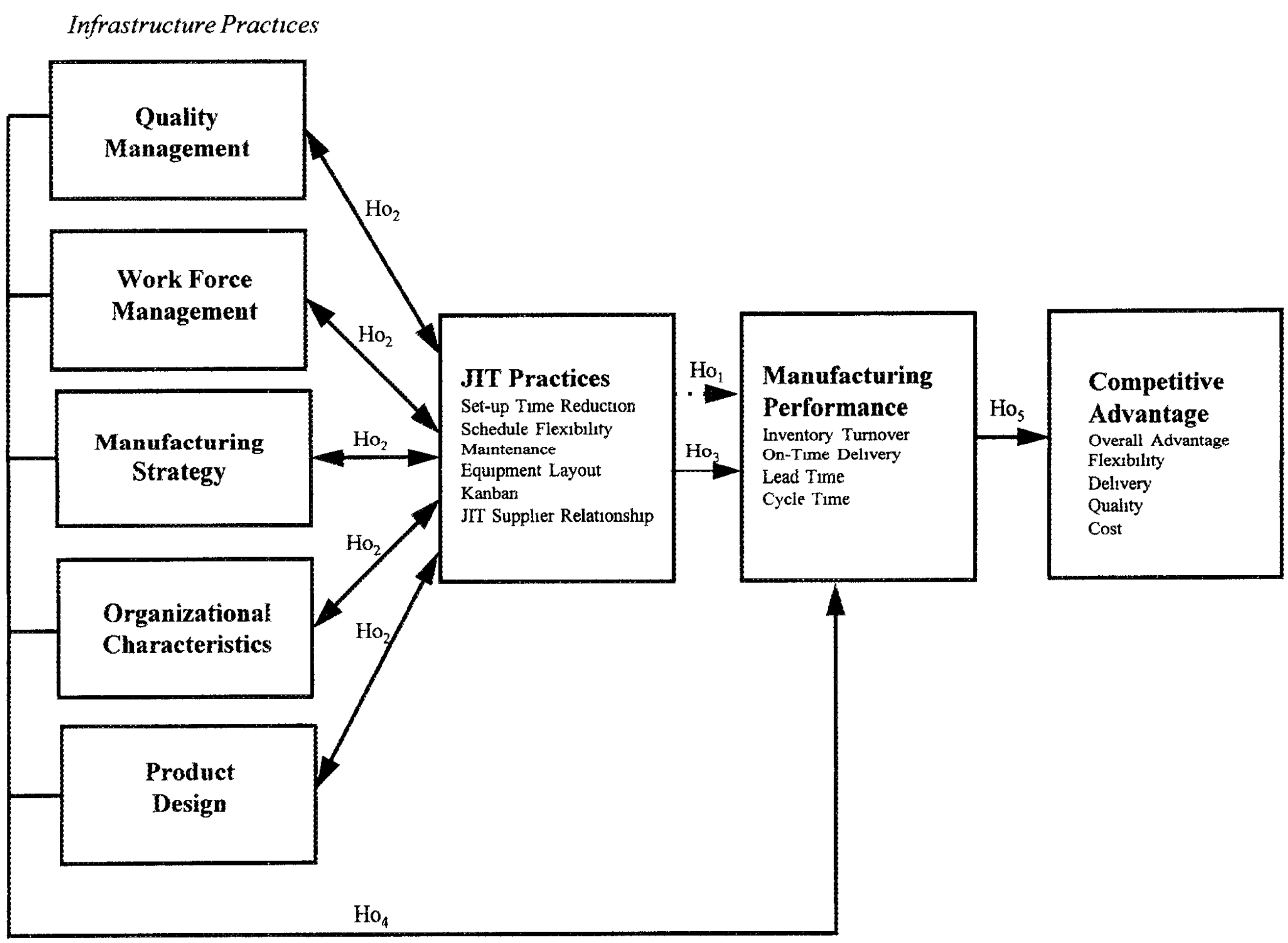
The discussion above is summarized by the model we propose to guide the study of JIT, in terms of practices, manufacturing performance, and competitive advantage (see Figure 1). Although the literature suggests that a wide variety of practices have an effect on manufacturing performance, it is important to separate them into those that are unique to JIT (JIT practices) and those that are primarily related to the support of JIT within the organization (infrastructure practices). Figure 1 indicates a synergistic relationship between JIT and infrastructure practices; thus, we suggest that this relationship may be mutually supportive.

