

PLANT INFORMATION SYSTEMS, MANUFACTURING CAPABILITIES, AND PLANT PERFORMANCE¹

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Abstract

Firms have been investing over \$5 billion a year in recent years on new information technology and software in their manufacturing plants. In this study, we develop a conceptual model based on the theory of dynamic capabilities to study how manufacturing plants realize improvements in plant performance by leveraging plant information systems to enable implementation of advanced manufacturing capabilities. We develop hypotheses about relationships between information systems, their impact on manufacturing practices, and the overall impact on plant performance. Analysis of survey data from 1,077 U.S. manufacturing plants provides empirical support for the dynamic capabilities model and suggests that manufacturing capabilities mediate the impact of information systems on plant performance. Our results underscore the importance of manufacturing and organizational capabilities in studying the impact of IT on manufacturing plant productivity, and provide a sharper theoretical lens to evaluate their impact.

Keywords: Manufacturing capabilities, information systems, resource planning systems, electronic data interchange, just-in-time manufacturing

Introduction

The 1990s witnessed a rapid growth in investments in information technology for supply chain management to improve productivity in manufacturing industries. The role of IT in manufacturing has changed dramatically, from its early use as a means to automate individual transactional processes to its current status as a mission-critical enabler of enterprise pro-

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cesses. Despite the high growth in plant-level IT investments during the last decade, little academic research has been conducted to study the impact of information systems on manufacturing plant performance. Understanding the role of IT in enabling the development of manufacturing capabilities is critical in evaluating and rationalizing IT investments.

Prior research has mostly focused on the impact of IT investments on firm-level performance (Chatterjee et al. 2001; Dos Santos et al. 1993), and several have found that IT spending has a positive impact (Barua et al. 1995; Brynjolfsson and Hitt 1996; Kohli and Devaraj 2003; Menon et al. 2000). These approaches lump all IT-related spending, including investments in computer hardware, telecom infrastructure, and peripherals, under one category, typically measured as "IT capital." While IT capital is a useful measure of firm IT investments, it does not allow us to isolate the impact of software applications on plant processes (Mukhopadhyay et al. 1997). Second, examining the direct relationship between IT resources and a firm's *overall* performance can lead to misleading conclusions, since the competitive advantages associated with IT-enabled business processes may be appropriated before they are reflected in the firm's aggregate performance (Ray et al. 2004). Since IT investment decisions are often made at the application level, we focus on their impact on business processes, which allows us to trace their impact on specific types of manufacturing capabilities and plant performance metrics.

Despite a large body of literature on the business value of IT, the impact of specific types of enterprise software applications remains unclear (Melville et al. 2004). Prior research has observed that successful application of IT is often accompanied by the complementary organizational capabilities, including organizational structure, decision-making processes, and other firm-specific practices. In their study on the productivity impact of IT across a large cross-section of firms and industries, Brynjolfsson and Hitt (1995) found that firm effects may account for as much as 50 percent of the productivity benefits imputed to IT in earlier studies. Since organizational and managerial capabilities comprise an important element of firm-specific characteristics, it is critical to develop a holistic understanding of the role of IT in enabling these types of organizational-specific effects and their impact on manufacturing performance.

In this research, we propose to study two important questions in a manufacturing environment:

(1) Do plant information systems enable manufacturing capabilities?

(2) What is the impact of plant information systems on plant performance?

We draw on the theory of dynamic capabilities to develop a research model to address these questions. Dynamic capabilities refer to a firm's ability to create competitive advantage by leveraging IT and complementary organizational resources to develop unique, change-oriented capabilities that enable firms to meet customer needs and respond to competitors.

Using survey data from a large cross-section of U.S. plants, we study three classes of plant-level information systems: resource planning systems (RPS), operations management systems (OMS), and electronic data interchange (EDI) applications. We find that the impact of information systems on plant performance is *mediated* through two types of advanced manufacturing capabilities: just-in-time (JIT) and customer and supplier participation (CSP) capabilities. Specifically, we find that both RPS and EDI technologies have a positive and statistically significant impact on improvements in plant quality, time to market, and efficiency. The impact of OMS on plant performance is positive but not statistically significant.

The paper is organized as follows. In the next section, we propose a typology of IS resources in manufacturing and describe the relationships between plant information systems and manufacturing capabilities. Next, we summarize our theoretical framework and research hypotheses followed by a description of the data and estimation model. We then present and discuss the results of our statistical estimation. We conclude with a discussion of the managerial implications of our study, its limitations, and issues for future research.

A Typology of Plant Information Systems

Alignment between information systems and manufacturing practices impact plants' abilities to meet customer requirements effectively. For example, suppliers of Dell Computer use an internet portal to view Dell's requirements, monitor changes in forecasts, and confirm their ability to meet delivery requirements. As orders are received, a pull signal triggers the just-in-time shipment of materials with a 2-hour lead time to fill customer orders (Mulani and Lee 2001). Little research has been conducted to empirically test the presence of such linkages between plant information systems and advanced manufacturing capabilities. While prior research has focused on the direct impact of IT on manufacturing per-

formance, we posit that information systems support inter- and intra-organizational information exchange, and foster joint decision-making capabilities with customers and suppliers.

We draw on earlier research by Day (1994) and Wade and Hulland (2004) on a typology for IS resources to classify the plant information systems in our study. They can be classified into three groups: *outside-in*, *inside-out*, and *spanning* resources. *Outside-in* resources encompass IS resources that enable firms to manage relationships with external stakeholders, such as customers, suppliers, and other partners. They enable firms to work with suppliers and partners and to manage customer relationships by supporting customer-focused capabilities, such as collaborative product development (Bharadwaj 2000; Feeny and Willcocks 1998). They foster capabilities for quick response and flexibility to deal with changes in market conditions (Ross et al. 1996; Zaheer and Zaheer 1997).

Electronic data interchange (EDI) applications represent *outside-in* IS resources that have changed how organizations conduct business by improving the accuracy and timeliness of information exchange. EDI applications provide interorganizational capabilities for joint decisions on procurement and new product development with suppliers (Mukhopadhyay and Kekre 2002; Powell and Dent-Micallef 1997; Srinivasan et al. 1994). They also facilitate market responsiveness capabilities by fostering customer/supplier involvement in forecasting and order management processes (Anderson and Lanen 2002).

Inside-out IS resources are focused on enhancing the capabilities of internal firm operations (Wade and Hulland 2004). These resources include applications that enable firms to take advantage of technological advances to support effective IS operations (Zaheer and Zaheer 1997), and software that foster better IT infrastructure capabilities (Marchand et al. 2000). They also include infrastructure resources to support cost-effective operations, which helps firms to develop and sustain cost leadership positions in their respective industries (Ross et al. 1996).

Plant operations management systems (OMS) represent *inside-out* IS resources since they control and monitor internal plant processes by supporting computerization of shop floor operations and synchronization across multiple plants. OMS applications encompass manufacturing execution systems (MES) and product data management (PDM) applications which control plant-level operational processes. OMS enable engineers to create, document, and share product data specifications with other design teams/firms, provide revision control, and support plant operations by providing the

appropriate control and monitoring capabilities necessary for efficient process workflows. One example of a MES is the Virtual Factory application, from Camstar, which enables companies to implement collaborative manufacturing strategies where workflows of multiple factories are coordinated centrally to provide plant managers with real-time tracking, visibility, and control across several plants.

