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Abstract

Firms have invested over $15 billion in the past three years on new information technology and software in their manufacturing plants. In this study, we document how the implementation of new types of manufacturing practices has impacted the types of information technology investments in manufacturing plants. We present a conceptual model to develop hypotheses about relationships between manufacturing practices and the choice of information systems at the plant level. Analysis of cross-sectional survey data from 932 manufacturing plants provides strong empirical support for our hypotheses about how manufacturing practices influence decisions regarding adoption of plant-level IT applications.

Keywords: Manufacturing practices, information systems, resource planning systems, electronic data interchange, just-in-time manufacturing, supply chain coordination

Introduction

The 1990s witnessed a rapid growth in investments in supply chain information technology (IT) to improve productivity in manufacturing industries. The role of IT in manufacturing changed dramatically, from the early use of IT as a means to automate individual transactional processes, and later to communicate product data, to its current status as a mission-critical enabler of most enterprise processes (Chatterjee et al. 2001).

The business press provides anecdotal evidence on how the implementation of new types of manufacturing practices has impacted the types of investments which firms make in their manufacturing plants. Despite the high growth in plant-level IT investments during the last decade, little academic research has been conducted to study the impact of manufacturing practices on the choice of plant information systems. This raises an important empirical research question: Do manufacturing practices impact the adoption choice of plant information systems? We address this question about IT adoption at the plant level by examining IT adoption decisions for different types of applications.

Drawing on relevant theoretical frameworks, we model the role of manufacturing practices in determining the choice of plant-level information systems. Using survey data from a large cross-section of U.S. manufacturing plants for the year 1999, we study three types of manufacturing practices: just-in-time (JIT) production, Process Improvement Practices (PIP), and customer and supplier participation (CSP) practices. We evaluate their impact on the choice of three types of plant-level applications: resource planning systems (RPS), operations management systems (OMS), and electronic data interchange (EDI) applications.[1] We find that adoption of JIT has a significant positive impact on adoption of RPS. Our analyses indicate that plants with CSP practices are more likely to adopt EDI applications that enable customer and supplier coordination. Similarly, plants which implement process improvement programs are more likely to adopt plant-wide OMS which control shop floor processes.

The remainder of the paper is structured as follows. The next section describes the role of information technology in manufacturing and describes the interrelationships between information systems, manufacturing practices and other plant characteristics. We summarize our research hypotheses and then describe the research design and estimation model. We present and discuss the results of our statistical estimation models. Our findings are summarized and conclusions and issues for future research are discussed.

Role of Information Technology in Manufacturing

The manufacturing landscape has been altered with a large and growing segment of companies that have adopted flexible manufacturing operations with the goal of being able to react better to changes in customer demand. Many manufacturers now plan production jointly with their customers and suppliers and maintain constant communication with them. For example, Dell Computer has automated its processes to enable it to take thousands of orders, translate them into millions of component requirements, and work directly with its suppliers to build and deliver products customized to meet individual customer requirements. Suppliers use an Internet portal to view Dell's requirements, monitor changes in forecasts, and confirm their ability to meet Dell's delivery requirements. As Dell's factories receive orders and schedule assemblies, a "pull" signal to the supplier triggers the shipment of materials required to build current orders with a two-hour lead time. Thus, Dell illustrates the trends in plant information systems that enable companies to improve their flexibility to react to changes in customer demand, and develop close relationships with trading partners (Mulani and Lee 2001).

Alignment between manufacturing practices and information systems impact plants' capabilities in meeting customer requirements effectively. For instance, flexibility in manufacturing through JIT production may allow a firm to respond more effectively to market and technological uncertainties and facilitate long-term relationships with a few partners closely involved in collaborative product development (Mukhopadhyay and Kekre 2002; Morris and Hollman 1988). In turn, partners link their enterprise systems electronically so that order entry, invoicing, payment, and customer information are exchanged electronically, and demand planning and fulfillment systems are coordinated to mitigate the impact of uncertainty and errors associated with manual input. Hence, adoption of JIT makes it more attractive to adopt resource planning systems because such software enables companies to react quickly to changes in customer demand, increasing production flexibility, and reducing the risk of obsolete products.[2]

Manufacturing plants implement customer and supplier collaboration programs to improve coordination and control of cross-functional business processes by enabling greater visibility into relevant processes of customers and suppliers. For example, supplier involvement in new product development enables plants to communicate design changes quickly so that suppliers can adjust their production processes to produce new product prototypes efficiently. Such information exchange enables better coordination of production resources and also supports collaboration in areas such as forecasting and continuous replenishment programs. We organize these different plant level information systems into three groups: resource planning systems (RPS), operations management systems (OMS), and electronic data interchange (EDI) applications.