Based on this framework, we derive five hypotheses, which are stated in null form.

$H_0 1$. *There is no relationship between JIT practices and manufacturing performance.*

Hypothesis 1 tests whether there is a direct relationship between the JIT practices and manufacturing performance. Figure 1 uses the dashed arrow to indicate that this hypothesis is based on the relationship between JIT practices and manufacturing performance only, it does not include the effect of infrastructure practices. Rejection of this hypothesis would indicate that

Figure 1 Conceptual Framework for Research in JIT Management



the use of JIT practices, alone, is sufficient to explain manufacturing performance.

$H_0 2$. *There is no relationship between infrastructure practices and JIT practices.*

This hypothesis tests whether there is a linkage between infrastructure practices and JIT practices. Rejection of the null hypothesis would indicate that infrastructure practices are related to JIT practices.

$H_0 3$. *There is no relationship between the combination of JIT practices with infrastructure practices and manufacturing performance.*

The third hypothesis tests the "larger definition" of JIT and its effect on manufacturing performance. Figure 1 uses the solid arrow to indicate that this hypothesis considers the combined effect of infrastructure and JIT practices. It is best interpreted in conjunction with the results of the first null hypothesis. If the test of the third hypothesis leads to the establishment of a stronger relationship than that established in the test of the first hypothesis, this will lend support to the notion that infrastructure practices enhance the usage of JIT practices.

$H_0 4$. *There is no relationship between infrastructure practices and manufacturing performance.*

This hypothesis tests the relationship between infrastructure and manufacturing performance. The main purpose of this hypothesis is to examine whether infrastructure alone is sufficient to predict manufacturing performance without JIT practices.

$H_0 5$. *There is no relationship between manufacturing performance and competitive advantage.*

The final hypothesis examines the relationship between manufacturing performance and competitive advantage. Rejection of this hypothesis would indicate that higher levels of manufacturing performance enhance the level of competitive advantage of the plant.

3. Method

3.1. Measurement of Practices and Manufacturing Performance

A set of questionnaire items was developed to correspond to the groups of JIT practices and infrastructure practices. Each set, referred to as a "scale," was designed to measure specific content. Responses were measured by a five-point Likert scale, where a value of 1 indicated *strongly agree* and a value of 5 indicated *strongly disagree*. The responses to the items were averaged to arrive at the overall scale score. Twenty-four scales were developed, for constructs with no appropriate measurement scales available in the literature, and five scales were adapted from previously existing scales (complete scales are listed in Sakakibara et al. 1993).

Manufacturing performance was measured by four objective (quantitative) variables, whose values were reported by the plant accountant. *Inventory turnover* was calculated as the ratio of cost of goods sold to aggregate inventory *Cycle time* was measured as the average time from raw materials procurement to customer delivery, while *lead time* was measured as the average length of time to fill an order We treated cycle time and lead time separately, because lead time can be affected by plant environment (e.g., make-to-order vs. make-to-stock). The fourth performance measure was *on-time delivery rate*, which was measured as the percentage of on-time delivery to customers. *Competitive advantage* was measured by five perceptual variables that measured plant management's opinion of the plant's performance relative to global competition, in terms of unit cost of manufacturing, quality of product and service, fast delivery, and flexibility to change volume, relative to competition. These measures were chosen to represent commonly cited competitive priorities.

3.2. Questionnaire Construction, Data Collection, and Measurement Analysis

The measures were targeted at the respondents who were expected to be the most knowledgeable in providing the desired information. The items from the various scales were intermixed, so that scale membership was not readily apparent in the questionnaires. Each scale appeared on at least two different questionnaires to ensure better reliability.

The plants were randomly selected from lists of U.S.-owned and Japanese transplants in the transportation components, electronics, and machinery industries. All together, 21 questionnaires were distributed to specific managers and workers in each of the plants surveyed.

There was a high participation rate from the plants we contacted (60%), with a total of 822 responses received from the 41 plants.

To determine the reliability of each scale, Cronbach's (1951) alpha was calculated All scales had alpha values in excess of the minimum criterion value of 0.60 for newly developed scales (Nunnally 1978), and many had reliabilities of 0.70 to 0.80, indicating they were internally consistent (see Table 1)

Evidence of construct validity is provided if factor analysis of a scale results in a single factor, indicating that the items in the scale all measure a common construct. Factor analysis by principal components yielded eigenvalues greater than 1, and the item loadings were all greater than the customary minimum of 0.40, with many loadings in the 0.70 to 0.90 range. These results indicate that all scales have good construct validity. More detailed measurement information is contained in Sakakibara et al. (1993).

