Impact of Information Technology Integration and Lean/Just-In-Time Practices on Lead-Time Performance*

Peter Ward
Department of Management Sciences, Fisher College of Business, The Ohio State University, 2100 Neil Avenue, Columbus, OH 43210, e-mail: ward.1@osu.edu

Honggeng Zhou[†]
Department of Decision Sciences, Whittemore School of Business and Economics, University of New Hampshire, 15 College Road, Durham, NH 03824, e-mail: honggeng.zhou@unh.edu

ABSTRACT

Managers seeking to improve lead-time performance are challenged by how to balance resources and investments between process improvement achieved through lean/just-in-time (JIT) practices and information technology (IT) deployment. However, extant literature provides little guidance on this question. Motivated by both practical importance and lack of academic research, this article examines empirically the relationships among interfirm IT integration, intrafirm IT integration, lean/JIT practices, and lead-time performance using data from *IndustryWeek*'s Census of Manufacturers (*IndustryWeek*, 2006). The results provide several new insights on the relationship between IT integration and lean/JIT practices. First, the study confirms that implementing lean/JIT practices significantly reduces lead time. Second, lean/JIT practices mediate the influence of IT integration on lead-time performance. This suggests that process improvements that result from lean/JIT practices are important contributors to the success of IT integration. Even companies that have experienced success in reducing lead time through lean/JIT practices may benefit from IT integration practices such as those embodied in enterprise resource planning systems. The findings provide managers with empirical evidence and a theoretical framework on the balance between lean/JIT and IT for effecting improvement in lead-time performance, thus offering practical guidance on this important question. Future research is needed to extend the lean/JIT practices in this study to supply chain practices and explore the relationship between supply chain practices and IT integration.

Subject Areas: Information Systems, Just-in-Time, Lean Manufacturing, and Survey Research.

INTRODUCTION

Lead-time performance is a major competitive battleground for manufacturers across many industries (Blackburn, 1991; Treville, 2004). Recent studies in

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[†]Corresponding author.

time-based manufacturing (Nahm, Vonderembse, & Koufteros, 2004; Tu, Vonderembse, Ragu-Nathan, & Ragu-Nathan, 2004) explore the practices that can reduce lead time and improve firm performance. The reduction of lead time can lead to faster response to customer needs, thus making organizations more customer-oriented (Fisher, Raman, & McClelland, 2000). It also leads to higher levels of standardization, formalization, and integration, which enhance competitive capabilities (Rondeau, Vonderembse, & Ragu-Nathan, 2000).

Two general approaches have been taken to reduce lead times in manufacturing: information technology (IT) integration within and between firms in the supply chain and process improvements that, as a group, are often referred to as lean/just-in-time (JIT) manufacturing practices. IT integration refers to information systems that electronically transmit information within firms and between firms. IT investment in North America has increased significantly. One estimate indicates that IT spending in the United States will increase to $417 billion in 2005 and reach $497 billion by 2008 (Sotirova, 2005). IT has had an impressive impact on firm performance such as lead time. Lean/JIT practices include practices such as quick changeover techniques, kanban systems, and lot-size reduction. A good lean/JIT implementation produces high-quality products at the pace of customer demand with little waste. It allows customers to be served with less inventory investment and a higher level of responsiveness (Womack, Jones, & Roos, 1990; Womack & Jones, 1996).

Although these IT integration and lean/JIT initiatives are complementary in concept, in practice they are often considered to be competing (Piszczalski, 2002). The sense of competition stems from two major sources. First, the source of organizational expertise required is quite different for each approach, IT professionals in the case of IT integration versus manufacturing management and manufacturing engineering for the lean/JIT approach. Second, the financial resources and top management attention required by each of these approaches often obviate initiating both IT integration and lean/JIT in a large scale at the same time. For example, Toyota developed its lean production system for decades before it adopted SAP as its enterprise resource planning (ERP) system in the late 1990s. Even a company as large as Ford Motor Company has had to attempt to balance implementation of lean/JIT programs and ERP (Ford Motor Company, 2004).

The research question that we address is how managers should balance investments between lean/JIT practices and IT in order to maximize lead-time reduction. Many studies have explored gauging and reducing customer lead time or manufacturing lead time. However, the empirical evidence provides little guidance to managers needing to make a reasoned choice about the merits of pursuing either or both of these two initiatives or their relative impact on lead-time performance. Extant literature generally considers the effects on lead time of either IT integration or lean/JIT but not both. In addition, "most published research over the past two decades has been field studies or anecdotal evidence gleaned from surveys with small samples that attempt to validate empirically the benefits of JIT adoption" (Fullerton, McWatters, & Fawson, 2003, p. 385). We address this relatively neglected area using a large data set provided to us by the publishers of *IndustryWeek* (*IW*). Specifically, we explore the issue of the relative contribution to lead-time reduction of IT integration and lean/JIT programs as well as the nature of the linkages among IT integration, lean/JIT, and lead-time reduction.

In the next section we briefly review the literature on lean/JIT practices and lead-time reduction, IT integration and lead-time reduction, and IT integration and lean/JIT practices. Based on the literature review, we develop several hypotheses. The third section describes the data used in our analysis. The fourth section reports the analysis and results. The fifth section contains a discussion of research implications, and the last section provides a conclusion.
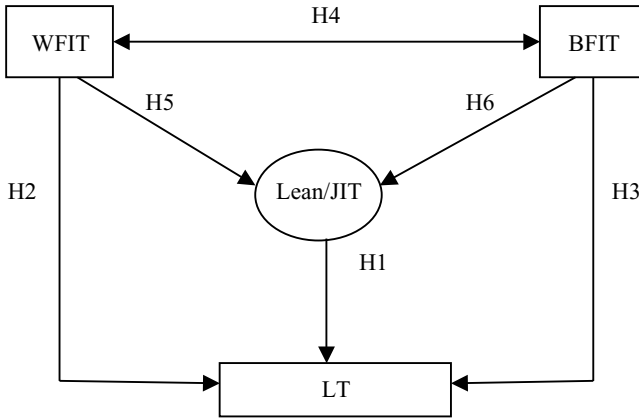
LEAN/JIT PRACTICES, IT INTEGRATION, AND LEAD-TIME REDUCTION

Sustained performance improvement on multiple dimensions has been expected of management in general, and manufacturing management in particular, over the past 20 years. Because of the focus on fast response to customers in many markets, lead-time reduction has been a common focus for performance improvement efforts (Treville, 2004). Lead time can be measured in a number of ways, including manufacturing lead time (Jayaram, Vickery, & Droge, 1999) and customer lead time (Duenyas & Hopp, 1995). We focus on the effects of lean/JIT practices and IT integration on customer lead time. *Customer lead time* is defined as "the time elapsed from receipt of an order until the finished product is either shipped or delivered to the customer" (*IndustryWeek*'s Census Glossary, 1999). We performed a parallel analysis on the effects of lean/JIT practices and IT integration on manufacturing lead time with results nearly identical to those reported here. Therefore, this article only reports the results related to customer lead time.