Spanning IS resources enable integration and alignment between IS and other functional areas. They provide capabilities necessary to integrate a firm's inside-out and outside-in resources, and allow managers to plan, manage, and use appropriate technology standards and span functional gaps across business processes (Feeny and Willcocks 1998; Ross et al. 1996). They enable inter- and intra-firm collaboration by providing the infrastructure for assimilation and integration of information across different functional areas (Bharadwaj 2000).

Resource planning systems (RPS) represent *spanning* IS resources which support enterprise-wide data integration, and enable synergistic relationships across different functional areas. RPS encompass three classes of applications: ERP systems, which manage customer, product, planning, and financial data; advanced planning and scheduling (APS) systems, which provide decision support tools for supply chain management; and material requirements planning (MRP II) systems, which support production planning, shop floor control, and order processing. RPS facilitates data integration and enables installation of standardized, scaleable architectures across the firm (Davenport 1998; Scott and Vessey 2000).

Next, we develop our research hypotheses about the impact of these types of plant information systems on manufacturing capabilities and plant performance.

Research Model

We draw on the theory of dynamic capabilities which explain how firms create value by creating relevant organizational processes and structures to leverage their IT assets (Teece et al. 1997). It explains how firms create sustainable performance advantage by assembling difficult to imitate resources that work together to create organizational capabilities (Barney 1991; Wernerfelt 1984). Although IT assets may be viewed as mobile and imitable resources, they enable unique organizational routines and are often bundled with an organization's commitment to specific business processes. Customization of IT infrastructure to firm-specific processes

is complex and often inimitable (Henderson and Clark 1990; Melville et al. 2004). Hence, IT assets provide the building blocks for business processes to form capabilities, and a firm's ability to enhance these capabilities leads to competitive advantage (Tallon and Kraemer 2004).

Capabilities are dynamic to the extent that firms must continually reconfigure internal and external competencies to adapt to business conditions, especially in fast-paced technological environments where speed to market is critical (Eisenhardt and Martin 2000; Iansiti and Clark 1994; Pavlou and El Sawy 2004). Consistent with this theory, the ability of firms to leverage their IT capabilities to develop closer relationships and create agile and flexible competencies represents dynamic capabilities which can lead to improved customer value (Sambamurthy 2000; Sambamurthy et al. 2003; Wheeler 2002). Early research by Clark and Fujimoto (1991) and Cooper and Zmud (1990) indicates that plant information processing requirements are closely aligned to manufacturing capabilities in high performance plants. Schroeder et al. (2002) show that a plant's ability to incorporate external and internal learning, through interactions with customers and suppliers, translates into proprietary capabilities, an important enabler of plant performance.

In our research context, dynamic capabilities theory provides the theoretical foundation for studying the context in which plant information systems may lead to better plant performance. We posit that IT enables implementation of advanced manufacturing capabilities which, in turn, lead to improvements in plant performance. JIT manufacturing and customer/supplier participation in supply chain processes represent two critical manufacturing capabilities (Miller and Roth 1994). The business value from IT is linked to complementary changes in organizational process capabilities. Hence, IT assets by themselves may not provide much direct value but, when combined with other organizational practices, enable unique combinations of organizational capabilities leading to superior performance (Zhu and Kraemer 2002).

Building on prior research in manufacturing strategy, we measure plant performance along multiple dimensions that include plant quality, time to market, and productivity (Ferdows and De Meyer 1990; Miller and Roth 1994). It is important to measure performance along different dimensions since there exist tradeoffs between improvements in these measures. Hence, we collect metrics that represent these three dimensions to develop a more complete view of plant performance. Our conceptual research model, which describes the relationship between plant information systems, manufacturing capabilities, and plant performance, is shown in Figure 1.

Impact of Resource Planning Systems on Plant Performance

RPS provide seamless integration of enterprise information flow which increases the accuracy of customer information for forecasting and planning, and enables efficient resource allocation (Baskerville et al. 2000; Davenport 1998).² RPS facilitate JIT capabilities by supporting a high intensity of information exchange and coordination between manufacturing plants, customers, and suppliers (Turnbull et al. 1992). This enables plants to develop agile manufacturing capabilities, increase their production flexibility, and reduce the risk of obsolete products, thus increasing the effectiveness of JIT production.

Firms that develop JIT capabilities are better aligned to customer needs and have short manufacturing lead times (Srinivasan et al. 1994). Benefits due to JIT implementation range from reduced work-in-progress and finished goods, and lower space requirements, to better quality and higher productivity (Gupta and Somers 1996). The benefits of improved flexibility translate into improved plant- and firm-level performance (Bates and Flynn 1999; Gerwin 1993; Hendricks and Singhal 1997; Sakakibara et al. 1997). Hence, by helping to integrate business information across the firm, RPS improve plant managers' abilities to track work progress, spot and correct deviations, and consistently execute on business initiatives. Improvements in consistency and plant flexibility, due to JIT capabilities, lead to better plant performance.

H1a: *The impact of RPS on plant performance is mediated through JIT capabilities.*

Manufacturing plants implement customer and supplier participation (CSP) programs to improve collaboration and obtain greater visibility into their business processes. Improving customer-supplier interaction helps to reduce plant manufacturing complexity by establishing cooperative relations to jointly solve problems (Galbraith 1977). Such programs include participation in new product development, collaborative planning, forecasting, and replenishment decisions (Nambisan 2003). RPS enable implementation of CSP capabilities by providing the IT infrastructure required to exchange information about changes in customer demand, product design specifications, and plant resources. By providing greater transparency to process workflows, RPS enable

²A few examples of RPS applications include SAP's ERP and APO (advanced planning optimizer) tools and supply chain software from i2 Technologies and Manugistics. These systems typically consist of several modules that automate workflows across procurement, logistics, production, accounting, and order management functions.