Resource planning systems (RPS) encompass three major classes of applications: enterprise resources planning (ERP) systems, which manage customer, product, planning, and financial information; advanced planning and scheduling (APS) systems which simulate business processes and provide decision support tools for supply chain management;[3] and material requirements planning

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[1]These manufacturing practices and applications are representative of modern-day manufacturing in a vast majority of manufacturing plants in North America (Davy 1992; Miltenburg 1995). Detailed characteristics of these practices and applications are provided in the research model section of this paper.

[2]Examples of RPS applications include SAP's mySAP product for supply chain management and the SCM software (previously known as TradeMatrix) from i2 Technologies.

[3]The footprint of RPS has evolved to include APS, which provides manufacturing plants with capabilities for constraint-based scheduling and real-time information processing for decision support.

(MRP II) systems, which support production planning, scheduling, shop floor control, job costing, forecasting, order processing, and performance measurement. From a business perspective, RPS facilitate reengineering of global business processes and data integration across the enterprise, while from a technical perspective, they facilitate installation of scaleable architectures and promise to be of significant importance to companies that implement them (Holland and Light 1999; Scott and Vessey 2000).

Operations management systems (OMS) control a wide range of plant processes including computerization of shop floor operations and synchronization of manufacturing activities across globally distributed plants. These applications enable product design engineers to create, document and share product data specifications with other design teams and support real-time design changes of manufacturing processes. For example, OMS applications manage process and product specifications for multiple plants centrally, provide revision control over constantly changing specifications, and enable plant managers to compare real-time plant measurements to customer specifications.

Electronic data interchange (EDI) applications significantly change how organizations conduct business with their customers and suppliers by improving the accuracy and timeliness of information exchanged over manual methods. Prior field studies found that EDI-enabled systems had favorable impact measured in terms of improved quality, higher inventory measures, and reduced shipment discrepancies (Anderson and Lanen 2002; Kekre and Mukhopadhyay 1992; Srinivasan et al 1994). A study of order processing systems reported that combining EDI with business process reengineering efforts lead to fewer errors in order processing and faster recovery of payments from customers (Mukhopadhyay and Kekre 2002). A study of the automotive industry reported that EDI-enabled systems led to savings of over $100 per vehicle for a typical assembly plant, in terms of impact on inventory, obsolescence, and electronic documentation and transmission costs (Mukhopadhyay et al. 1995).

We drew on earlier studies reported by practitioners and other researchers (ASCET 2001) to develop the classification of different types of information systems.[4] For instance, MRP II was an early predecessor to the present-day ERP systems and can logically be grouped together in the same category of enterprise planning systems. Similarly, APS can be viewed as extensions or add-ons to ERP systems as evidenced by the evolution of widely used ERP systems. The same logic applies to warehouse management systems (WMS). We also conducted an exploratory factor analysis, which showed that the indicator loadings were along patterns similar to those reported in Table 1.

We note that the three types of information systems are mutually exclusive, since their capabilities are fundamentally different. For instance, RPS and OMS may feed data to EDI-enabled applications but do not provide the EDI functionality. For instance, if a plant has implemented RPS which feeds data to EDI, the plant manager would then respond that both types of systems have been implemented at the plant.[5]

Research Model

We draw on earlier work in the area of *business value of information technology* to develop our research hypotheses with regard to the impact of manufacturing practices on the choice of plant information systems.[6] The choice of information systems implementation is a topic of considerable interest since managers are concerned with alignment between business requirements and information systems that support the business processes. Cooper and Zmud (1990) evaluated factors that impact implementation of MRP systems and focused on the interaction of managerial tasks with MRP and the resulting effect on adoption and infusion of the system. In this research, we estimate the impact of multiple types of business practices on the choice of different types of information systems at the plant level.

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[4]The papers in this volume discuss the functionality of different types of supply chain management systems, their scope, and how they may be grouped to address supply chain needs.

[5]On the other hand, if RPS does not have the capability to feed data to EDI or if an EDI application has not been implemented, the plant manager would then respond that only RPS has been implemented and not EDI.

[6]Another approach popular is to look at the fit between tasks and technologies as described in Goodhue and Thompson's (1995) task-technology fit (TTF) model or factors that drive technology acceptance as described in Davis' (1989) technology acceptance model (TAM). In our research, we do not measure TTF because the survey does not provide users' perceived evaluations or satisfaction with plant information systems or their perceptions of task characteristics.