3.3. Method of Analysis

The hypotheses require testing the strength of the relationship between two sets of variables, for example, between the set of four manufacturing performance variables and the set of six JIT variables (H_01). Canonical correlation analysis was used to test this relationship. It constructs a weighted linear combination of the variables in each of the two sets being correlated, with weights selected to maximize the correlation between the two weighted vectors, or canonical variates One of the advantages of canonical correlation analysis is that it requires only multivariate normality of the variables in the data sets. In addition, canonical correlation permits the use of multiple dependent variables.

To assess the strength of the overall relationship described by canonical correlation analysis, Hair et al. (1992) recommend three criteria: (1) the level of statistical significance, (2) the magnitude of the canonical correlation coefficient, and (3) the redundancy measure for the percentage of variance explained by the correlation. The first canonical pair comprises the two canonical variates that have the strongest relationship with each other, and is sufficient evidence to reject the null hypothesis. The second canonical pair is orthogonal to the first and comprises the two canonical variates (a different set of variable weightings than in the first canonical pair) that have the next strongest relationship to each other. For example, in Table 5, the canonical variate in the first canonical pair represents primarily setup time reduction, schedule flexibility and maintenance, whereas the canonical variate in the second canonical pair represents primarily equipment layout and Kanban. Similarly, subsequent canonical pairs are orthogonal and represent decreasingly strong relationships. Thus, each canonical pair simply represents a different perspective on the same question.

For the significant canonical pairs, canonical crossloadings are calculated as the correlation between each of the original variables in one set and the weighted canonical variate from the other set of variables. This set of crossloadings is used to interpret the strength of each of the variables in explaining the relationship with the other set as a whole Thus, canonical correlation analysis provides a good test of the overall relationship specified by each hypothesis, as well as providing further analysis of the effect of the individual variables.

3.4. Preliminary Analysis and Data Transformation

The first null hypothesis tested the relationship between the set of JIT practices and the set of manufacturing performance measures. Prior to testing the second through fourth null hypotheses, the scales within each infrastructure group were combined into a "superscale" to permit testing each infrastructure component as a group of characteristics, rather than arbitrarily selecting a "typical" scale to represent each component. For example, the score for the Product Design superscale is the mean of the scores on three scales: New Product Quality, Design Characteristics, and Interfunctional Design Efforts. Thus, in the test of the second null hypothesis, the two groups of variables were the set of five infrastructure superscales and the set of six JIT practices scales. A JIT practices superscale was used in testing the third and fourth null hypotheses. All superscales have strong reliability and construct validity, as shown in Table 1.

The data was transformed before testing the hypotheses, because our initial analysis indicated that the transportation components industry tended to have better performance than the machineryindustry on several manufacturing performance measures.

Table 1 Reliability and Construct Validity of Superscales

	Scale Alpha	Superscale Alpha	Superscale Eigenvalue	Superscale Factor Loading
JIT Practices		0.781	3.180	
Setup Time Reduction	0.68			0.912
Schedule Flexibility	0.60			0.690
Maintenance	0.67			0.747
Equipment Layout	0.60			0.615
Kanban	0.88			0.675
JIT Supplier Relationship	0.63			0.692
Product Design		0.670	1.802	
New Product Quality	0.69			0.679
Design Characteristics	0.62			0.772
Interfunctional Design Efforts	0.78			0.862
Workforce Management		0.841	3.780	
Supervisory Leadership	0.77			0.793
Incentives for Group Performance	0.66			0.841
Labor Flexibility	0.62			0.863
Small Group Problem Solving	0.71			0.670
Recruiting and Selection	0.72			0.678
Supervisors as Team Leaders	0.73			0.889
Organizational Characteristics		0.817	2.234	
Coordination of Decision Making	0.74			0.922
Decentralization of Authority	0.77			0.708
Plant-Wide Philosophy	0.71			0.945
Quality Management		0.754	2.638	
Process Control	0.77			0.725
Feedback	0.77			0.746
Rewards for Quality	0.78			0.749
Top Management Quality Leadership	0.70			0.764
Supplier Quality Involvement	0.73			0.645
Manufacturing Strategy		0.844	3.097	
Communication of Strategy	0.77			0.792
Long-Range Orientation	0.62			0.544
Manufacturing Strategy Strength	0.72			0.877
Stage 3 Manufacturing	0.79			0.936
Stage 4 Manufacturing	0.67			0.841

These differences were partly due to the products each industry produces. For instance, the number of parts required for the primary product line is generally smaller in the transportation components industry and larger in the machinery industry. To eliminate the potential industry effect on performance, all variables were standardized by industry, with a mean of 0 and a standard deviation of 1.