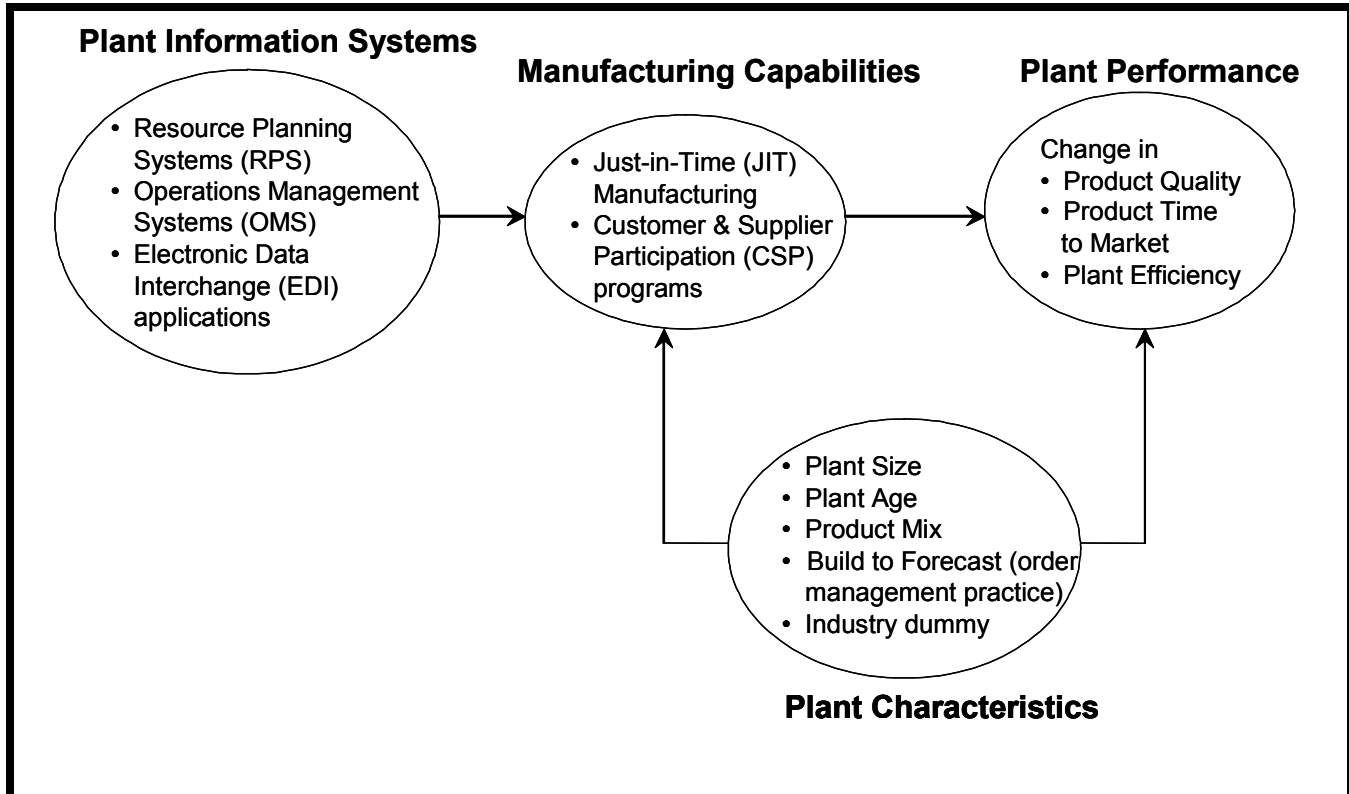


Figure 1. Conceptual Research Model

plant managers to improve alignment with strategic objectives, rationalize project/product portfolios, and eliminate redundant initiatives.

Fostering collaborative relationships and encouraging customer and supplier involvement in plant manufacturing processes has several potential benefits (Bakos and Brynjolfsson 1993; Barua et al. 2004). For example, improving customer and supplier participation in new product development (NPD) enables plants to communicate design changes earlier in the design cycle which, in turn, is associated with lower product defect rates. CSP capabilities enable cooperation on problems ranging from product design to collaborative forecasting and inventory replenishment (Barua et al. 2004; Subramani 2004). Such collaboration, through greater use of RPS software, translates into quicker plant response times which can result in greater plant efficiency (Dudley and Lasserre 1989). Hence, we hypothesize that RPS will improve plant performance by enabling the development of closer customer-supplier relationships.

H1b: *The impact of RPS on plant performance is mediated through CSP capabilities.*

Impact of Operations Management Systems on Plant Performance

OMS applications enable synchronization of manufacturing activities across globally distributed plants and automate complex business processes. OMS applications, such as MES and PDM systems, support JIT capabilities by providing visibility to real-time changes in demand, optimizing the use of production assets, and enabling plant managers to manage process and product specifications for multiple plants (Schroeder and Flynn 2001). OMS also help plants to leverage their network in a number of ways including identifying low cost and high quality partners, reuse of product component libraries, and integration of other plant assets.

Development of JIT manufacturing capabilities is associated with improvements in plant agility and flexibility, which in turn lead to improvements in plant time to market and efficiency. By leveraging a network of partners to improve the sourcing and execution of plant production activities, OMS improve plant performance by enabling JIT manufacturing capabilities.

H2a: *The impact of OMS on plant performance is mediated through JIT capabilities.*

OMS provide the IT infrastructure that enables engineers to share critical product data specifications, collaborate with product development teams, and facilitate integration between product development and manufacturing processes. OMS support CSP programs by enabling plants to implement collaborative manufacturing programs, where workflows from multiple plants are coordinated to provide customers with real-time visibility into the supply chain. For example, manufacturing execution systems foster tighter integration between suppliers and their customers by identifying critical resource dependencies and coordinating common processes.

In turn, CSP capabilities mitigate the effects of demand uncertainty by providing stakeholders with greater visibility into process workflows. Such collaboration fosters customer relevance and improves plant performance by reducing stock-outs and improving inventory turnover (Johnston and Vitale 1988; Mukhopadhyay et al. 1995). Hence,

H2b: *The impact of OMS on plant performance is mediated through CSP capabilities.*

Impact of Electronic Data Interchange on Plant Performance

EDI-enabled systems facilitate sharing of JIT schedules by providing precise information on future materials requirements (Cash and Konsynski 1985; Kekre and Mukhopadhyay 1992). Srinivasan et al. (1994) delineate the importance of EDI in facilitating the coordination tasks inherent in a JIT environment in the auto industry. Their research shows that suppliers that received shipment schedules electronically and integrated the data directly via EDI had sharply lower shipment errors and discrepancies. EDI also facilitates implementation of JIT capabilities by enabling real-time exchange of production and demand data within and across manufacturing plants. In turn, development of JIT capabilities leads to improvements in product quality, lower turnaround times, and greater plant efficiency (Schroeder et al. 2002).

H3a: *The impact of EDI on plant performance is mediated through JIT capabilities.*

EDI-enabled applications help plant managers to build “higher bandwidth” communication channels with their customers and suppliers, and to capture tacit and emerging customer need information. They facilitate intra- and inter-organizational information exchange to improve the richness

of real-time interactions with customers and suppliers (Lee and Whang 2001; Powell and Dent-Micallef 1997). For example, retailers use EDI to improve supply chain coordination, increase efficiencies, and develop closer relationships with their customers and suppliers. EDI-enabled supply-side interactions are associated with better supplier relationships and cash conversion cycle times (Magretta 1988), while customer-side interactions using web-enabled EDI applications result in reduced paperwork and order entry errors, cost efficiencies, and lower lead times (Barua et al. 2004; Subramani 2004). Hence, EDI enables the development of closer customer-supplier collaboration capabilities which are associated with improvements in plant quality and efficiency.

H3b: *The impact of EDI on plant performance is mediated through CSP capabilities.*

We summarize the definitions of the constructs that represent the manufacturing capabilities, plant IS resources and performance measures in Table 1.

Research Data

Data for this research was drawn from a survey of U.S. manufacturing plants, conducted in 1999, by *IndustryWeek* and *PricewaterhouseCoopers Consulting*. The two-part survey was designed to collect information about manufacturing trends and manufacturing performance metrics using a mail-in survey, followed by a smaller telephone survey with manufacturing executives. The survey consisted of a questionnaire mailed to plants, with two-digit standard industrial classification (SIC) codes from 20 to 39, which employed a minimum of 100 people.³ We describe the survey questions, relevant to our model, in the Appendix.

The survey was mailed to approximately 27,000 plant managers and controllers from *IndustryWeek*'s database of manufacturing plants. Plant managers provided data on a broad range of manufacturing capabilities and types of information systems used in each plant. Data on plant performance measures were based on assessments of plant records by plant controllers. A total of 1,738 plants responded to the questionnaire. Our usable sample contains 1,077 plants that provided complete responses to the variables of interest. While this response rate is small compared to empirical studies in the IS literature, it is comparable to large plant surveys as reported

³A description of these codes can be found in Table 2.