From a practitioner perspective, the tension between lean/JIT approaches and IT approaches to performance improvement is well established (Piszczalski, 2002; Bruun & Mefford, 2004). Lean/JIT approaches advocate that less is better. It asks for less inventory, less variability, less material handling, fewer options, and fewer choices in work, and so on. Advocates of IT approaches often argue that more is better; or at least that IT approaches allow companies to better manage more information, more flexibility, more functions, and more features. As many firms desire to catch up with their best global competitors, they need to decide how to balance the investment in lean/JIT practices and IT systems, because both approaches require significant resources for implementation.

Regardless of approach, however, process rationalization is a key element in achieving improvements. Major vendors of ERP systems provide extensive guidance for getting processes right before embarking on implementation of the IT itself. Adherents of lean/JIT processes, on the other hand, focus on creating processes that envelop the important information elements as part of the process by using simple technologies such as kanban signals. However, Toyota, the exemplar of JIT production, implemented SAP R/3 in the late 1990s to help in managing supply chains (EASY Software, 2006). In practice, arguments about the relative benefits from the two approaches continue unabated, supported primarily by anecdotal evidence. Bruun and Mefford (2004) discuss conceptually the relationship between lean and IT, and also demonstrate the ideas with three case studies. McAfee (2002) uses a high-tech manufacturer case study to show the relationship between IT investment and improvement in firm performance including lead time. Schmenner (1988) uses

Figure 1: Conceptual model of within-firm IT integration, between-firm IT integration, lean/JIT practices, and customer lead time.

Notes: (1) WFIT refers to within-firm IT integration; BFIT refers to between-firm IT integration; Lean/JIT refers to lean/JIT practices; LT refers to customer lead time; (2) *H5* and *H6* indicate that the relationships between the two IT integrations and lead time are mediated by lean/JIT practices.

three case studies to show the relationship between JIT practices and reduction in cycle time. We are not aware of any large-scale empirical study that evaluates the relative benefits from both lean/JIT approaches and IT approaches simultaneously.

A few recent studies consider the impact of IT integration and/or supply chain integration on firm performance (Frohlich & Westbrook, 2001; Vickery, Jayaram, Droge, & Calantone, 2003; Koufteros, Vonderembse, & Jayaram, 2005; Saeed, Malhotra, & Grover, 2005). However, these studies focus on the interface among supply chain partners rather than interaction between supply chain integration and internal operations such as lean/JIT practices addressed in this study. Most published academic research has generally ignored the argument altogether by considering IT integration and lean/JIT approaches to lead-time reduction separately and, therefore, not addressing the issue of the relative contribution of these two approaches. We address the issue by simultaneously examining the contributions of lean/JIT practices and IT integration programs to improvements in lead-time performance by testing the model shown in Figure 1. We explore each of the linkages in Figure 1 in turn and suggest a hypothesis for each.

Lean/JIT Practices and Lead-Time Reduction

Lean/JIT manufacturing practices include pull system, cellular manufacturing, agile manufacturing strategy, bottleneck removal, and so on. These practices result in reduced inventory levels and reduced lot sizes, which in turn improve the timeliness of process feedback and reduce material movement time (Fullerton et al., 2003; Li, Rao, Ragu-Nathan, & Ragu-Nathan, 2005). Practitioner literature (Womack et al., 1990; Womack & Jones, 1996) reveals the importance of lean/JIT practices

to firm performance through numerous cases. Recent academic studies (Rondeau et al., 2000; Fullerton et al., 2003; Nahm et al., 2004) also show the importance of these lean/JIT practices to competitive capabilities and firm performance in today's time-based competitive environment.

Both practitioner and academic literature suggests that lean/JIT practices are significantly associated with lead-time reduction (Schmenner, 1988; Amstel, 1990; Womack et al., 1990; Womack & Jones, 1996). Womack et al. (1990) report summary statistics that demonstrate marked cycle-time advantages related to lean practices. Schmenner (1988) uses case studies to show the importance of reducing cycle time and how firms use JIT practices to achieve the reduction in cycle time. Amstel (1990) shows how to use JIT practices to reduce the lead time in the pipeline.

Based on the literature review, we propose the following hypothesis:

> *H1:   Lead-time reduction is related to the extent of implementation of lean/JIT practices.*

IT Integration and Lead-Time Reduction

The relationship between IT investment and firm performance continues to interest academics and practitioners (Devaraj & Kohli, 2003; Vickery et al., 2003). Most studies suggest that IT investment leads to improved firm performance including lead time (Co, Patuwo, & Hu, 1998; Small, 1999; McAfee, 2002). In fact, reducing lead times has been cited as an important reason for adopting IT integration programs (Attaran, 1989; Schlie & Goldhar, 1995; Co et al., 1998; McAfee, 2002). Because key differences exist between internal (within-firm) and external (between-firm) information systems integration (Bergeron & Raymond, 1992), we discuss them separately.

Internal IT integration

Internal integration connects the different functions in a firm such as manufacturing, purchasing, and materials management. In particular, internal integration is aimed at improving the performance of cross-functional processes that make up the order-to-cash process. ERP systems are one example of IT designed to achieve high levels of internal integration (Davenport, 1994, 1998). These information systems can be used to generate information and facilitate information sharing within the firm, which can enhance a firm's production capabilities (e.g., Schlie & Goldhar, 1995; Small, 1999).

Our focus is on the extent to which integration results in reduced lead times. A number of previous studies have explored the impact of within-firm IT integration on lead time. Attaran (1989) finds that intrafirm information systems enable manufacturers to offer a broader range of products by shortening setup time, thus enabling small batch runs, both of which result in reduced lead times. Co et al. (1998) provide a list of benefits derived from implementing information systems within a firm, including reduced lead times. Schlie and Goldhar (1995) summarize the changes that occurred in U.S. manufacturing as a result of computer-integrated manufacturing technology, including greater throughput speed and customer responsiveness capabilities.

Based on such empirical support in the literature for the positive impact of within-firm IT integration on lead-time performance, we hypothesize the following:

H2:   Within-firm IT integration is associated with shorter lead times.

External IT integration

External integration refers to information systems that connect a firm with its suppliers and customers. Studies such as Frohlich (2002) and Subramani (2004) find that IT integration with suppliers and customers lead to improved firm performance. Many researchers have focused on mechanisms for coping with environmental uncertainties through information processing capabilities (e.g., Tushman & Nadler, 1978). Interorganizational information systems are one such mechanism.

As with internal integration, literature suggests that between-firm IT integration does contribute to reducing lead times. Mason-Jones and Towill (1999) propose the *information-enriched* supply chain concept, which separates the lead time in a supply chain into material movement lead time and information movement lead time. In an information-enriched supply chain, firms are more closely connected both internally and externally because of information sharing resulting in reduced information lead time and reduced total lead time in a supply chain.