Choice of Plant Information Systems

We now turn to factors that influence plants' decisions to adopt information systems.

Impact of JIT

The JIT production system is a line-flow production system that produces many products in low to medium volumes (Goetsch and Davis 2001; Miltenburg 1995). Since JIT systems are characterized by high frequency and intensity of customer-supplier interactions, they require greater information exchange between manufacturing plants and partners/suppliers. Prior research has also shown that JIT systems perform well when manufacturing processes support a high degree of information integration across the enterprise value chain (Monden 1998; Turnbull et al. 1992). Hence, we expect that JIT plants will have a greater propensity to adopt resource planning systems (RPS) to enable integration of manufacturing and related data.

Table 1. Confirmatory Factor Analysis Results for Scale Development

Construct	Indicator	Std. Factor Loading	t-value	p-value	Error Variance	Indicator Reliability	Composite Reliability
EDI	EDI1	0.617	14.11	< 0.01	0.15	0.38	0.85
	EDI2	0.597	13.69	< 0.01	0.157	0.36	
	EDI3	0.653	14.81	< 0.01	0.143	0.43	
	EDI4	0.53	13.26	< 0.01	0.14	0.28	
	EDI5	0.631	14.15	< 0.01	0.15	0.40	
	EDI6	0.652	14.32	< 0.01	0.144	0.43	
OMS	OMS1	0.546	6.03	< 0.01	0.114	0.30	0.74
	OMS2	0.623	6.88	< 0.01	0.056	0.39	
RPS	RPS1	0.460	10.21	< 0.01	0.115	0.21	0.81
	RPS2	0.739	12.36	< 0.01	0.097	0.55	
	RPS3	0.655	11.87	< 0.01	0.117	0.43	
	RPS4	0.30	dropped	-	-	-	
JIT	JIT1	0.685	16.57	< 0.01	0.282	0.47	0.73
	JIT2	0.535	14.08	< 0.01	0.383	0.29	
	JIT3	0.589	15.82	< 0.01	0.353	0.35	
	JIT4	0.545	14.35	< 0.01	0.29	0.30	
	JIT5	0.574	14.73	< 0.01	0.277	0.33	
	JIT6	0.553	14.69	< 0.01	0.354	0.31	
	JIT7	0.508	13.31	< 0.01	0.326	0.26	
	JIT8	0.554	14.36	< 0.01	0.329	0.31	
PIP	PIP1	0.656	13.87	< 0.01	0.242	0.43	0.64
	PIP2	0.516	12.44	< 0.01	0.39	0.27	
	PIP3	0.46	11.34	< 0.01	0.333	0.21	
	PIP4	0.53	12.25	< 0.01	0.286	0.28	
	PIP5	0.642	14.96	< 0.01	0.293	0.41	
CSP	CSP1	0.42	8.43	< 0.01	0.35	0.17	0.62
	CSP2	0.55	9.72	< 0.01	0.28	0.30	
	CSP3	0.63	10.31	< 0.01	0.28	0.39	
	CSP4	0.39	7.90	< 0.01	0.30	0.15	
	CSP5	0.40	8.23	< 0.01	0.35	0.15	
	CSP6	0.53	9.65	< 0.01	0.26	0.28	
	CSP7	0.58	10.01	< 0.01	0.28	0.33	

H1: *Plants employing JIT manufacturing are more likely to adopt resource planning systems.*

Integrated information systems using EDI facilitate sharing of JIT schedules with suppliers by providing precise information on future materials requirements (Cash and Konsynski 1985; Kekre and Mukhopadhyay 1992). Srinivasan et al. (1994) report a field study in the auto industry which highlights the importance of EDI in facilitating many of the coordination tasks inherent in a JIT environment. They report that suppliers which receive shipment schedules electronically and integrate the data directly into their enterprise systems via EDI have sharply lower shipment errors and discrepancies. Hence, we expect that JIT plants will adopt EDI to facilitate access to real-time production and demand data.

H2: *JIT plants are more likely to adopt EDI-enabled applications.*

Impact of Process Improvement Practices (PIP)

Process improvement practices are organizational infrastructure practices that serve as enablers for continuing improvements in manufacturing processes (Sakakibara et al. 1997). The fundamental elements consist of continuous process improvement, competitive benchmarking, statistical process control, and employee involvement and empowerment (Flynn et al. 1995). PIP, therefore, are likely to influence the choice of operations management systems (OMS), which encompass manufacturing execution systems (MES) and product data management (PDM) applications that address the complexity inherent in manufacturing processes.