Table 1. Definitions of Constructs in the Model

Construct	Definition
Just-in-Time (JIT) Manufacturing	A line flow production system that produces many products in low to medium volumes, and provides the flexibility associated with batch flow systems.
Customer & Supplier Participation Programs (CSP)	Establishment of cooperative relations by involving customers and suppliers in the value chain processes with the goal of jointly solving problems.
Resource Planning Systems (RPS)	Enterprise-wide planning systems that facilitate information integration across the firm and enable resource allocation and planning decisions.
Operations Management Systems (OMS)	Systems that control plant-level operational processes, such as shop floor control and computerized process simulation, and provide monitoring and control capabilities at the plant level.
Electronic Data Interchange (EDI)	A standard for inter- and intra-organizational information exchange of transaction data using a common language
Quality	Plant quality, including first-pass yield rate, and product scrap and rework costs
Time to Market	Time that it takes to get the product to market, including plant cycle time and lead time.
Efficiency	Plant productivity in terms of the total value of plant output and the manufacturing costs associated with output.

in Roth and van der Velde (1991) and Stock, Greis and Kasarda (2000).⁴

In Table 2, we compare the distribution of the manufacturing plants in our study sample to the distribution of all manufacturing plants as reported in the Statistical Abstract of the United States, published by the U.S. Census Bureau (2000). Our study sample has a larger proportion of durable manufacturing plants compared to the U.S. census. We note that these differences between our sample distribution and the U.S. census can be explained, in part, because the *Industry Week* survey was designed to sample plants that employed at least 100 people while the U.S. census reports plants of all sizes.

Since we obtained the data from a secondary data source, we did not have information with respect to the profiles of non-respondent plants. To evaluate the generalizability of our research findings, we compared the average dollar value of plant shipments per employee (i.e., productivity per employee) of our sample plants to the average productivity of all

U.S. manufacturing plants, as reported in the U.S. Statistical Abstract (2000). The average productivity per employee of our sample plants was \$219,814, while the average plant productivity per employee in the U.S. census data was reported to be \$225,440. The difference in average plant productivity was not statistically significant (t -statistic = 0.52; p -value = 0.602) and, hence, we observe that the plants in our sample are not significantly different from the general population based on average plant productivity.

Data and Variable Measurements

We now define the data measures which we use to operationalize our research model.

Plant Information Systems

Plant information systems are represented in our survey by measuring the extent of implementation of 11 different types of plant IS applications that are commonly used in manufacturing plants.⁵ These plant applications belong to the three

⁴A plausible explanation for the relatively low response rate emerged after a follow-up telephone conversation with the survey research team leaders at *IndustryWeek*. Even though the population consisted of approximately 27,000 plant managers, between 10 and 15 percent of the contacts in their directory either did not work at the plant or were not the right contacts for the survey. Hence, the effective size of the representative population is about 22,950 and our true sample response rate is estimated to be approximately 5 percent.

⁵Refer to Mulani and Lee (2001) for a review of the different types of enterprise software that have been typically implemented and used for supply chain management and related business processes in manufacturing plants.

Table 2. Distribution of Manufacturing Plants by Standard Industrial Classification (SIC) Code

SIC Code	Industry Sector	Number of Plants in Sample	Percent of Sample	Percent of U.S. Manufacturers*
Nondurable Manufacturing				
20	Food & kindred products	40	3.71	5.76
21	Tobacco products	0	0.00	0.03
22	Textile mill products	21	1.95	1.70
23	Apparel & other textile products	10	0.93	6.45
24	Lumber & wood products	18	1.67	10.13
25	Furniture & fixtures	41	3.81	3.33
26	Paper & allied products	49	4.55	1.79
27	Printing & publishing	17	1.58	17.19
28	Chemicals & allied products	66	6.13	3.41
29	Petroleum & coal products	4	0.37	0.59
	Subtotal	266	25.00	50.38
Durable Manufacturing**				
30	Rubber & plastics products	61	5.66	0.52
31	Leather & leather products	5	0.46	0.51
32	Stone, clay & glass products	32	2.97	4.52
33	Primary metal industries	60	5.57	1.73
34	Fabricated metal products	132	12.26	10.47
35	Industrial machinery & equipment	207	19.22	15.54
36	Electronics & electrical equipment	140	13.00	4.71
37	Transportation equipment	87	8.08	3.41
38	Instruments & related products	74	6.87	3.23
39	Miscellaneous manufacturing	13	1.21	4.97
	Subtotal	811	75.00	49.61
	Total	1,077	100	100

*Source: U.S. Census Bureau, *Statistical Abstract of the United States: 2000*.

**The U.S. Census Bureau defines durable goods as those that have a durable lifespan greater than 3 years.

categories of plant IT resources that are based on our proposed typology of plant IT resources. We measure the extent of implementation of each type of plant information system on a two-point scale reflecting whether it is currently implemented or not, based on implementation data provided by plant managers.⁶ Hence, for each plant, the values of the three IS constructs represent the extent of implementation of the applications that comprise these constructs.

⁶We note that our representation of IT implementation as a 0-1 variable (where 0 represents no implementation and 1 represents implementation of the software) is similar to the approach described by Hitt et al. (2002), where the extent of ERP technology implementation within firms is measured as a 0-1 dummy variable.

Manufacturing Capabilities

We represent manufacturing capabilities by measuring the extent of implementation of 14 types of manufacturing practices. These practices belong to the two categories of manufacturing capabilities, JIT and CSP, which we proposed in an earlier section. We measure the extent of implementation of each type of manufacturing capability on a three-point scale, depending on whether it is not currently implemented, partially implemented, or extensively implemented. Hence, the values of the JIT and CSP constructs represent the extent of implementation of their underlying capabilities. We draw on prior research in operations management to develop and validate the JIT construct (Davy et al. 1992). Our CSP con-

struct is based on the description of customer and supplier partnerships in the prior IS literature (Bakos and Brynjolfsson 1993; Brynjolfsson and Hitt 2000).

Plant Performance

We measure the dependent variable as the change (D) in plant performance during the previous 5-year period (i.e., 1994 to 1999). We define three performance measures that represent changes in plant quality, time to market, and plant efficiency, respectively. $\Delta(\text{Quality})$, which represents the change in plant quality, is a latent variable consisting of two indicator variables, $\Delta(\text{Quality yield})$ and $\Delta(\text{Scrap/rework costs})$. $\Delta(\text{Quality yield})$ represents the change in the first-pass quality yield, while $\Delta(\text{Scrap/rework costs})$ represents the change in scrap and rework costs. The change in plant time to market, $\Delta(\text{Time})$, consists of two indicator variables: change in plant cycle time and lead time. $\Delta(\text{Efficiency})$ is a latent variable composed of two indicators: change in unit manufacturing costs and plant productivity. Since plant productivity is a measure of the output per employee and unit manufacturing costs represent labor and other resource costs, this factor provides a measure of plant efficiency.

While all three performance measures are reflective of plant performance, plants can elect to pursue one form of performance improvement over another.⁷ Industry dynamics and environmental conditions may make it infeasible to achieve all performance objectives simultaneously. For example, in high clock-speed industries such as electronics and computer manufacturing, time to market is critical for firms to capture market share and, therefore, firms may emphasize improvements in time to market over other outcomes.

Control Variables

The survey also provides information on additional variables to control for the impact of plant characteristics on manufacturing capabilities and plant performance (Sakakibara et al. 1997). These variables include plant age (AGE), plant size (SIZE), product mix (MIX), and order fulfillment practices (BUILD to FCST). Large plants are more likely to have the scale required to justify adoption of advanced manufacturing practices (Hendricks and Singhal 1997). Plant AGE is likely to play a significant role, since older plants are less likely to adopt advanced practices and often fail to realize the impact of IT-enabled processes on plant performance.

⁷We observe that exploratory factor analyses (EFA) suggests the presence of three plant performance factors, and the three factors do not load on a single, higher-order construct.