Between-firm IT integration reduces the decision-making process time as well. Data integration is necessary for data to serve as a common language for the events happening in the organization (Galbraith, 1973). Insufficient data integration leads to delays, decreases in communication, and greater distortion of meaning (Huber, 1982). Between-firm integration aids supply chain partners in reaching joint decisions by facilitating information exchange, recollection, and standardization (Dennis, 1996).

Analytical studies provide evidence that between-firm IT integration reduces lead time. Cachon and Fisher (2000) find that sharing demand and inventory data can shorten the order processing lead time. Lee, So, and Tang (2000) study information sharing in a two-level supply chain and show that sharing the current demand variation information leads to significant inventory reduction, which is generally associated with reduced lead times.

Thus, the literature suggests that between-firm integration is associated with shorter lead times, leading to the following hypothesis:

H3:   Between-firm IT integration is associated with shorter lead times.

Internal and external IT integration

Bergeron and Raymond (1992) categorize IT integration into two categories: internal integration and external integration. Most discrete manufacturers implement their internal IT systems, such as material requirements planning (MRP), first and then expand the scope of their IT integration into the supply chain. Some manufacturers only need a minimal internal IT system, especially when the product variety is limited, but they do need sophisticated supply chain systems.

Although between-firm IT integration and within-firm IT integration are conceptually distinct, we expect that they are closely related. Absent sufficient

within-firm IT infrastructure, the quality of the data input for the between-firm IT system is unlikely to be satisfactory. By the same token, if a firm does not have good between-firm IT infrastructure in place it cannot receive updated demand information, supplier information, and customer information needed to support an effective within-firm IT system. Therefore, we hypothesize a reciprocally supportive relationship between between-firm and within-firm IT integration.

>   *H4:   Between-firm IT integration and within-firm IT integration are correlated.*

IT Integration and Lean/JIT

The key question addressed by this research is whether the use of IT integration works in conjunction with lean/JIT practices to improve lead-time performance. Because of the increasing importance of supply chain considerations, contemporary lean/JIT systems require not only local information from internal IT systems such MRP and ERP but also need information from supply chain partners that is provided through external IT integration. Internal IT systems such as advanced planning and scheduling can help bottleneck/constraint removal and facilitate cycle-time reduction. External IT systems such as direct connections between suppliers and buyers can help reduce production lot size, enhance pull-system effectiveness, and facilitate agile manufacturing approaches.

In the IT literature, the relationship between IT and performance has been a *black box*, that is, the variables that mediate the effect of IT use on performance have not been identified (Barua, Kriebel, & Mukhopadhyay, 1995). Resource-based view studies have directly linked IT resources to firm performance, without considering mediation or moderation variables (Mata, Fuerst, & Barney, 1995; Santhanam & Hartono, 2003). In this study, we hypothesize that lean/JIT practices mediate the effects of IT integration on lead-time performance. Lean/JIT practices can mediate the influence of IT integration on lead-time performance in many ways. For example, practices such as quick changeover techniques and lot-size reduction can provide timely feedback to information systems such as MRP and forecast-demand management software, which can increase the responsiveness of those IT systems and thus reduce customer lead time. The mediation hypotheses are consistent with the process-oriented view, that is, operational processes mediate the influence of IT integration on lead-time performance (Davenport, 1993; Barua et al., 1995). However, few empirical studies have tested this view (Bharadwaj, 2000).

As Figure 1 shows, the mediation hypotheses essentially suggest that IT integration facilitates lean/JIT practices, which has been discussed extensively in the literature (Karmarkar, 1989; Pyke & Cohen, 1990; Bruun & Mefford, 2004). Pyke and Cohen (1990) argue that control systems such as JIT systems use local information for control. Karmarkar (1989) argues that integrating MRP systems and JIT systems can improve the manufacturing system efficiency. Bruun and Mefford (2004) conceptually discuss how IT integration can facilitate lean practices and provide three case studies. First, IT integration facilitates the use of pull systems. Without information systems, pull systems can only work well in one link of a supply chain. With internal and external IT integration, pull systems can transmit

the order information through the entire supply chain in a timely fashion, thus reducing customer lead time. Dell provides an example of using IT systems to facilitate its pull production system (Bruun & Mefford, 2004). Second, IT systems can facilitate lot-size reduction practices, which in turn reduce lead time. Cisco is a good example of using IT systems to reduce lot-size reduction (Bruun & Mefford, 2004). As Cisco moves toward becoming a virtual corporation, it uses IT systems to transmit order information to the most appropriate supplier, thus reducing the lot-size and saving inventory. Third, between-firm IT systems such as online customer service and/or help desk can get information from customers and provide customer information to lean/JIT production systems in a timely fashion, which facilitates lean/JIT practices and reduces customer lead time. For example, Dell uses an online customer service system to provide customer service and feeds the timely customer information to its lean production system. Although Brunn and Mefford (2004) provide a thorough conceptual discussion on the relationship between lean and IT as well as three detailed case studies, we are not aware of any empirical study that has tested the hypothesis, that is, lean/JIT practices mediate the influence of IT integration on lead-time performance. The difference between this study and Vickery et al. (2003) is that the earlier study tests the influence of IT integration on supply chain integration while we examine the influence of IT integration on internal lean/JIT practices.

Although proponents of IT integration and lean/JIT practices often appear to be at odds, there is no technical reason for such competition. The information systems in question are generally higher-level planning systems, while lean/JIT practices are primarily related to shop floor control and execution activities (Vollmann, Berry, Whybark, & Jacobs, 2005). Factory-level lean/JIT practices are needed to leverage the information from higher-level external and internal IT systems. Thus, lean/JIT practices are hypothesized to mediate the influence of between-firm and within-firm IT integrations on lead-time performance.

> H5:   The effect of within-firm IT integration on lead-time performance is mediated by the level of adoption of lean/JIT practices.

> H6:   The effect of between-firm IT integration on lead-time performance is mediated by the level of adoption of lean/JIT practices.

METHODOLOGY

Instrument Development and Data Collection

The publishers of *IW* conduct an annual survey of manufacturing managers and provided their 1999 data to us. *IW* is an industrial magazine targeted at executives and managers of U.S. manufacturing firms. The sample consists of approximately 28,000 subscribers to *IW* and is carefully targeted to executives and mangers in virtually all major North American manufacturing enterprises. Survey recipients hold titles such as plant manager, plant leader, and manufacturing manager. The unit of analysis in the present study is the manufacturing plant. Each individual in the sample was sent a letter describing the survey, a survey form, a business reply envelope, and a separate participation card to ensure anonymity of responses.

The questionnaires were mailed in mid-April 1999, and completed questionnaires were accepted through early June 1999. A total of 1,757 completed surveys were received, corresponding to a response rate of approximately 6.7%. While the response rate is lower than many empirical studies, it compares favorably with large-sample operations surveys (e.g., Roth & van der Velde, 1991; Stock, Greis, & Kasarda, 2000). In light of the low response rate, nonresponse bias was assessed by comparing the proportion of respondent firms to the proportion of total mailed surveys for each SIC code. The data indicate no significant difference ($\chi^2 = 12.3$, df = 19, $p = .83$). Only companies with the SIC code between 3200 and 3900 are used, because lean/JIT practices are more often used in these industries. Within the 1,124 responses with the SIC code between 3200 and 3900, we eliminate all responses that are missing one or more items. After limiting the sample by industry and eliminating responses with missing values, the final sample size is 769.