MES applications enable improved management of shop floor operations to support quality improvements. PDM applications enable more efficient product design processes. These applications support implementation of total quality management (TQM) and competitive benchmarking by providing visibility into enterprise data which span multiple processes and enable product defects to be detected at earlier stages of the product life cycle.

H3: *Plants deploying process improvement practices are more likely to employ operations management systems.*

Impact of Customer and Supplier Participation (CSP) Practices

CSP practices are increasingly becoming differentiators of performance in many industries (Nambisan 2003). CSP practices include customer and supplier participation in new product development, customer-employee interaction, and collaborative planning, forecasting, and replenishment. Lee and Whang (2001) argue that EDI-enabled systems provide the foundation for coordinating customers and suppliers which is a necessary component for e-business integration. Srinivasan et al. (1994) provide empirical evidence from the automobile industry to document that vertical information integration using EDI enhances the shipment performance of OEM suppliers and enables closer coordination with suppliers. Based on a field study, they found that EDI enabled production schedules to be shared easily with suppliers by providing information on future material requirements. They reported that suppliers with EDI connectivity had significantly lower shipment errors. We expect that implementation of CSP will enhance the adoption of EDI applications.

H4: *Plants deploying CSP programs are more likely to adopt EDI applications.*

We note that not all linkages between manufacturing practices and information systems can be supported by theoretical or empirical evidence. For instance, there is no theory to support linkages between CSP and RPS, CSP and OMS, or between JIT and OMS. For example, even though PIPs may potentially have an impact on implementation of all three types of IS, we focus primarily on their impact on OMS since process reengineering practices entail implementation of supporting MES more so compared to other types of systems.

Research Method

Data Collection

Data for this research was based on a survey of manufacturing plant managers in the year 1999 conducted by *IndustryWeek* and PricewaterhouseCoopers Consulting. The survey consisted of a questionnaire mailed to plant managers and manufacturing executives across the United States. Targeted plants had two-digit SIC codes from 20 to 39 and employed a minimum of 100 people. Data were collected on manufacturing and management practices and information systems used within each plant. A total of 1,757 plants responded to the questionnaire for an overall response rate of 7 percent.[7] The usable sample contains 932 plants that provided complete responses to the variables of interest in our model.[8] The survey questions are presented in the Appendix.

Estimation Model

Figure 1 provides a schematic representation of our conceptual model which relates the adoption of information systems to manufacturing practices and other plant characteristics. We specify our conceptual model in terms of equations (1) through (3).

$$RPS = \alpha_0 + \alpha_1 * JIT + \alpha_2 * PIP + \alpha_3 * CSP + \alpha_4 * SIZE + \alpha_5 * AGE + \alpha_6 * VOLUME + a_7 * PROD\ MIX + \alpha_8 * DISCRETE + \alpha_9 * BUILD\ to\ FCST + \varepsilon_1 \quad (1)$$

$$OMS = \beta_0 + \beta_1 * JIT + \beta_2 * PIP + \beta_3 * CSP + \beta_4 * SIZE + \beta_5 * AGE + \beta_6 * VOLUME + \beta_7 * PROD\ MIX + \beta_8 * DISCRETE + \beta_9 * BUILD\ to\ FCST + \varepsilon_2 \quad (2)$$

$$EDI = \gamma_0 + \gamma_1 * JIT + \gamma_2 * PIP + \gamma_3 * CSP + \gamma_4 * SIZE + \gamma_5 * AGE + \gamma_6 * VOLUME + \gamma_7 * PROD\ MIX + \gamma_8 * DISCRETE + \gamma_9 * BUILD\ to\ FCST + \varepsilon_3 \quad (3)$$

Since the three dependent variables and the three key independent variables are measured as latent variables, we used a structural equation model (SEM) approach to estimate the specified relationships. We estimated the three equations simultaneously using the AMOS 4.0 structural equations modeling software.

Measure Validity and Reliability

We performed a confirmatory factor analysis (CFA) to establish the reliability of our measures of the three plant information systems and the three manufacturing practices.[9] The factor loadings for all constructs were significant at the 1 percent level. Two measures of reliability using CFA are indicator reliability and composite reliability for each construct (Fornell and Larcker 1981) as shown in Table 1. Indicator reliability is the percent of variation that is explained by the construct measure. Composite reliability reflects the internal consistency of the indicators (Werts et al. 1974). It was above 0.6 for all six constructs and exceeded the recommended threshold value for new scale development (Nunnally and Bernstein 1994).