We measure product MIX as a binary variable based on low or high product mix. Plants with high product mix are likely to implement JIT manufacturing capabilities (Miltenburg 1995). We also control for the type of order fulfillment practices (BUILD to FCST), since these practices may impact manufacturing capabilities and performance. For example, development of JIT capabilities depends on having build-to-order strategies in place, which provide managers with real-time visibility into customer demand (Brynjolfsson and Hitt 2000). Hence, plants with build-to-forecast strategies may be less likely to develop JIT production capabilities.

Manufacturing plants in high clock-speed industries, such as electronics and high-tech manufacturing, have shorter product lifecycles where time-to-market is of critical importance (Mendelson and Pillai 1999). They exhibit higher revenue volatility and customer turnover compared to those in low clock-speed industries, such as plastics, apparel and textile products, and primary metal industries (Tallon and Kraemer 2004).⁸ We introduce a dummy variable INDUSTRY, which represents three high clock-speed industries: electrical equipment (SIC code = 36), instruments and related products (SIC code = 38), and industrial machinery and equipment (SIC code = 35). INDUSTRY is equal to 1 if a plant belongs to any of these three high clock-speed categories, and zero otherwise.

Data Analysis

In this section, we present the validation of our constructs and model, and describe our model estimation method.

Measurement Model

Exploratory factor analyses (EFA) was first conducted to check if the proposed factors are consistent with our survey data. EFA showed the presence of eight factors in the data and the factor structures matched the ones we identified in our research model. Since our survey data are self-reported, we performed Harmon's one-factor test to check for common methods bias. The explanatory and dependent variables loaded on different constructs, which indicates that common methods bias is not evident in the data (Podsakoff and Organ 1986).

⁸We thank one of the reviewers for their suggestion to test the impact of environmental turbulence on manufacturing plant performance.

Table 3. Confirmatory Factor Analysis Results for Scale Development

Construct	Indicator*	Standardized Loading	t-statistic	Indicator Reliability	Composite Reliability
RPS	RPS1	0.500	20.441	0.250	0.73
	RPS2	0.779	39.186	0.607	
	RPS3	0.760	37.010	0.578	
OMS	OMS1	0.588	19.597	0.346	0.60
	OMS2	0.615	19.349	0.378	
EDI	EDI1	0.749	49.157	0.561	0.86
	EDI2	0.694	45.225	0.481	
	EDI3	0.693	47.210	0.480	
	EDI4	0.664	41.590	0.440	
	EDI5	0.701	45.713	0.492	
	EDI6	0.736	46.843	0.541	
JIT	JIT1	0.782	62.730	0.612	0.86
	JIT2	0.665	43.979	0.442	
	JIT3	0.734	53.816	0.538	
	JIT4	0.672	41.922	0.452	
	JIT5	0.585	35.701	0.342	
	JIT6	0.621	38.681	0.385	
	JIT7	0.550	32.160	0.302	
	JIT8	0.614	38.065	0.377	
CSP	CSP1	0.557	28.477	0.311	0.73
	CSP2	0.613	37.255	0.375	
	CSP3	0.492	21.429	0.242	
	CSP4	0.570	31.423	0.324	
	CSP5	0.528	26.833	0.279	
	CSP6	0.625	35.149	0.391	
Δ(Quality)	QUAL1	0.670	30.353	0.449	0.69
	QUAL2	0.781	35.446	0.610	
Δ(Time to Market)	TIME1	0.802	39.839	0.643	0.64
	TIME2	0.524	25.241	0.275	
Δ(Plant Efficiency)	EFF1	0.598	22.451	0.358	0.60
	EFF2	0.606	22.935	0.368	

*See the Appendix for detailed questions corresponding to each indicator item.

Table 4. Model Validity Statistics

Goodness-of-Fit Indices	Δ (Quality)	Δ (Time to Market)	Δ (Efficiency)	Recommended GFI Value*
AGFI	0.99	0.99	0.99	> 0.9
CFI	0.88	0.87	0.88	> 0.9
NFI	0.84	0.83	0.84	> 0.9
IFI	0.88	0.87	0.88	> 0.9
RMSEA	0.06	0.06	0.06	0.05 to 0.08
Chi-square/df	3.59	3.79	3.39	< 3.0
Tucker-Lewis Index	0.85	0.85	0.86	> 0.9

*Recommended goodness-of-fit indices (GFI) are based on Teo et al. (2003), although lower thresholds for fit indices have been reported in the prior literature.

Construct Validity and Reliability

We next test the validity and reliability of the model constructs of our measurement model. The results are shown in Table 3, where the indicators correspond to the survey questions in the Appendix. We use the items reflectively in developing the equations of the measurement model. The relationship between the controls and the dependent variables is formative. Two measures of construct reliability are indicator and composite reliability (Fornell and Larcker 1981). Indicator reliability represents the percent of variation that is explained by the construct it measures, and ranges from 0.24 to 0.64. Composite reliability reflects the internal consistency of the indicators (Werts et al. 1974). The composite reliability values exceed the recommended value of 0.7 for scale development for all constructs, except for those with two items where the reliability was above the threshold of 0.6 (Nunnally and Bernstein 1994).

Construct validity was established by measuring the convergent and discriminant validity of the survey items (Phillips and Bagozzi 1986; Straub 1989). The t-values for all factor loadings were significant and indicate that our measures satisfy convergent validity (Gefen et al. 2000). We used a sequential χ^2 difference test (SCDT) to establish discriminant validity (Anderson and Gerbing 1988). We estimated 28 separate structural equation models, where each model represents a constrained and unconstrained pairing of any two of the eight constructs. The difference in χ^2 statistics between the unconstrained and constrained models was significant for each pair, and these results confirm discriminant validity.

Model Validity

We present several goodness-of-fit statistics in Table 4 to assess how well the specified model explains the observed data in terms of absolute and incremental fit and model parsimony. The p-value of 0.26 for the χ^2 statistic implies good absolute model fit. The incremental fit indices include the adjusted goodness of fit index (AGFI), comparative fit index (CFI), incremental fit index (IFI), and the normed fit index (NFI). These indices imply good model fit (Chatterjee et al. 2002).

Small values of the root mean square error of approximation (RMSEA) represent low residual variance and suggest good model fit. The RMSEA for our measurement model is 0.06, which falls below the threshold of 0.08, and indicates an acceptable level of internal consistency (Hu and Bentler 1999). These tests provide support for confirming the proposed model.

Model Estimation

Since manufacturing capabilities, information systems, and plant performance are measured as latent variables, we estimate the mediation model shown in Figure 1 using structural equation model (SEM) procedures implemented in the SAS statistical software. We estimated the path coefficients of the structural model using weighted least squares (WLS) estimation. The WLS approach allows for non-normality and provides asymptotically efficient path estimates (Browne 1984). We used the covariance matrix for estimation, which required 10 iterations for convergence.