Scales

Lean/JIT practices are measured on three-point scales (1 = not adopted, 2 = some adoption, 3 = wide adoption). The underlying rationale is that lean/JIT is a manufacturing program with the primary goal of continuously reducing, and ultimately eliminating, all forms of waste (Sugimori, Kusunoki, Cho, & Uchikawa, 1977; Fullerton et al., 2003). Practices commonly considered under this rubric include JIT/continuous flow production, lot size reduction, cycle-time reduction, pull system, and quick changeover techniques, among others (Shah & Ward, 2003; Li et al., 2005). The survey items of lean/JIT practices are directly from Shah and Ward (2003). The summary statistics are in Table 1.

Within-firm IT integration practices are measured on two-point scales (1 = not implemented, 2 = implemented). These practices include advanced MRP systems, advanced planning and scheduling systems, ERP systems, computer integrated manufacturing, forecast-demand management systems, manufacturing execution systems, and product data management systems. This set of measurements comes primarily from the advanced manufacturing technology literature (Boyer, Leong, Ward, & Krajewski, 1997; Boyer & Pagell, 2000; Jonsson, 2000). Each of these systems seeks to integrate *information islands* within the firm and each represents fairly aggressive, newer technologies.

Items describing between-firm IT integration practices are measured on two-point scales that are reverse coded and are transformed as 1 = not implemented, 2 = implemented. Items include collaborative business forecasting with customers or suppliers, direct material procurement, invoice or payment systems, customer order entry systems, and customer service/help desk. This set of measurements draws on the recent supply chain IT literature (Chopra & Meindl, 2001; Supply Chain Council, 2002). Each of these items represents mechanisms that simplify or eliminate the need for transactions between firms and thus serve to integrate business functions.

Lead-time performance has been a major battleground in many industries (Blackburn, 1991; Supply Chain Council, 2002; Nahm et al., 2004). Customer lead-time improvement in this study is measured by six categories: 1 = increased more than 20%, 2 = increased 1–20%, 3 = stayed the same, 4 = decreased

Table 1: Performance scales: Reliability, mean, and standard deviation.

Factor 1: Lean/JIT Practices (Alpha = .82)	*Scale*	*Mean*	*SD*
Reengineering Production Processes (JIT1)		2.00	.621
Cycle-Time Reduction (JIT2)	1 = Not Adopted	2.11	.636
Agile Manufacturing Strategies (JIT3)		1.69	.634
Quick Changeover Techniques (JIT4)	2 = Some Adoption	1.79	.650
Focused-Factory Production Systems (JIT5)		1.68	.724
JIT/Continuous-Flow Production (JIT6)	3 = Wide Adoption	1.85	.730
Cellular Manufacturing (JIT7)		1.94	.756
Lot-Size Reduction (JIT8)		1.85	.741
Pull System/Kanban (JIT9)		1.76	.753
Bottleneck/Constrain Removal (JIT10)		1.84	.689
Factor 2: Within-Firm IT Integration (Alpha = .66)	*Scale*	*Mean*	*SD*
Advanced MRP (WFIT1)		1.34	.472
Advanced Planning and Scheduling (WFIT2)	1 = Not Implemented	1.27	.446
ERP System (WFIT3)		1.18	.385
Computerized Integrated Manufacturing (WFIT4)	2 = Implemented	1.31	.461
Forecast-Demand Management Software (WFIT5)		1.17	.380
Manufacturing Execution Systems for Production Management (WFIT6)		1.09	.293
Product Data Management (WFIT7)		1.19	.394
Factor 3: Between-Firm IT Integration (Alpha = .76)	*Scale*	*Mean*	*SD*
Invoices and/or Payment (BFIT1)		1.41	.493
Collaborative Business Forecasting with Customers and/or Suppliers (BFIT2)	1 = Not Implemented	1.46	.499
Direct Material Procurement (BFIT3)		1.49	.500
Customers Enter Orders (BFIT4)	2 = Implemented	1.52	.500
Customer Service and/or Help Desk (BFIT5)		1.42	.494

1–20%, 5 = decreased 21–40%, 6 = decreased more than 40%. The median value of customer lead-time improvement is 4, which means the customer lead time of the major product in the surveyed company has decreased between 1% and 20% in the past 5 years. Among the 769 companies, the lead times of nine firms increased more than 20%. Thirty-nine firms increased 1–20%. One hundred eighty-five firms stayed the same. Two hundred seventy-two firms decreased 1–20%. One hundred fifty-four firms decreased 21–40%. One hundred ten firms decreased more than 40%.

The appropriate number of points on a scale has been the focus of considerable discussion in the survey methods literature. While some research shows that reliability increases with scale length (Jenkins & Taber, 1977), there is no clear-cut relationship between validity and scale length (Smith & Peterson, 1985; Smith, 1994). Muthen (1978, 1984) shows that factor analysis and structural equation modeling (SEM) methods can be applied to two- or three-point scales.

Table 2: Factor analysis for lean/JIT practices.

Measurement Items	Factor Loading
Reengineering Production Processes	.54
Cycle-Time Reduction	.63
Agile Manufacturing Strategies	.64
Quick Changeover Techniques	.58
Focused-Factory Production Systems	.59
JIT/Continuous-Flow Production	.71
Cellular Manufacturing	.55
Lot-Size Reduction	.62
Pull System/Kanban	.66
Bottleneck/Constrain Removal	.63

Reliability and Validity

Reliability is defined as the extent to which the measures can yield the same results on other replications. Cronbach's coefficient alpha is a widely accepted measure for internal reliability. The recommended criterion is .7 for established scales and .6 for newly developed scales (Hair, Anderson, Tatham, & Black, 1998). Table 1 shows that the coefficient alpha for lean/JIT practice exceeds .7 and those for the two newly developed IT scales exceed .6.

Factor analysis is conducted to evaluate the construct validity. Because we will add up the item scores of the two IT integration measurements to form composite scales for SEM analysis, only the factor analysis result for lean/JIT practices is reported here. The result indicates that only one eigenvalue is larger than 1. The factor loadings reported in Table 2 indicate that scale items each meet the .3 criterion (Hair et al., 1998).

ANALYSIS AND RESULTS

SEM has become a preferred data analysis method in empirical operations management research (Shah & Goldstein, 2006). SEM is used to capture the relationships among manifest variables and latent variables. Because of limitations inherent in the data, we treat the data as ordinal in this study. We use the LISREL software to run the structural equation model. Polychoric correlations and asymptotic covariance matrix are calculated. We use weighted least-square method (Toit & Toit, 2001). Following convention, we develop separate measurement and structural models. The measurement model describes the relationship between manifest variables and latent variables. The structural model describes the relationships among latent variables. To test the structural equation models, we create two composite scales for within-firm IT integration and between-firm IT integration, respectively (i.e., we add the measurement item scores for each construct).