Convergent and discriminant validity is established by measuring the degree of agreement in responses to different survey items (Phillips and Bagozzi 1986). The t-values for all factor loadings exceeded the critical value of 3.29, significant at the 1 percent level. This indicates that our measures satisfy convergent validity (Anderson and Gerbing 1988). To establish the discriminant validity of the six constructs, we used a sequential chi-square difference test (SCDT) as described in Anderson and Gerbing (1988). We estimated 15 CFA models with pairs of constructs in each model. The difference in the chi-square statistic between unconstrained and constrained models was greater than 3.84, statistically significant at the 1 percent level, and indicated that the construct measures satisfied discriminant validity.

[7]While the response rate is small compared to empirical studies in the IS literature, it is comparable to large operations surveys as reported in Roth and Van der velde (1991) and in Stock et al. (2000).

[8]Nonresponse bias was assessed by comparing the proportion of respondents to total surveys mailed for each SIC code. The data does not indicate a significant difference based on chi-square = 11.8, df = 19, and p = 0.80.

[9]We used the questionnaire items reflexively in developing the measurement equations in the CFA model.

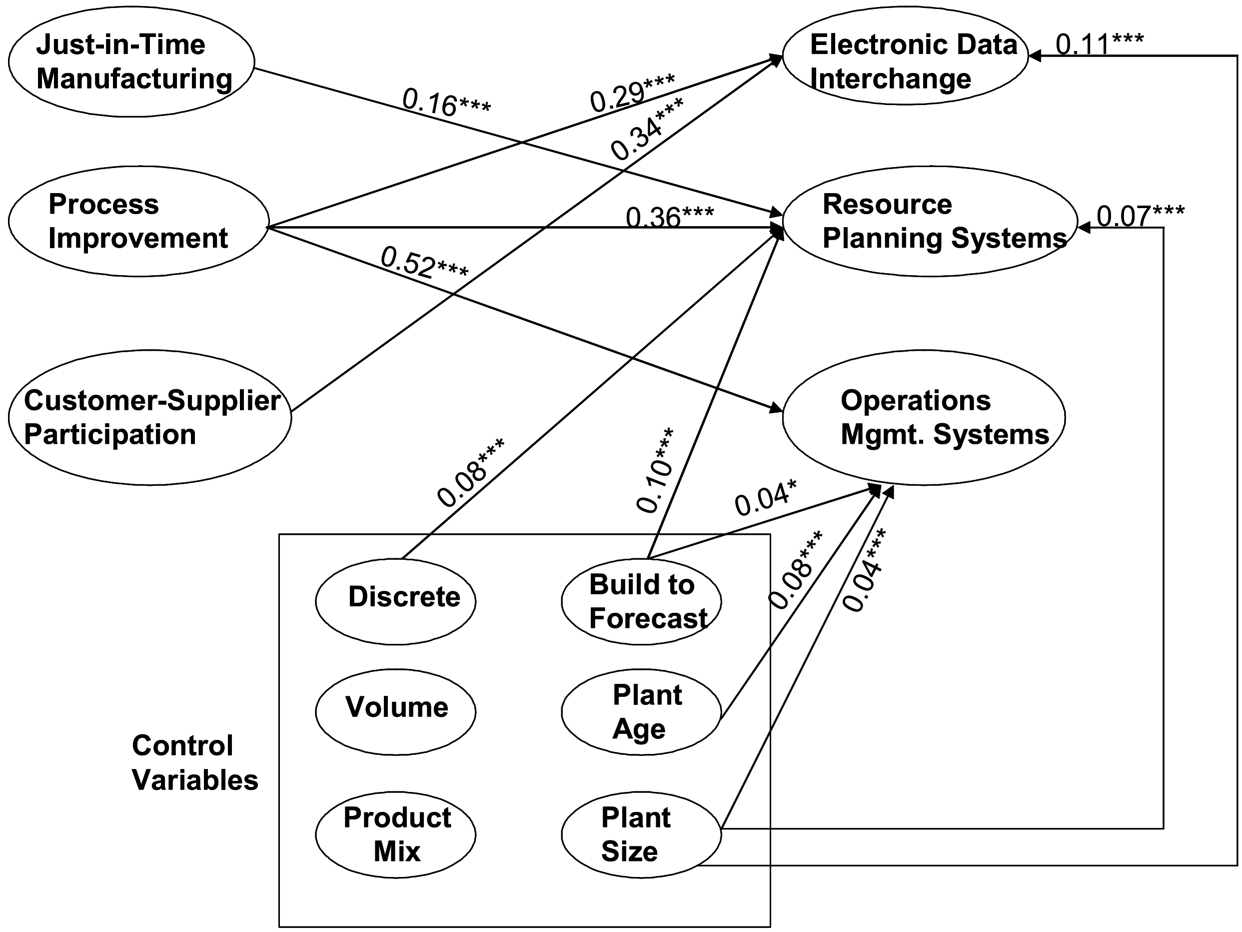

Figure 1. Estimated Path Model of Adoption of Plant Information Systems
(Only paths significant at $p < 0.10$ are shown)