4. Results and Discussion

While the first and second canonical pairs can be computed with respect to *any* sample of *any* set of variables, it is, for the purpose of establishing significance of the correlation values, convenient to be able to assume that the variables follow a multivariate Normal distribution. Moreover, it is easier to establish significant correlations when the sample size is large. We have only tested whether the marginal distributions of the variables are Normal, using the Shapiro and Wilk (1965) test, the hypothesis of Normality could not be rejected at the 0.05 level of significance.

The sample size for this analysis was 41, reduced by the number of plants that had missing data on particular variables.

First Hypothesis

To test the first hypothesis, we computed the canonical correlation between the set of six JIT practices and the set of four manufacturing performance variables. Although the canonical correlation was 0.6779, there were no statistically significant canonical pairs and the redundancy index was relatively low (see Table 2). Thus, there was not sufficient evidence to establish a significant relationship between the set of JIT practices and manufacturing performance. Although this is somewhat surprising, it is not totally unexpected. It may lend support to the notion that there is more to the construct "JIT" than just the use of JIT practices. Thus, the failure to reject the first hypothesis may be due to the narrowness with which the set of JIT practices was defined.

Table 2 **Relationship Between JIT Practices and Manufacturing Performance (Hypothesis 1)**

	First Canonical Pair
Canonical Correlation	0.6779
Level of Significance	0 1791
Redundancy Index	0 1634
Loading of Manufacturing Performance Variables on Their Canonical Variate	
Lead Time	0 7518
Cycle Time	0 3903
Inventory Turnover Ratio	0 3738
On-Time Delivery	0 2242
Crossloading of JIT Practices	
Setup Time Reduction	0 1118
Schedule Flexibility	0 3445
Maintenance	−0 1608
Equipment Layout	0 1275
Kanban	−0 1994
JIT Supplier Relationship	−0 0473

Table 3 **Relationship Between JIT Practices and Infrastructure Practices (Hypothesis 2)**

	First Canonical Pair	Second Canonical Pair
Canonical correlation	0.7613	0 5999
Level of Significance	0 0013	0 0799
Redundancy Index	0.4615	0 1410
Loading of JIT Practices on Their Canonical Variate		
Setup Time Reduction	0 8421	0 3806
Schedule Flexibility	0 9075	−0 1898
Maintenance	0 7429	−0 0341
Equipment Layout	0 2602	0 5967
Kanban	0 4743	0 7495
JIT Supplier Relationship	0 4330	0 3531
Crossloading of Infrastructure Practices		
Product Design	0 5137	0 2440
Workforce Management	0 6581	0.1983
Organizational Characteristics	0 6372	0 0518
Quality Management	0 5833	0 1365
Manufacturing Strategy	0 3934	0 4204

Second Hypothesis

The second hypothesis tested the relationship between the set of JIT practices and the set of superscales representing infrastructure practices (Table 3). The first two canonical pairs were statistically significant, with a combined redundancy index of 0.6025, indicating that more than half of the variance in JIT practices can be explained by the infrastructure variables. These results indicate there is a very strong relationship between infrastructure practices and JIT practices.

The second section of Table 3 illustrates the weight of each individual JIT practice in the canonical variate which represents JIT practices. Loadings of at least 0.31 are considered significantly different from zero at the 0.05 level of significance (Graybill 1961). Thus, for the first canonical pair, the JIT practices canonical variate is primarily composed of schedule flexibility, setup time reduction and maintenance, with Kanban and JIT supplier relationship represented to a lesser extent. For the second canonical pair, the JIT practices canonical variate comprises primarily Kanban and equipment layout, with setup time reduction and JIT supplier relationship

Table 4 **Relationship Between JIT/Infrastructure Practices and Manufacturing Performance (Hypothesis 3)**