We test two models, an original model shown in Figure 1 and an alternative model shown in Figure 2. The salient difference between the original model and the alternative model is that lean/JIT practices mediate the influence of between-firm

Figure 2: Alternative conceptual model.
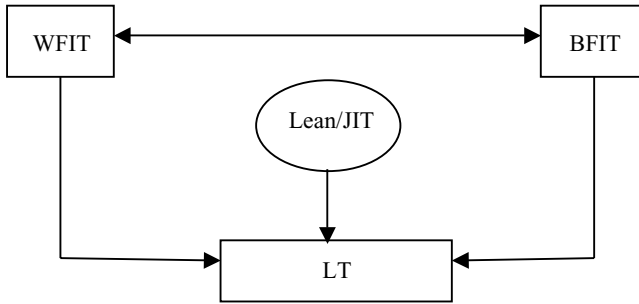
Note: WFIT refers to within-firm IT integration; BFIT refers to between-firm IT integration; Lean/JIT refers to lean/JIT practices; LT refers to customer lead time.

IT integration and within-firm IT integration on lead time in the original model while these two links are not included in the alternative model.

Model Fit Statistics

A number of fit statistics are used to evaluate the models because no single measure is adequate (Bollen & Long, 1993; Shah & Goldstein, 2006). Browne and Cudeck (1993) recommend that an absolute Root Mean Square Error of Approximation (RMSEA) value of less than .05 suggests a good fit, and a RMSEA value between .05 and .08 indicates a reasonable fit. The RMSEA measures the sample discrepancy function value per degree of freedom. Other fit indices include normed fit index (NFI), nonnormed fit index (NNFI), and comparative fit index (CFI) (Shah & Goldstein, 2006). Hair, Anderson, Tatham, and Black (1998) suggest that the model fit is good if NFI, NNFI, and CFI are above .9. While NFI does not adjust the sample discrepancy function by the degree of freedom, NNFI and CFI adjust the sample discrepancy function by the degree of freedom. Because the sample size for this study is fairly large ($n = 769$), using fit indices adjusted by the degree of freedom is more appropriate because that takes the model complexity into consideration. The model fit statistics for both the original model and the alternative model are presented in Table 3. Based on the model fit statistics in Table 3, the original model has a much better fit than the alternative model. Because the two models are nested, a chi-square difference test is performed. The chi-square difference is $450.75 - 171.32 = 279.43$. The degree of freedom is $64 - 62 = 2$. The p value of this chi-square difference test is less than .01. Thus, we conclude that the original model is statistically superior to the alternative model. For the original model, all fit statistics fall in the desirable ranges and suggest that the model has a good fit. Based on power calculation in MacCullum, Browne, and Sugawara (1996), the power of each model is close to 1.00. Because the original model has a much better fit, the rest of the article will focus on the original model.

Table 3: Measures of overall model fit for the original and alternative models.

	Original model	Alternative model	Desirable range
Chi-Square Test Statistic	171.32	450.75	
RMSEA—Point Estimate	.048	.089	
RMSEA—90-Percent Confidence Interval	(.039, .057)	(.081, .097)	
p Value *H0*: Close Fit (RMSEA < .05)	.64	.00	$\geq .05$
Degrees of Freedom	62	64	
Nonnorm Fit Index	.90	.65	$\geq .90$
Comparative Fix Index	.92	.71	$\geq .90$
Sample Size	769	769	
Power of the Model Analysis	1.00	1.00	$\geq .80$

Table 4: Measurement model parameters for the original model.

	Scales	Parameter estimator (*t* value)
Lean/JIT Practices	Reengineering Production Processes (λ_1)	.59[a]
	Cycle-Time Reduction (λ_2)	.69 (16.3)
	Agile Manufacturing Strategies (λ_3)	.71 (16.8)
	Quick Changeover Techniques (λ_4)	.64 (14.6)
	Focused Factory Production Systems (λ_5)	.67 (15.5)
	JIT/Continuous Flow Production (λ_6)	.82 (17.2)
	Cellular Manufacturing (λ_7)	.60 (14.3)
	Lot-Size Reductions (λ_6)	.69 (15.7)
	Pull System/Kanban (λ_9)	.78 (16.6)
	Bottleneck/Constraint Removal (λ_{10})	.69 (16.7)

[a]This is used as a reference indicator in the LISREL model.

Measurement Model

Table 4 shows the estimates of the links between the lean/JIT latent variable and its indicators. All estimates are positive and significant at the .05 level with *t* values significantly larger than 2. The results shown in Table 4 suggest that all indicators are relevant measures of the lean/JIT latent variable. Thus, the measurement model is appropriate and significant.

Findings

Lean/JIT practices and lead-time reduction

The estimate of the link from lean/JIT practices to customer lead time is positive and significant in Figure 3 (.32 in Figure 3). The significant positive estimate indicates that a wider adoption of JIT practices contributes significantly to reduced customer lead time. The *t* value of the estimate is greater than 2 (6.90 in Table 5). Thus, *H1* in Figure 3 is supported.

Figure 3: Covariance structure for the original model.
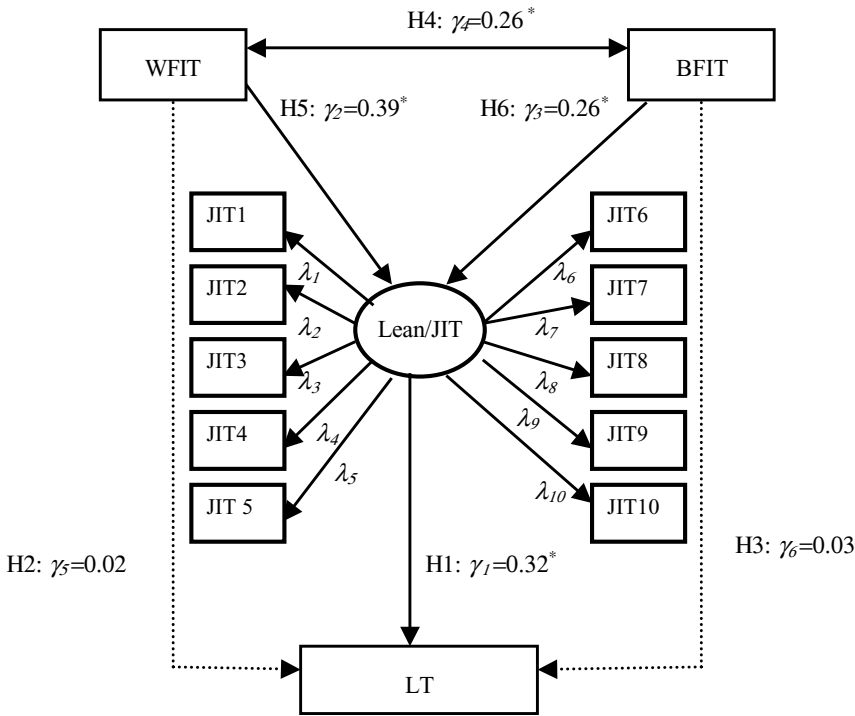
Note: WFIT refers to within-firm IT integration; BFIT refers to between-firm IT integration. Lean/JIT refers to lean/JIT practices; LT refers to customer lead time. Solid paths indicate significant results, while dashed paths indicate nonsignificant results. *Indicates significance at $p < .05$.