Table 5. SEM Estimation Results of the Mediation Model

	Mediating Variables (Manufacturing Capabilities)		Dependent Variable	Mediating Variables (Manufacturing Capabilities)		Dependent Variable	Mediating Variables (Manufacturing Capabilities)		Dependent Variable
	JIT	CSP		D(Quality)	JIT		CSP	Δ(Time to Market)	
IT Resources									
RPS	0.437***	0.213***	-	0.389***	0.188***	-	0.466***	0.218***	-
OMS	-0.022	0.068**	-	0.028	0.098***	-	-0.017	0.093**	-
EDI	0.406***	0.323***	-	0.388***	0.332***	-	0.410***	0.341***	-
Plant Controls									
Size	0.102***	0.070***	-0.041**	0.083***	0.068***	-0.023	0.065***	0.038***	-0.096***
Age	-0.007	-0.021	-0.052***	-0.029	-0.031**	-0.023	-0.004	-0.029**	-0.058***
Mix	0.073***	0.055***	-0.094***	0.069***	0.057***	0.000	0.069***	0.059***	0.004
Build to Forecast	-0.001	-0.020	-0.069***	-0.027	-0.034***	-0.005	-0.021	-0.016	0.022
Industry	0.058***	0.000	0.024	0.050***	-0.016	0.053***	0.066***	0.001	-0.019
Manufacturing Capabilities									
JIT	-	-	0.349***	-	-	0.838***	-	-	0.348***
CSP	-	-	0.120**	-	-	-0.223***	-	-	0.089
R²	0.334	0.405	0.285	0.324	0.400	0.485	0.342	0.400	0.304

p < 0.05; *p < 0.01 in two-tailed t-tests.

Results

We present the regression estimates of the structural equation model in Table 5. The results are organized in three panels, representing the regressions for plant quality, time to market, and efficiency, respectively. The model R^2 values range from 0.28 to 0.48, and suggest a satisfactory fit of the measurement model to the data.

The regression estimates, in the first two columns of each panel, represent the impact of plant IT resources and other control variables on JIT and CSP capabilities. The results indicate that RPS and EDI-enabled applications are more likely to be associated with the development of JIT manufacturing and CSP capabilities. These results confirm that RPS and EDI support implementation of agile, flexible production capabilities that are typical of JIT environments, and they foster creation of collaborative customer-supplier relationships. Our results also indicate that OMS does not have a significant impact on JIT or CSP capabilities.

The path estimates, shown in the third column, represent the impact of JIT and CSP capabilities on plant performance. Our results indicate that JIT capabilities have a significant positive impact on $\Delta(\text{Quality})$, $\Delta(\text{Time to Market})$, and $\Delta(\text{Efficiency})$. The results also suggest that CSP capabilities have a positive impact on product quality and plant efficiency, while their impact on $\Delta(\text{Time to Market})$ is negative and significant. The negative coefficient suggests that customer/supplier involvement may actually increase the time required to process and ship products, and implies some tradeoffs between improvements in quality and time to market.

We note that both plant SIZE and AGE have a negative impact on $\Delta(\text{Quality})$ and $\Delta(\text{Efficiency})$. This suggests that smaller plants exhibit higher operating efficiencies and greater product quality compared to larger plants *ceteris paribus*. Similarly, older plants are likely to exhibit lower product quality and efficiency compared to newer plants. Plants with low product MIX are more likely to realize improvements in plant quality, since it is typically easier to manage quality control processes for fewer product lines. We note that plants with BUILD to FCST strategies are likely to have lower product quality. This suggests that plants with “build to order” strategies, which are “in-sync” with real-time product changes, are less likely to exhibit adverse quality problems. The positive coefficient for the INDUSTRY variable suggests that plants in high clock-speed industries are more likely to realize improvements in product time to market, since there is a premium on the speed of innovation.

We next estimate the direct paths between the IS factors, manufacturing capabilities, and plant performance factors to

test our mediation hypotheses. The mediated path estimates are shown in Table 6. The indirect effect of IT on plant performance is estimated as $a \times b$, where a and b represent the magnitudes of the paths between IT and manufacturing capabilities, and manufacturing capabilities and plant performance, respectively (Hoyle and Kenny 1999). The standard deviation of the mediated path is approximated as the square root of $(a^2s_b^2 + b^2s_a^2)$, where s_a and s_b are the standard errors of a and b , respectively (Sobel 1982).

Our results suggest that the positive impact of RPS on $\Delta(\text{Quality})$, $\Delta(\text{Time to Market})$, and $\Delta(\text{Efficiency})$ is mediated through JIT. These results support hypotheses H1a. The results also suggest that CSP capabilities mediate the impact of RPS on $\Delta(\text{Quality})$ as observed by the positive coefficient value of the RPS \rightarrow CSP \rightarrow $\Delta(\text{Quality})$ path. However, CSP practices have a negative effect on the relationship between RPS and $\Delta(\text{Time to Market})$. Our results suggest that developing collaborative customer-supplier relationships may improve product quality at the expense of time to market, and provides partial support for hypothesis H1b. We note, however, that when the INDUSTRY control variable is set to one (for high clock-speed industries), we add 0.053 (from Table 5) to -0.042 to find an overall positive impact of RPS on product time to market. Hence, our results suggest that the creation of IT-enabled dynamic capabilities allows plants to operate effectively under conditions of environmental flux. Hence, in turbulent industries, CSP is an essential capability for reaching out to business partners and working through specific issues arising from changing business requirements.

We find that neither JIT nor CSP mediate the relationships between OMS and plant performance. We find that CSP also has a negative effect on the relationship between OMS and $\Delta(\text{Time to Market})$, which is consistent with our earlier findings. Hence, we do not find evidence to support hypotheses H2a and H2b. We find that JIT capabilities mediate the relationship between EDI and all three performance factors, while CSP mediates the positive impact of EDI on $\Delta(\text{Quality})$. However, the mediated impact of EDI on $\Delta(\text{Time to Market})$ is negative, and these results confirm the tradeoff between improvements in product quality and time to market. Hence, our results support hypothesis H3a but only partially support H3b. We note that, when business conditions are relatively stable and we do not require tight customer-supplier integration, CSP may have a negative impact on plant time to market because they consume critical IT resources that could be better applied to other business processes.

We estimate the overall impact of RPS, OMS, and EDI on plant performance as the sum of the individual effects using the estimation approach described in Sobel (1982). The results, as reported in Panel A of Table 7, indicate that RPS

Table 6. Impact of Mediated Paths from Plant Information Systems to Performance Measures

Overall Effect	Mediated Paths	Path	Z stat
RPS→Δ(Quality)	RPS→JIT→Δ(Quality)	0.152	6.309***
	RPS→CSP→Δ(Quality)	0.026	2.106**
OMS→Δ(Quality)	OMS→JIT→Δ(Quality)	-0.008	-0.479
	OMS→CSP→Δ(Quality)	0.008	1.490
EDI→Δ(Quality)	EDI→JIT→Δ(Quality)	0.141	7.959***
	EDI→CSP→Δ(Quality)	0.039	2.208**
RPS→Δ(Time to Market)	RPS→JIT→Δ(Time to Market)	0.326	7.527***
	RPS→CSP→Δ(Time to Market)	-0.042	-2.964***
OMS→Δ(Time to Market)	OMS→JIT→Δ(Time to Market)	0.024	0.649
	OMS→CSP→Δ(Time to Market)	-0.022	-2.133**
EDI→Δ(Time to Market)	EDI→JIT→Δ(Time to Market)	0.325	12.047***
	EDI→CSP→Δ(Time to Market)	-0.074	-3.476***
RPS→Δ(Efficiency)	RPS→JIT→Δ(Efficiency)	0.162	6.227***
	RPS→CSP→Δ(Efficiency)	0.019	1.529
OMS→Δ(Efficiency)	OMS→JIT→Δ(Efficiency)	-0.006	-0.353
	OMS→CSP→Δ(Efficiency)	0.008	1.339
EDI→Δ(Efficiency)	EDI→JIT→Δ(Efficiency)	0.143	7.570***
	EDI→CSP→Δ(Efficiency)	0.030	1.572

p < 0.05; *p < 0.01 in two tailed t-tests

Table 7. Overall Impact of Plant Information Systems on Plant Performance

Panel A: 1999 Data						
	Δ(Quality)		Δ(Time to Market)		Δ(Efficiency)	
	Overall Effect	Z stat	Overall Effect	Z stat	Overall Effect	Z stat
RPS	0.178	6.583***	0.284	6.236***	0.182	6.267***
OMS	0.001	0.027	0.002	0.052	0.002	0.131
EDI	0.180	7.211***	0.251	7.292***	0.173	6.408***
Panel B: 2001 Data						
	Δ(Cycle Time)		Δ(Lead Time)		Δ(Unit Manufacturing Cost)	
	Overall Effect	Z stat	Overall Effect	Z stat	Overall Effect	Z stat
OMS	0.208	4.375***	0.139	3.544***	0.174	4.017***
EDI	0.195	4.294***	0.140	3.236***	0.171	3.858***