Control Variables

We also include variables to control for the impact of plant characteristics on the adoption of plant information systems.[10] These variables include plant age (AGE), plant size (SIZE), product volume (VOLUME), product mix (PRODMIX), nature of manufacturing operations (DISCRETE), and order fulfillment practices (BUILD to FCST). Plant size is likely to be related to the choice of information systems since large plants may have the scale and financial resources required to justify investments in comprehensive enterprise information systems to manage complex information processing needs. Product volume and product mix characterize the nature of the manufacturing operations, and thereby influence the choice of information systems. We include order fulfillment practice (BUILD to FCST) since plants that adopt build-to-forecast strategies incur a need for applications that support a high level of planning, forecasting, and scheduling.

[10]The relationship between these control variables and the plant IS constructs is formative.

Table 2. SEM Estimation Results of the Impact of Manufacturing Practices on the Adoption of Plant Information Systems
(p-values are shown in parentheses)

Independent Variable	Resource Planning Systems (RPS) (1)	Operations Management Systems (OMS) (2)	Electronic Data Interchange (EDI) (3)
Just-in-Time (JIT) Manufacturing	0.16*** (0.01)	-0.09 (0.35)	-0.07 (0.35)
Process Improvement Practices (PIP)	0.36*** (0.000)	0.52*** (0.000)	0.29*** (0.000)
Customer and Supplier Participation (CSP)	-0.001 (0.99)	0.09 (0.37)	0.34*** (0.000)
Plant Size (SIZE)	0.07*** (0.000)	0.04*** (0.001)	0.11*** (0.001)
Plant Age (AGE)	-0.02 (0.56)	0.08*** (0.001)	-0.02 (0.55)
VOLUME	-0.03 (0.388)	-0.07 (0.16)	0.05 (0.17)
Product Mix (PRODMIX)	0.05 (0.21)	-0.001 (0.99)	-0.03 (0.31)
DISCRETE	0.08*** (0.01)	-0.04 (0.10)	0.03 (0.36)
BUILD to FORECAST	0.10*** (0.01)	0.04* (0.06)	0.02 (0.49)

Estimation Results

Figure 1 shows the path estimates of the impact of manufacturing practices on the adoption of plant information systems.[11] The CFA fit measures, represented by the adjusted goodness of fit index (AGFI) and comparative fit index (CFI), are 0.95 and 0.91, respectively, above the threshold level for satisfactory model fit (Chatterjee et al. 2002; Hair et al. 1995). The root mean square error of approximation (RMSEA) for our measurement model was equal to 0.05, below the threshold value of RMSEA set at 0.06 which indicates an acceptable level of internal consistency (Hu and Bentler 1999).[12]

Regression estimates of the SEM path coefficients are shown in Table 2. Column 1 of Table 2 indicates that JIT practices have a significant impact on the adoption of RPS. This result supports hypothesis H1, and indicates that RPS serve as enablers in a JIT environment and provide the application infrastructure necessary to achieve integration of enterprise data in a real-time manner. Furthermore, PIP also has a significant impact on the adoption of RPS. This result indicates that business process improvement practices drive the adoption of RPS and reinforces observations made by practitioners that process improvement is a critical success factor for ERP implementations (Davenport 1998).

The path estimation coefficients in column 2 of Table 2 indicate that PIP have a significant impact on the adoption of OMS, supporting our hypothesis H2 that plants which implement process improvement practices choose to adopt OMS for automating and improving manufacturing processes. Estimates of path coefficients in column 3 indicate that CSP programs significantly impact the adoption of EDI and support hypothesis H3.

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[11]Only the significant path estimates ($p < 0.10$) are shown by solid arrows in Figure 1. We tested the significance of the other paths as well. The results, as noted in Table 2, indicate that *not all* manufacturing practices have a significant impact on the three types of information systems.

[12]We used the covariance matrix for estimation. The model required 11 iterations for convergence.