	First Canonical Pair
Canonical Correlation	0.8328
Level of Significance	0.0056
Redundancy Index	0.3647
Loading of Manufacturing Performance Variables on Their Canonical Variate	
Lead Time	0.3308
Cycle Time	0.6518
Inventory Turnover Ratio	−0.9100
On-Time Delivery	−0.4438
Crossloading of JIT/Infrastructure Practices	
JIT Practices	0.2305
Product Design	0.1813
Workforce Management	0.3424
Organizational Characteristics	0.1582
Quality Management	0.5238
Manufacturing Strategy	0.5598

represented to a lesser extent. The third section of Table 3 shows the crossloadings, which are the correlations between each variable and the canonical variate for that canonical pair. Thus, for the first canonical pair, all five infrastructure variables were significantly related to the canonical variate representing JIT practices, while for the second canonical pair, only manufacturing strategy was significantly related to the canonical variate representing JIT practices.

Third Hypothesis

In the analysis of the third null hypothesis, the scales representing JIT practices were combined into a single superscale, in addition to the infrastructure superscales. Thus, the two groups of variables tested were the set of six superscales (five infrastructure superscales plus the JIT practices superscale) and the set of four manufacturing performance variables. The results (Table 4) indicate that there is a statistically significant relationship between the combined set of JIT and infrastructure practices and the set of manufacturing performance measures. Also, the redundancy index was substantially higher than in the first hypothesis test, indicating the incremental effect of infrastructure practices on manufacturing performance. This supports the notion that manufacturing performance is related to a combination of practices.

The manufacturing performance canonical variate was most heavily weighted by inventory turnover ratio, followed by cycle time, although all four variables had significant loadings. The signs of the loadings were as expected, since all indicate better JIT performance: short lead time and cycle time (positively related to the practices scales, where a value of 1 indicates the best performance), and a higher inventory turnover ratio and percent on-time delivery (negatively related to the practices scales). The canonical crossloadings in the bottom of Table 4 indicate which specific types of practices were most strongly related to manufacturing performance. The practices most strongly related to manufacturing performance were manufacturing strategy and quality management, followed by workforce management.

Fourth Hypothesis

The next question of interest was whether infrastructure, by itself, is sufficient to explain manufacturing performance. The test of this hypothesis, summarized in Table 5, indicates that there is a statistically significant relationship between the set of infrastructure practices

Table 5 **Relationship Between Infrastructure Practices and Manufacturing Performance (Hypothesis 4)**

	First Canonical Pair
Canonical Correlation	0.8215
Level of Significance	0.0035
Redundancy Index	0.3901
Loading of Manufacturing Performance Variables on Their Canonical Variate	
Lead Time	0.3700
Cycle Time	0.7187
Inventory Turnover Ratio	−0.8704
On-Time Delivery	−0.4715
Crossloading of Infrastructure Practices	
Product Design	0.2117
Workforce Management	0.3431
Organizational Characteristics	0.1921
Quality Management	0.5568
Manufacturing Strategy	0.5824

and the set of manufacturing performance measures. These results indicate that manufacturing performance can be explained by the five infrastructure practices, without including JIT practices.

Fifth Hypothesis

The final hypothesis tests whether the set of manufacturing performance measures is related to the set of competitive advantage measures. Table 6 provides a detailed description of the results. The canonical correlation, the level of statistical significance, and the redundancy index provide strong evidence that there is a relationship between the set of manufacturing performance variables and the set of competitive advantage variables, which leads to the rejection of the fifth hypothesis. These results also lead to the argument that a plant which is high in terms of the manufacturing performance measures should also have a competitive advantage.

The results of our analysis show that two infrastructure variables (quality management and manufacturing strategy) had the greatest impact on manufacturing performance, with workforce management in third place. Thus, we can reasonably assert that the major strength of JIT manufacturing comes from the way it leads an organization to create its manufacturing strategy and a strong emphasis on quality management. For example, as a firm moves into Stages 3 and 4 of Hayes and Wheelwright's framework, it is imperative that manufacturing processes are functioning in control and waste is minimized for manufacturing to be the driver of competitive strategy. These results are consistent with many case studies in the literature, which indicate that a strong manufacturing strategy and a successful quality program are necessary for successful JIT implementation, along with contributions from workforce management

It is interesting to note that our analysis for the fourth hypothesis indicates that infrastructure practices, alone, explain manufacturing performance sufficiently without JIT practices. This result leads to two interesting potential interpretations: (1) JIT practices affect manufacturing performance only through their interaction with infrastructure, and (2) infrastructure practices alone lead to manufacturing performance.