*p < 0.1; **p < 0.05; ***p < 0.01 in two tailed t-tests.

and EDI have a positive impact on all plant performance measures. Although OMS has a positive effect, it is not statistically significant.

Data from a separate survey, administered by *IndustryWeek* in 2001, was analyzed using a similar mediation model to validate the consistency of our findings.⁹ These results are reported in Panel B for 1,326 plants, and show that OMS and EDI have a positive overall impact on plant performance. Our analyses indicates that JIT capabilities mediate the impact of OMS and EDI on plant cycle time, lead time, and unit manufacturing costs, while CSP capabilities mediate the positive impact of OMS and EDI on plant lead times. Thus, our findings, with respect to the mediation role of manufacturing capabilities, remain consistent and we validate the reliability of our earlier results with data obtained from a different sample of plants in a *later* period.

In order to test if dynamic capabilities theory provides a satisfactory explanation of the mediation model, we followed the approach described by Baron and Kenny (1986) and Kenny et al., (1998). First, we estimated the *partial* impact of IT on plant performance without the presence of the mediators. The regression coefficients of RPS and EDI were positive and significant for all three performance measures, which suggest that IS resources have a positive impact on plant outcomes. Next, we estimated a *full model*, which includes direct paths from the IT resources and manufacturing capabilities to plant performance. Estimation of the full model showed that the coefficients of the direct paths from RPS, OMS, and EDI to the plant performance measures are smaller in magnitude and not statistically significant. The estimates of the JIT and CSP capabilities were positive and significant and dominated the impact of plant information systems. These results confirm that manufacturing capabilities mediate the impact of IT on plant performance.

We now compare the complete mediation model to the full model using the approach described in Jöreskog and Sörbom (1979). We report the χ^2 values of the mediated and full models in Table 8. For the $\Delta(\text{Quality})$ model, the complete mediation model has a χ^2 equal to 1032.16 while the full model has a χ^2 equal to 1030.72. The difference in χ^2 values is equal to 1.44 ($df = 3$) which is not statistically significant (Hair et al. 1998). The differences in χ^2 values for $\Delta(\text{Time to$

Market) and $\Delta(\text{Efficiency})$ are equal to 2.28 and 1.14, respectively, and indicate that the differences between the complete mediation and full models are not significant. Hence, our results confirm that manufacturing capabilities completely mediate the impact of IT on plant performance. Overall, our findings indicate that the impact of IT on plant performance is mediated through manufacturing capabilities rather than through the direct impact of IT.

Since our study sample has a larger proportion of durable manufacturing plants, we split our sample into two clusters consisting of durable and nondurable manufacturers and estimated the mediation model for each cluster separately. Our results are consistent with our findings from the overall sample, and do not suggest a bias due to the greater proportion of durable plants.

Discussion and Implications

Drawing on an established body of literature on dynamic capabilities theory, our research represents one of the first studies to provide empirical evidence to validate the impact of information systems on plant performance using a large cross-sectional sample of U.S. manufacturing plants. We summarize the results of our hypotheses tests in Table 9. Our results indicate that manufacturing capabilities mediate the impact of information systems on plant performance, after controlling for the effects of plant characteristics.

The fundamental contribution of our paper is to extend prior research by developing and empirically validating a theoretical framework that integrates the relationships between IT resources, manufacturing capabilities and plant performance using manufacturing plant data. Prior research in this area has several shortcomings. First, most studies have focused on the impact of IT spending on aggregate financial measures of firm performance (Brynjolfsson and Hitt 1996; Melville et al. 2004; Siegel 1997). However, examining the relationships between IT resources and firm performance can lead to inaccurate conclusions, since the improvements in process-level performance that are enabled by IT may dissipate before they are reflected in a firm's overall performance (Ray et al. 2004). Thus, measuring the effectiveness of *business processes* through plant-level performance metrics, rather than overall firm performance, provides a better way to test resource-based logic.¹⁰

⁹Although many of the survey questions in the 2001 survey are similar to the ones used in 1999, there were some differences in data on plant information systems and plant performance measures between the two surveys. For instance, some indicators that comprise the RPS construct were not available and data on only three of the six plant performance variables were available in 2001.

¹⁰This is consistent with the observations of Brynjolfsson and Hitt (1996), who argue that process-level impact could dissipate through pricing pressures at the firm-level, leaving little or no impact on firm financial performance.

Table 8. Mediated and Direct Impact of IT on Plant Performance

	χ^2 - Mediation Model	χ^2 - Full Model	$\Delta(\chi^2)$	DIFF IN DF	p-value
$\Delta(\text{Quality})$	1032.16	1030.71	1.449	3	0.694
$\Delta(\text{Time to Market})$	1102.07	1099.79	2.280	3	0.516
$\Delta(\text{Efficiency})$	1044.41	1043.27	1.145	3	0.766

*p < 0.1; **p < 0.05; ***p < 0.01 in two tailed t-tests.

Table 9. Summary Findings of Hypotheses Tests

Subsidiary Hypothesis	Hypothesis Description	Finding
H1a	The impact of RPS on plant performance is mediated through its impact on JIT manufacturing capabilities	Supported
H1b	The impact of RPS on plant performance is mediated through its impact on CSP practices	Partially Supported
H2a	The impact of OMS on plant performance is mediated through JIT manufacturing capabilities	Not Supported
H2b	The impact of OMS on plant performance is mediated through CSP capabilities	Not Supported
H3a	The impact of EDI-enabled systems on plant performance is mediated thru its impact on JIT manufacturing capabilities	Supported
H3b	The impact of EDI-enabled systems on plant performance is mediated thru its impact on CSP capabilities	Partially Supported

Second, prior research has focused on the relationship between manufacturing capabilities and firm performance without considering the role of IS resources and how they may enable specific types of manufacturing capabilities (Rabinovich et al. 2003 Schroeder et al. 2002). Our research shows that IT has a *significant indirect effect* on plant performance that is mediated through these dynamic capabilities. We show that the dynamic capabilities framework provides an alternative lens to better understand the role of IT, and explain how three major classes of plant IS can improve plant performance by enabling two distinct types of manufacturing capabilities. We further validate our findings using plant data across a multiyear horizon.

Our results support the observations of Brynjolffson and Hitt (2000) in that IT investments should be aligned with complementary business practices and organizational structures. Hence, even though IT may represent mobile and imitable resources, they support firm-specific routines that enable the execution of business processes. Although firms may develop

JIT and CSP capabilities in different ways, IT supports these capabilities by providing managers with the infrastructure to conceive, develop, and exchange process-specific knowledge (Mata et al. 1995). Our findings amplify the need for firms to strengthen their organizational capabilities, after making investments in IT, and supports evidence which suggests that firms can reap significant benefits by combining IT investments with good management (Dorgan and Dowdy 2004).