Table 5: Structural model parameters for the original model.

Paths in the structural model	Point estimate	*t* value	Significant path?
Lean/JIT Practices → Customer Lead Time	.32	6.90	Yes
Within-Firm IT Integration → Customer Lead Time	.02	.54	No
Between-Firm IT Integration → Customer Lead Time	.03	.61	No
Within-Firm IT Integration <–> Between-Firm IT Integration	.26	6.84	Yes
Within-Firm IT Integration → Lean/JIT Practices	.39	9.05	Yes
Between-Firm IT Integration → Lean/JIT Practices	.26	6.49	Yes

This finding is consistent with most extant studies (Schmenner, 1988; Womack & Jones, 1996) suggesting that implementing lean/JIT practices helps improve performance, in this case lead-time performance. A number of explanations can be offered for this finding. Lean/JIT practices standardize processes, which in turn reduce the uncertainty in manufacturing systems (Rondeau et al., 2000).

With less uncertainty, firms can reduce inventory in the system without eroding the customer service level. Firms also can remove bottlenecks to maximize system efficiency, adjust system level planning to quickly respond to customer needs without hurting currently loaded customer orders, organize cellular manufacturing or focused factory production based on the system-level resources and requirements, and make engineering changes or process changes based on internal or external changes. All of these actions serve to reduce customer lead time.

IT integration and lead-time reduction

The findings suggest that neither within-firm IT integration (*H2* in Figure 3) nor between-firm IT integration (*H3* in Figure 3) helps reduce customer lead time directly. Rather, Figure 3 suggests that lean/JIT practices mediate the influence of both between-firm and within-firm IT integration on customer lead time. The finding that IT integration has no direct influence on lead time is surprising in light of the numerous articles such as McAfee (2002) reviewed earlier reporting IT integration as an effective approach to lead-time reduction. However, McAfee (2002) is a single case study and does not address whether the company in the study has an effective lean/JIT system. This study is unique in that it jointly considers the effects of lean/JIT and IT integration on lead time. By empirically testing a large data set, we show that when lean/JIT practices and IT integration are considered together, the direct effect of IT integration on lead time is overwhelmed by the indirect effect of IT integration as mediated by lean/JIT practices. This finding suggests that enhancing IT integration in itself is not as effective in reducing lead time as when used in conjunction with lean/JIT practices.

While it is relatively easy for firms to buy a suite of IT solutions, it is hard for firms to change their operating processes to enjoy the benefits of IT solutions. For example, one Intel manager said, "The biggest challenge is changing the process, not changing the technology" (Supply Chain Council, 2002). Because of the difficulty of altering operating processes, many firms that have adopted enterprise information systems have reported only limited benefits. Findings reported in both operations management and management information systems literature suggest that some IT investments have had big returns while others have not (Loveman, 1994; Mukhopadhyay, Kekre, & Kalathur, 1995). The findings reported here provide a possible explanation for such disparities.

Between-firm IT integration and within-firm IT integration

Between-firm IT integration is significantly associated with within-firm IT integration (*H4* in Figure 3). The point estimate of the correlation between between-firm IT integration and within-firm IT integration is positive (.26 for *H4* in Figure 3). Because the *t* value is greater than 2 (6.84 for *H4* in Table 5), *H4* in Figure 3 is supported by the analysis. Without high-quality information from the external environment, internal information communication cannot be effective. By the same token, without high-quality information from the internal environment, firms will not be able to communicate effectively with suppliers and customers.

IT integration and lean/JIT practices

The analysis shows that both within-firm IT integration and between-firm IT integration (*H5* and *H6* in Figure 3) have a significant positive influence on lean/JIT practices. The positive coefficients (.39 for *H5* and .26 for *H6* in Figure 3) of the links from within-firm IT integration and between-firm IT integration to lean/JIT practices imply that a higher level of within-firm IT integration and between-firm IT integration facilitates the adoption of lean/JIT practices. The *t* values of the estimates are significantly larger than 2 (9.05 for *H5* and 6.49 for *H6* in Table 5). Thus, *H5* and *H6* are supported in Figure 3.

This finding suggests that the extent of implementation of lean/JIT practices is enhanced by improved IT integration. IT integration improves the quality of information to lean/JIT systems, thus facilitating the adoption of lean/JIT practices. IT integration is especially important in high-variety production. In such environments, IT integration helps capture the dynamic information needed to guide lean/JIT operations when customer requirements are varied, complex, and prone to change. This finding also implies that the lead-time benefits of IT integration are mediated by lean/JIT practices. Thus, the extent to which lead-time reductions are realized depends on the lean/JIT improvement effort in place.

Regression Analysis

While the results in Figure 3 show that lean/JIT practices significantly mediate the influence of IT integration on lead-time performance at an aggregate level, we performed further analysis at a more disaggregate level (i.e., at the individual-indicator level) to check this mediation effect. We have a total of 10 indicators for lean/JIT practices and 12 indicators for IT integrations. To test the mediation effect, three regression tests are required for each pair of lean/JIT indicator and IT integration indicator. Take JIT1 and WFIT1 as an example (see Table 1 for the variable names). First, WFIT1 must have significant influence on the lead-time variable. Second, WFIT1 must have significant influence on JIT1. Third, the relationship of WFIT1 to the lead-time variable must change significantly when JIT1 is entered into the regression model (Swink, Narasimhan, & Kim, 2005). Then a Sobel test is performed to test the significance of the mediation effect (Venkatraman, 1989). The analysis results for the JIT1 and WFIT1 pair is in Table 6.

Model 1 in Table 6 shows that WFIT1 has a significant influence on lead-time performance. The regression coefficient is .2556. The *p* value is .003. Model 2 shows that WFIT1 has a significant influence on JIT1. The regression coefficient is .1711, which is significant at the .05 level. Model 3 shows that the coefficient of WFIT1 is .227 when JIT1 is entered into regression together with WFIT1. The *p* value for .227 is .010, which is reduced from .003 in model 1. To test whether this reduction is significant, a Sobel test is performed. The calculation of the Sobel test statistics is shown at the bottom of Table 6. The result shows that the Sobel test statistic is 2.085. The *p* value of this Sobel test is .037. This means that JIT1 significantly mediates the influence of WFIT1 on lead-time performance. Similar regression analysis is performed for each pair of lean/JIT and IT integration indicators. The Sobel test statistics are shown in Table 7. Only 5% of the Sobel test statistics are

Table 6: Regression analysis with JIT1 and WFIT1.