For the first possibility, we can argue that a large proportion of the variability of JIT practices (about 60%) was explained by the infrastructure practices. In other words, the results suggest that a plant that has a strong infrastructure is likely to have a strong JIT management program, and the JIT practices may contribute to manufacturing performance through their interaction with infrastructure practices.

The second possibility is that the JIT practices do not contribute to manufacturing performance, and that only infrastructure practices matter. This leads to the alternative of a plant concentrating its efforts only on aspects of infrastructure, such as total quality management and manufacturing strategy. As the results of our analysis indicate, emphasis on quality management and manufacturing strategy, along with workforce management, seems to be a very good strategy for competing regardless of whether JIT practices are included.

Table 6 **Relationship Between Manufacturing Performance and Competitive Advantage (Hypothesis 5)**

	First Canonical Pair
Canonical Correlation	0.8149
Level of Significance	0 0142
Redundancy Index	0 3542
Loading of Manufacturing Performance Variables on Their Canonical Variate	
Lead Time	0 8854
Cycle Time	0 4562
Inventory Turnover Ratio	−0 2855
On-Time Delivery	−0 5321
Crossloading of JIT Practices	
Unit Cost of Manufacturing	0.0194
Quality of Goods and Services	0 2853
Fast Delivery	0 6183
Flexibility to Change Volume	0 5302
Comparison with Competition on a Global Basis	0 4751

5. Conclusions

The major conclusion of this paper is that JIT is an overall organizational phenomenon. Although this has been described in the conceptual literature, it has not been previously demonstrated empirically. As we discussed, the effectiveness of JIT manufacturing is dependent on the

Table 7 Intercorrelation of Superscales

	JIT Practices	Product Design	Workforce Management	Organizational Characteristics	Quality Management	Manufacturing Strategy
JIT Practices	–	0.457*	0 611**	0 505**	0 462*	0 483*
Product Design		–	0 519**	0 588**	0 688**	0 651**
Workforce Management			–	0 661**	0 663**	0 575**
Organizational Characteristics				–	0 657**	0.751**
Quality Management					–	0 655**
Manufacturing Strategy						–

* $p <$ 05
** $p <$ 01

overall strength of an organization. In fact, the results of our analysis suggest that JIT practices have value only when they are used to build infrastructure, and have no direct effect on performance. We found that JIT practices generate an indirect effect that works through improvement of manufacturing infrastructure by providing a set of targets and discipline for the organization, rather than having a direct effect on performance. This is a significant finding, since many firms attempt to employ core JIT practices without considering other issues and are dismayed when performance fails to improve.

The results also suggest that how a firm manages its infrastructure, especially quality management and manufacturing strategy and workforce management, seems to play an important role in manufacturing performance. In addition, we also found strong statistical evidence that manufacturing performance enhances competitive advantage at the plant level.

Before drawing the conclusion that stressing infrastructure is sufficient to compete, however, the interconnected relationships among different manufacturing practices should also be investigated. For example, quality management practices are very likely supported by their own infrastructure. In fact, all infrastructure practices were highly correlated with each other, as shown in Table 7. This implies that a plant that shows strengths in quality management and manufacturing strategy is very likely to have good practices in other areas. This suggests two opportunities for further research. First, analysis of pairs of approaches may indicate that they are mutually supportive. For example, the literature indicates that quality management may support JIT through establishing a process that is in control, while JIT may support quality management through exposing opportunities for process improvement through inventory reduction. Second, at a broader level, future research may indicate that there is a common infrastructure that supports a wide variety of initiatives. Knowledge of the characteristics of this infrastructure would be useful to organizations pursuing Stage 3 and 4 manufacturing strategies.

In interpreting these results, it is important to remember that the study was conducted in only three industries. Although these industries were selected because they were industries in which the full range of JIT implementation could be observed, it is possible that our results may not be generalizable to other industries, indicating the need for further study.

This paper differs from existing empirical JIT research in two important ways. First, we consider the possibility of JIT as an overall organizational phenomenon, and accordingly, have created and analyzed a model that includes infrastructure practices, in addition to the practices typically associated with JIT. Second, we used a measurement instrument that has been thoroughly tested for reliability and validity. Because reliable and valid scales are used in the instrument, the results drawn from our research are more likely to be repeatable.[1]

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