Our study has several limitations. First, the survey measures perceptions of changes in plant performance over a 5-year period. These measures need to be validated through archival and field data collection in future research. It is conceivable that some of the information systems could have been in place before the 5-year period or implemented sometime during this period, but the secondary nature of the data did not allow us to isolate these occurrences. We note, however, that this is a limitation of most *multi-firm* studies on the business value of IT, since it is not practical to obtain detailed implementation timelines for a large portfolio of enterprise information

systems. Furthermore, we observe that many of the IT applications in our study were adopted by manufacturing plants during the mid- to late-1990s, which also coincides with the time period (i.e., 1994-1999) during which we measure the performance impact of IT in our research.

Our focus on plants that employ a minimum of only 100 employees limits the generalizability of our results to industries with larger manufacturing plants. We also did not account for country- or culture-specific differences in manufacturing characteristics since the scope of the survey was limited to U.S. plants.

We believe it is important to track plant performance over time to better understand changes in plant performance due to adoption of new types of technologies and/or processes (Banker et al. 2001). We address this issue partially by validating our mediation model using plant data from 2001, and show that the new results are consistent with our earlier findings in terms of the role of manufacturing capabilities in mediating the impact of IT resources on plant performance. Our findings must be validated with additional data collected in industry-specific settings to examine the impact of industry characteristics and differences in plant manufacturing strategies across different industries. Finally, our data set did not provide information on managerial skills that may be related to the organizational use of plant information systems (Armstrong and Sambamurthy 2000; Devaraj and Kohli 2003). Our findings, however, suggest an avenue for future research to explore how IT and intangible resources are converted into specific organizational capabilities.

Conclusions

This research constitutes one of the first studies to provide empirical evidence on the relationships between different types of plant manufacturing capabilities, information systems, and their impact on plant performance. The contribution of our research is two-fold: (1) development of a dynamic capabilities framework to study the impact of plant information systems on manufacturing plant performance, and (2) empirical evidence on the role of manufacturing capabilities in mediating the impact of plant information systems on plant performance. Our study indicates that plant information systems have a significant impact on the development of dynamic manufacturing capabilities, such as JIT and customer and supplier involvement, in core supply chain processes. These capabilities have become key differentiators of manufacturing performance, as demand uncertainty and supply chain visibility make it imperative to adopt flexible

manufacturing strategies and interact closely with customers, suppliers, and partners (Mulani and Lee 2001).

Our results suggest that the dynamic capabilities theory offers a sharper theoretical lens to study the impact of IT-enabled capabilities and resources on organizational performance. Contrary to the thesis posited by Carr (2003), we have shown that there exist tight linkages between manufacturing capabilities and information systems such that process-specific business routines cannot be implemented effectively without the use of IT. Our methodology for restricting the unit of analyses to the plant level to isolate process-level performance impacts is consistent with the intent of the resource-based view (RBV) of the firm (Ray et al. 2004). We contribute to the extant body of knowledge by showing that it is possible to measure theory-driven constructs of IS resources and manufacturing capabilities, and use latent variable modeling to test our hypotheses.

A potential area for future research may include extending these models to evaluate relationships between operational measures of plant performance and financial metrics at the plant- and firm-level. Future research may also include collection of time-series data to evaluate the lagged impact of new technologies and manufacturing capabilities on plant performance. This will be of importance to the extant research in information systems and operations management, which has thus far been limited by the unavailability of objective plant-level data that spans a significant time horizon.

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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 \geq 1,000
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 \geq 20 years
MIX ¹¹	How would you describe the primary product mix? 1 = high volume, high mix; 2 = high volume, low mix; 3 = low volume, high mix; 4 = low volume, low mix
BUILD to Forecast ¹² (BUILD TO FCST)	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 CAPABILITIES: 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

A. 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	2
5. Agile manufacturing	1	2	2
6. Focused-factory production	1	2	2
7. Quick changeover techniques	1	2	2
8. Bottleneck/constraint removal	1	2	2

¹¹For our analysis, we split the data into two variables such that MIX = 1 if high mix; 0 = otherwise, and VOLUME = 1 if high volume; 0 = otherwise. We dropped the VOLUME variable from our research model since it did not have an impact on manufacturing capabilities or plant performance outcomes.

¹²To facilitate analysis, we aggregated the responses so that 1 = Build to Forecast and 0 = otherwise.

B. CUSTOMER AND SUPPLIER PARTICIPATION (CSP)

1. Continuous replenishment programs for customers	1	2	3
2. Suppliers involved early in new product development	1	2	3
3. Customers interact with production employees	1	2	3
4. Customers participate in new product development	1	2	3
5. Suppliers manage inventory	1	2	3
6. 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

A. 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

B. OPERATIONS MANAGEMENT SYSTEMS (OMS)

1. Product Data Management (PDM) System	0	1
2. Manufacturing Execution System (MES) for production	0	1

C. ELECTRONIC DATA INTERCHANGE (EDI) APPLICATIONS

1. Collaborative business forecasting with customers and/or suppliers via EDI/web-enabled applications	0	1
2. Customer service and/or help desk via EDI/web-enabled applications	0	1
3. Customer order entry via EDI/web-enabled applications	0	1
4. Collaborative new product development with customers and/or suppliers via EDI/web-enabled applications	0	1
5. Direct material procurement via EDI/web-enabled applications	0	1
6. Invoices and/or payments via EDI/web-enabled applications	0	1

IV. PLANT PERFORMANCE MEASURES¹³

A. Δ(Quality) Factor

Δ(Quality Yield): How has finished product first-pass quality yield changed over the last five years?

1 = Declined more than 20%, 2 = Declined 1-20%, 3 = Stayed the same, 4 = Improved 1-20%, 5 = Improved more than 20%

Δ(Scrap / Rework Costs): How have scrap and rework costs changed over the last five years?

1 = Increased more than 20%, 2 = Increased 1-20%, 3 = Stayed the same, 4 = Decreased 1-20%, 5 = Decreased more than 20%

B. Δ(Time to Market) Factor

Δ(Cycle Time): By what percentage has manufacturing cycle time changed over the last five years?

1 = No reduction, 2 = Decreased 1-10%, 3 = Decreased 11-20%, 4 = Decreased 21-50%, 5 = Decreased more than 50%

Δ(Lead Time): How has customer lead time changed over the last five years?

1 = Increased more than 20%, 2 = Increased 1-20%, 3 = Stayed the same, 4 = Decreased 1-20%, 5 = Decreased more than 20%

¹³To facilitate analyses, we grouped the performance categories into a five- or seven-point Likert scale.

C. Δ (Plant Efficiency) Factor

Δ (Per-unit Manufacturing Costs): How have unit manufacturing costs at this plant, excluding purchased materials, changed over the last five years?

1 = Increased more than 20%, 2 = Increased 11-20%, 3 = Increased 1-10%, 4 = No change, 5 = Decreased 1-10%, 6 = Decreased 11-20%, 7 = Decreased more than 20%

Δ (Productivity): How has productivity, defined as dollar value of shipments per employee, changed over the last five years?

1 = Decreased more than 10%, 2 = Decreased 1-10%, 3 = No change, 4 = Increased 1-10%, 5 = Increased 11-20%, 6 = Increased 21-40%, 7 = Increased more than 40%

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