Variable	Model 1 (dependent variable: lead time)	Model 2 (dependent variable: JIT1)	Model 3 (dependent variable: lead time)
WFIT1	.2556* (.087015)	.1711* (.047041)	.227* (.087)
JIT1			.1694* (.066554)
F	8.628*	13.226*	7.583*

Notes: The numbers in the parentheses are the standard errors of the coefficients. Sobel test statistics is $.1694 \times .1711/\text{sqrt}(.1694^2 \times .047041^2 + .1711^2 \times .066554^2) = 2.085$.
*Indicates significance at $p < .05$.

Table 7: Regression analysis with individual lean/JIT practice and IT integration indicators.

	JIT1	JIT2	JIT3	JIT4	JIT5	JIT6	JIT7	JIT8	JIT9	JIT10
WFIT1[a]	2.09	3.45	3.30	2.40	2.77	2.71	3.07	4.11	2.97	2.47
WFIT2	2.12	3.29	3.70	2.37	2.93	3.03	2.76	3.31	3.14	3.01
WFIT3	2.10	2.74	3.09	2.24	2.57	2.38	2.90	3.45	3.13	2.82
WFIT4	2.37	3.60	3.59	2.75	2.83	2.60	2.12	3.30	3.38	3.01
WFIT5	1.20*	3.05	2.42	2.45	3.05	2.64	2.38	2.98	2.61	2.91
WFIT6	1.07*	2.56	2.19	2.39	1.57*	1.87	1.58*	1.94	.22*	2.77
WFIT7	2.15	2.69	2.96	2.38	2.72	2.22	1.94	2.99	2.86	3.06
BFIT1	1.99	3.10	3.42	2.42	2.82	2.90	2.63	2.85	2.75	2.69
BFIT2	1.83	2.92	2.69	2.34	2.77	3.08	2.67	2.81	3.34	2.19
BFIT3	2.16	1.72	2.46	2.25	2.51	2.84	2.03	1.41*	2.52	2.38
BFIT4	2.00	3.00	2.53	2.32	2.55	2.69	1.98	2.86	3.31	2.74
BFIT5	2.10	2.99	3.50	2.21	3.12	2.66	2.03	3.21	2.84	2.75

[a]Please see Table 1 for the full name of each variable.
*Indicates significance at $p > .10$.

not significant at the .1 level. Thus, we conclude that lean/JIT practices mediate the influence of IT integration on lead-time performance.

To further confirm the mediation effect found in the SEM analysis, we add up the 10 indicators of the lean/JIT practices to form a composite score and conduct Sobel tests with the composite scores of lean/JIT practice and two IT integrations. The results in Table 8 show that both Sobel test statistics are significant, which implies that lean/JIT practices significantly mediate the influence of two IT integrations on lead-time performance.

IMPLICATIONS

Theoretical Implications

The findings may be considered in the context of several organizational theories, including organizational learning, institutional theory, and the resource-based view of the firm. Organizational learning theory focuses on how firms learn (i.e., assimilate information and increase variety) and organize (i.e., routinize and reduce variety) (Kiesler & Sproull, 1982; Weick & Westley, 1996). IT integration is a mechanism for companies to assimilate information from external and internal environments, while lean/JIT practices are the means to routinize the work. Thus, our

Table 8: Regression analysis with lean/JIT practices and two IT integration composite scores.

Variable	Model 1 (dependent variable: lead time)	Model 2 (dependent variable: lean/JIT)	Model 3 (dependent variable: lead time)
WFIT	.082* (.025)	.984* (.087)	.013 (.026)
Lean/JIT			.070* (.010)
F	10.8*	127.9*	29.9*

Sobel statistics is 5.92.
p Value of the Sobel statistics is .00.
*Indicates significance at $p < .05$.

Variable	Model 1 (dependent variable: lead time)	Model 2 (dependent variable: lean/JIT)	Model 3 (dependent variable: lead time)
BFIT	.065* (.023)	.706* (.083)	.016 (.024)
Lean/JIT			.070* (.010)
F	7.9*	71.7*	30.0*

Sobel statistics is 5.48.
p Value of the Sobel statistics is .00.
*Indicates significance at $p < .05$.

findings can be understood in terms of organizational learning. Firms use within-firm and between-firm IT integrations to learn, that is, assimilate information from the external and internal environments. Firms also use this information to organize operating processes.

Institutional theory suggests that organizations become more and more similar over time because the similar external institutional forces reward the similarity (Jepperson, 1991; North, 1991). It implies that firms tend to take similar actions based on the similar institutional forces. However, the resource-based view of the firm argues that firms should develop and take actions based on their own internal resources (not external institutional forces), which create sustainable competitive advantages for firms (Barney, 1991). It can be argued that many firms have adopted information systems simply because their competitors or their business partners have adopted similar information systems. That business partners or competitors adopt information systems is an institutional force. The finding that lean/JIT practices significantly mediate the influence of IT integration on lead-time performance suggests that unique resources may be required to achieve any competitive advantage that follows from improving lead-time performance. The findings also suggest that effective JIT practices are resources that firms need to have in place before they can gain full benefit from IT integration.

As Boyer et al. (1997) suggest that manufacturing infrastructure investment is critical to unlock the benefits of technology investment, this study reveals that effective lean/JIT practices are also crucial to unlock the benefits of both internal and external IT integration. The results of this study concur with several extant studies suggesting that IT investment can lead to improved firm performance (Co et al., 1998; Small, 1999; McAfee, 2002), although we find that the impact of IT investment on improved firm performance is more indirect than direct.

Managerial Implications

Executives in pursuit of reduced customer lead time often choose either IT integration or lean/JIT practices as a means to that end. Our research provides several managerial insights about the role of lean/JIT practices and IT integration in reducing customer lead time.

First, this study shows managers the importance of lean/JIT practices and IT integration to lead-time reduction. Lead-time reduction has been an important concern to both practitioners and academics (Treville et al., 2004). This study empirically shows that lean/JIT practices directly help reduce customer lead time and mediate the influence of IT integration on lead-time reduction, which supports previous studies (Fullerton et al., 2003; Vickery et al., 2003). It is apparent that lean/JIT practices have a greater influence on lead-time performance than IT integration, be it internal, external, or both. The evidence is quite clear: manufacturing companies that seek to reduce lead times are better served by the focus on manufacturing processes inherent in lean/JIT practices than by integrating IT technology. This does not mean that IT system integration does not contribute to lead-time reduction. Rather, we show that lean/JIT practices *mediate* the effects of IT integration on lead time. The meaning for managers is clear. Firms will benefit from reduced lead times due to IT integration when the process improvements generated by lean/JIT practices are in place. Put another way, IT integration without the manufacturing process improvements embodied in lean/JIT might not have much effect on lead times. The findings support the argument in Bruun and Mefford (2004), that is, IT integration facilitates the use of lean/JIT practices. Internal and external IT integration can help various aspects of lean manufacturing, including JIT practices, quality management, and so on. Dell and Cisco use IT integration to capture information from customers, coordinate suppliers, and improve the leanness of their own operations. While past studies are primarily conceptual and/or anecdotal (Fullerton et al., 2003; Bruun & Mefford, 2004), this study uses a large data set to empirically support those conceptual and anecdotal studies. In short, the findings provide support for the belief often reported by managers with whom we have spoken: A large portion of the benefit derived from IT implementation can be attributed to the process improvement activity that precedes IT implementation.