Our results also indicate that plant characteristics play an important role in the choice of information systems. For instance, plant SIZE has a significant impact on the adoption of all three types of plant information systems, which indicates that larger plants are more likely to expend the resources required for the implementation of plant-wide systems such as RPS, OMS, and EDI. The estimation results also indicate that both DISCRETE manufacturing and BUILD to FCST practices have a significant impact on adoption of RPS. The results show that plants with a discrete manufacturing process are more likely to adopt RPS since discrete manufacturing processes require greater coordination to support frequent product introductions, and RPS provide the enabling application infrastructure to support such coordination. Similarly, plants with build-to-forecast strategies are more likely to adopt RPS, since these applications support real-time integration of customer information which is required for real-time planning, forecasting and scheduling.

We conducted chi-square tests to test for differences in relative magnitudes of the estimated path coefficients. Table 3 presents the results of our chi-square tests to test for differences in path coefficient values for the manufacturing variables in equation (1).[13] In Panel A of Table 3, we test the difference between JIT and PIP path coefficients, since both have a significant impact on adoption of RPS applications. We note that the chi-square statistic for the null hypotheses $\alpha_1 = \alpha_2$ is equal to 3.41, which is significant at the 10 percent level. This indicates that process improvement practices are more influential than JIT in explaining adoption of RPS in manufacturing plants, consistent with findings from practitioner studies (Cliffe 1999). Panel A also indicates that both PIP and JIT have a significantly greater impact on RPS adoption compared to CSP.

Panel B provides chi-square test results for differences between PIP and CSP coefficients in equation (3). The chi-square statistic for the null hypotheses $\gamma_2 = \gamma_3$ is not statistically significant. This indicates that both PIP and CSP are equally important in explaining adoption of EDI applications in manufacturing plants. The results in panel B also indicate that both PIP and CSP have significantly greater impact on EDI adoption compared to JIT.

Table 3. Differences in the Impact of Manufacturing Practices on Information Systems

Impact of	Null hypotheses	χ^2 Statistic	p-value
Panel A: RPS	$\alpha_{1(JIT)} = \alpha_{2(PIP)}$	3.41	0.06*
	$\alpha_{1(JIT)} = \alpha_{3(CSP)}$	4.53	0.03**
	$\alpha_{2(PIP)} = \alpha_{3(CSP)}$	4.02	0.03**
	$\alpha_1 = \alpha_2 = \alpha_3$	6.07	0.04**
Panel B: EDI	$\gamma_{1(JIT)} = \gamma_{2(PIP)}$	10.72	0.001***
	$\gamma_{1(JIT)} = \gamma_{3(CSP)}$	11.19	0.001***
	$\gamma_{2(PIP)} = \gamma_{3(CSP)}$	1.71	0.19
	$\gamma_1 = \gamma_2 = \gamma_3$	15.46	0.0004***

$$RPS = \alpha_0 + \alpha_1\, JIT + \alpha_2\, PIP + \alpha_3\, CSP + \alpha_4\, BUILD\ to\ FCST + \alpha_5\, DISCRETE + \alpha_6\, VOLUME + \alpha_7\, PROD\ MIX + \alpha_8\, SIZE + \alpha_9\, AGE + \varepsilon_1 \quad (1)$$

$$EDI = \gamma_0 + \gamma_1\, JIT + \gamma_2\, PIP + \gamma_3\, CSP + \gamma_4\, SIZE + \gamma_5\, AGE + \gamma_6\, VOLUME + \gamma_7\, PROD\ MIX + \gamma_8\, DISCRETE + \gamma_9\, BUILD\ to\ FCST + \varepsilon_3 \quad (3)$$

* significance at 10% level, ** significance at 5% level, *** significance at 1% level.

Discussion of Findings

The results of the path analysis show that

1. JIT manufacturing plants are likely to adopt resource planning systems, supporting our hypothesis H1.

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[13]We do not conduct a test for equation (2) since PIP is the only manufacturing variable that is statistically significant.

2. Plants that implement process improvement practices are more likely to adopt operations management systems, supporting hypothesis H2.

3. Plants that implement customer and supplier participation programs are more likely to adopt EDI applications, supporting hypothesis H3.

4. Plant size, age, and type of order fulfillment practice have a significant impact on adoption of plant-level applications. Larger plants are more likely to adopt plant information systems while discrete manufacturing plants are more likely to adopt resource planning systems.

We find that PIPs also influence the adoption of other types of plant information systems such as RPS and EDI-enabled applications. There are several studies indicating that process improvement programs are a necessary prerequisite to realize the full benefits of RPS applications (Cliffe 1999; Markus and Tannis 2000; Scott and Vessey 2000). Adoption of process improvement programs enables processes to be streamlined and production bottlenecks to be identified prior to implementation of RPS applications (Holland and Light 1999; Robey et al. 1995). Similarly, they provide the capabilities necessary for the adoption of EDI applications which allow customers to conduct Web-based transactions such as order entry, procurement, customer service, and new product development.