Second, effective lean/JIT practices and good IT integration have different roles in reducing customer lead time. Effective lean/JIT practices standardize the processes and exploit the efficiency from the standardization (Rondeau et al., 2000). The standardization of operating processes tends to help companies make continuous improvements through more reliable production activities. We provide evidence that effective lean/JIT practices are a good way for firms to reduce customer lead time. On the other hand, IT integration is a means to reduce uncertainty in external and internal environments. When coupled with the standardization inherent in lean/JIT implementation, this uncertainty reduction allows progress in lead-time reduction. Without standardization, however, uncertainty reduction is less valuable, because the processes themselves are too unstable to control effectively. The evidence suggests that managers should seek to achieve lead-time reduction by exploiting both the opportunity to standardize through lean/JIT practices and the opportunity to reduce uncertainty through IT integration.

Third, the findings suggest that it is important for firms to align their investment level on IT and lean/JIT practices. A good example illustrating the importance of this alignment is from Toyota. Toyota has been well known for its effective lean/JIT practices. However, recognizing the importance of IT in improving firm performance, Toyota started to implement SAP in 1996 (EASY Software, 2006). Manufacturing managers needed to learn how and why IT integrations can facilitate lean/JIT practices, while IT managers learned the important role that lean/JIT practices play in making IT systems effective. While studies have found the importance of IT integration to firm performance (Cachon & Fisher, 2000; Lee et al., 2000; McAfee, 2002), many studies show that the influence of IT investment on firm performance is mediated by other factors (Boyer et al., 1997; Vickery et al., 2003).

CONCLUSION

As time-based competition intensifies, firms use various methods such as lean/JIT practices and IT integration to reduce lead time. This study highlights the relative contribution of lean/JIT practices and IT integration in reducing customer lead time. An empirical analysis of data from 769 manufacturing companies suggests the following findings: (1) effective lean/JIT practices significantly reduce customer lead time, (2) the influences of between-firm IT integration and within-firm IT integration on lead-time reduction are completely mediated by lean/JIT practices, (3) between-firm IT integration and within-firm IT integration facilitate the implementation and the use of effective lean/JIT practices, and (4) between-firm IT integration and within-firm IT integration are significantly correlated.

This study marks an early large-scale empirical effort to examine the influence of IT integration and lean/JIT practices on performance, in this case lead time, simultaneously. It indicates that lean/JIT practices mediate the impact of IT integration on customer lead time, thus providing a perspective on the IT productivity paradox issue (Solow, 1987; Brynjolfsson & Hitt, 1996). More specifically, this study suggests that lead-time reduction achieved through IT integration investments depends on the implementation and use of lean/JIT practices, that is, lean/JIT practices unlock the potential of both within-firm IT integration and between-firm IT integration. The finding that the two types of IT integration facilate the implementation and use of effective lean/JIT practices also corroborates the anecdotal evidence (Supply Chain Council, 2002).

One limitation of this study is that we only consider lean/JIT practices but not other operational practices. It is possible that IT integration's effect on some unidentified operational practices such as total quality management is squeezed into the links between IT integration and lean/JIT practices. Managers might be interested in finding other factors that might mediate the influence of IT integration on lead-time reduction. Those factors can be other manufacturing practices such as workforce management, process-quality management, supplier-relationship management, and product-process management (Swink et al., 2005). In addition, organizational issues such as organizational culture and organizational structure can be explored as well (Nahm, Vonderembse, & Koufteros, 2003; Nahm et al., 2004).

It is also crucial for managers to investigate the barriers and issues to implement effective lean/JIT practices and IT integrations.

Another limitation of this study is that the data are from 1999. However, the findings in this study are still relevant and valuable to today's business world. Our large sample includes firms in various stages of implementing IT integration and lean/JIT practices. Many firms are still in early stages of implementing IT integration and lean/JIT practices. The findings of this study are valuable to those firms implementing lean/JIT practices and IT integration. Although industry practices might have moved forward somewhat, recent studies do not show significant differences in the extent of use of lean/JIT practices in the past decade (Fullerton et al., 2003; Li et al., 2005). Although firms might have a wider range of IT integration practices today than in 1999, the IT practices considered in this study are still the ones that are widely adopted today. Therefore, we expect that the relationships between IT integration and lean/JIT practices that we describe still hold.

The findings in this study suggest at least two future research opportunities. First, a comparison of firms that emphasize lean/JIT practices but not IT integration versus the firms that emphasize IT integration but not lean/JIT practices might be fruitful. Based on the findings developed in this article, an emphasis on lean/JIT practices is associated with good lead-time performance. Therefore, it is expected at the extreme that firms that emphasize lean/JIT practices but neglect IT integration would have good lead-time performance. More interestingly, it is also expected that firms that emphasize IT integration but neglect lean/JIT practices do not exhibit good lead-time performance, despite their efforts in IT integration. An empirical test of this supposition would yield more insight on the relative merits of lean/JIT and IT integration approaches in reducing lead time.

Second, the model in this study can be extended to other firm performance measures such as financial performance, similar to Fullerton et al. (2003) that addresses the relationship between JIT and financial performance including stock price and/or firm value. In addition, the model can be extended to allow consideration of supply chain performance such as total supply chain cost, total lead time, and so on. Such an extension would provide insights into the extensiveness of the effects of lean/JIT and IT integration across the supply chain. [Received: February 2005. Accepted: April 2006.]

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Peter Ward is Professor of Operations Management and Chair of the Department of Management Sciences at The Ohio State University's Max M. Fisher College of Business in Columbus, Ohio. Dr. Ward' research has resulted in a number of articles on operations strategy that have appeared in journals such as *Journal of Operations Management* and *Production and Operations Management*. Dr. Ward is also Associate Director for research in the Center for Operational Excellence at Ohio State. He serves as a member of the advisory board of Ford Motor Company's Lean Resource Center and serves as a judge for *IndustryWeek's* America's Best Plants Program. He has also been Otto Mønsted Guest Professor at the Technical

University of Denmark in the Center for Technology, Engineering, and Management. Dr. Ward was a recipient of a Shingo Prize in 2004.

Honggeng Zhou is Assistant Professor in the Whittemore School of Business and Economics at the University of New Hampshire, where he teaches courses to both undergraduates and MBA students. His primary research interests include supply chain management and IT integration. He received his PhD in operations management from The Ohio State University, Columbus, Ohio.