Conclusions

This research constitutes one of the first studies to provide empirical evidence on the relationships between plant information systems and manufacturing practices. Our study documents that manufacturing practices have a significant impact on the choice of plant information systems. Our findings suggest that JIT production plants are more likely to adopt resource planning systems, while implementation of customer and supplier participation is associated with the adoption of EDI applications. Process improvement practices drive the choice of all three types of plant applications, but their impact is the greatest on the adoption of OMS.

In ongoing research, we plan to extend this line of inquiry to examine the joint impact of information systems and manufacturing practices on plant performance. This is an important consideration since workers may be reluctant to use new types of technologies and processes, especially if they entail significant changes to existing processes, skills, or work habits (Devaraj and Kohli 2003).

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Appendix: Survey Questions

I. Plant Characteristics

Variable	Question
SIZE	How many employees are at this plant location? 1 = Less than 100; 2 = 100-249; 3 = 250-499; 4 = 500-999; 5 = 1,000 or more employees
AGE:	How many years has it been since plant start-up? 1 = Less than 5 years; 2 = 5-10 years; 3 = 11-20 years; 4 = More than 20 years
VOLUME, MIX[14][15]	How would you describe the primary product mix? 1 = high volume, high mix; 2 = high volume, low mix, = Low volume, high mix; 4 = Low volume, low mix
DISCRETE[16]	What is the nature of the manufacturing operations for primary products at this plant? 1 = Discrete, 2 = Process, 3 = Hybrid
Build to FCST[17]	What is the primary order fulfillment practice of your plant operation? 1 = Build to Forecast; 2 = Build to Order; 3 = Configure to Order; 4 = Engineer to Order

II. Manufacturing Practices: Please indicate the extent to which each of the listed manufacturing practices has been adopted at your plant

	Question	1 = No Implementation	2 = Some Implementation	3 = Extensive Implementation
Just-in-Time (JIT) Manufacturing				
1	JIT production	1	2	3
2	Lot size reductions	1	2	3
3	Pull system/Kanban	1	2	3
4	Cycle-time reductions	1	2	3
5	Agile Manufacturing	1	2	3
6	Focused-factory production	1	2	3
7	Quick changeover techniques	1	2	3
8	Bottleneck / constraint removal	1	2	3
Process Improvement Practices (PIP)				
1	Formal continuous improvement programs	1	2	3
2	Process capability measurements	1	2	3
3	Predictive or preventive maintenance	1	2	3
4	Competitive benchmarking	1	2	3
5	Total Quality Management	1	2	3
6	Focused-factory production	1	2	3

[15]We split this into two dummy variables defined as VOLUME = 1 if high volume and zero otherwise, and MIX = 1 if high mix and zero otherwise

[16]We aggregated the responses so that 1 = Discrete and 0 = Process/Hybrid.

[17]We aggregated the responses so that 1 = Build to Forecast and 0 = otherwise.

	Question	1 = No Implementation	2 = Some Implementation	3 = Extensive Implementation
Customer and Supplier Participation Programs				
1	Continuous replenishment programs for customers	1	2	3
2	Suppliers involved early in new product development	1	2	3
3	Key suppliers deliver to plants on JIT basis	1	2	3
4	Customers interact with production employees	1	2	3
5	Customers participate in new product development	1	2	3
6	Suppliers manage inventory	1	2	3
7	Suppliers contractually committed to cost reductions	1	2	3

III. Plant-Level Information Systems

Which of the following technologies and technology-based systems have been implemented at your plant?

	Question	0 = Not Yet Implemented	1 = Implemented
Resource Planning Systems (RPS)			
1	Enterprise Resource Planning (ERP) System	0	1
2	Advanced Material Requirement Planning (MRP) II System	0	1
3	Advanced Planning and Scheduling	0	1
4	Transportation / Warehouse Management Systems	0	1
Operations Management Systems (OMS)			
1	Product Data Management (PDM) System	0	1
2	Manufacturing Execution System (MES) for production	0	1
Electronic Data Interchange (EDI) Applications			
1	Collaborative business forecasting with customers and/or suppliers via EDI/Web-enabled applications	1	0
2	Customer service and/or help desk via EDI/Web-enabled applications	1	0
4	Collaborative new product development with customers and/or suppliers via EDI/Web-enabled applications	1	0
5	Direct material procurement via EDI/Web-enabled applications	1	0
6	Invoices and/or payments via EDI/Web-enabled applications	1	0