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Abstract

This paper describes an empirical analysis of the mediating effects of both manufacturing IT infrastructure and supply chain coordination strategy on business complexity's negative relationship with strategic performance. To cope with the complexity (diversity and volatility) inherent in their product markets, manufacturers of small machine tools deploy more extensive manufacturing IT infrastructures. As this technology enables a transactional supply chain coordination strategy evidenced by enhanced measurement, and the coordination to support capacity leasing and more suppliers per part, these firms are able to improve performance with regard to throughput speed, delivery reliability and volume flexibility.

Keywords: Business complexity, IT infrastructure, supply chain coordination strategy, strategic performance

Introduction

Our research question asks, "How do manufacturing IT infrastructure and supply chain coordination strategy mediate the relationship between business complexity and strategic performance?" Business complexity measures a firm's degree of difficulty in customer-facing, supplier-facing and production processes due to the volatility and diversity of its product-market. Manufacturing IT infrastructure measures the extent of IT deployment for manufacturing planning and control (MPC) functions. Supply chain coordination strategy measures the firm's strategy in coordinating processes across firm boundaries. Strategic performance is measured on eight dimensions that reflect cost efficiency, product quality, agility and scalability.

Previous empirical studies have generally attempted to measure generic IT dollar investments and their relationships to productivity or profitability, or to firm valuation. These studies have mostly relied upon highly aggregated data, from a broad spectrum of firms representing a variety of industries (and contexts). A few theoretical studies (Das, Zahra and Warkentin, 1991; Holland and Lockett, 1997; Patnayakuni, Rai and Patnayakuni, 2002) have proposed models that include some subset of these variables, and suggest that their fit is important for firm performance. Few of these relationships have been tested empirically, and we are not aware of any studies that have empirically tested the mediation effects of both manufacturing IT infrastructure and coordination strategy on the relationship between business complexity and strategic performance. Our study offers rich theoretical and managerial insight since it measures eight different dimensions of strategic performance, rather than one narrowly focused measure. Also, since it is limited to one type of IT, in one industry in one country over a short time span, it controls for many confounding factors. This level of control, and the fact that our partial least squares (PLS) method of analysis is more precise than first generation multivariate methods, enable us to distinguish these mediation effects, where previous studies have not.

Next, we discuss relevant research as it regards our variables, their relationships and our research hypotheses. We then explain our research model and our empirical study. The last sections discuss the results, their theoretical and practical implications, our limitations and future research directions.

Theoretical Basis of Research

Variable Definitions and Theoretical Model Structure

Our theoretical model is represented in Figure 1. As firms diversify into new product lines, add products and additional inventory parts, their performance is significantly impacted by their ability to stage and move inventory across their supply chains. To the extent that manufacturing IT infrastructure and supply chain coordination strategy enable these abilities, they mediate the negative strategic impact of this increased business complexity. We suggest firms cope with business complexity by deploying a more extensive manufacturing IT infrastructure and this deployment should improve performance. Firms may also cope with business complexity by deploying a particular supply chain coordination strategy to improve strategic performance. An extensive manufacturing IT infrastructure should also enable this supply chain coordination strategy.

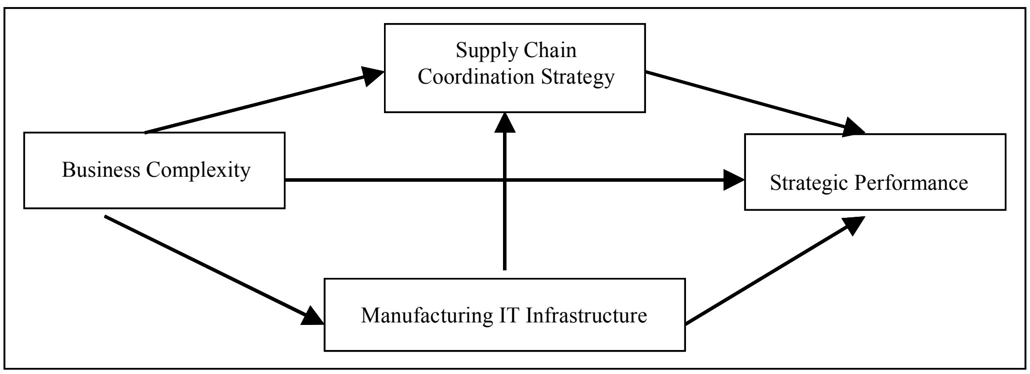


Figure 1. Research Model

Independent Variable Definition

Business Complexity

Business complexity is defined as the degree of difficulty associated with a firm's customer-facing, supplier-facing, and production processes (Holland and Lockett, 1997). Firms struggle to synchronize these processes, as emphasis is placed on shorter cycles and tighter integration across steps in these processes. Business complexity incorporates diversity and volatility aspects, consistent with the transactions cost perspective in which uncertainty results from imperfect foresight and difficulty in solving problems containing multiple interdependent variables. Its constituent dimensions, scales and reliability measures are summarized in Table 1.

Mediating Variables

Manufacturing IT Infrastructure

Manufacturing IT infrastructure's definition is detailed in Table 2. It is defined as the enabling base of shared manufacturing IT capabilities, which "…provide common services to a range of applications" (Broadbent, et al., 1997, p.175) "…including information to efficiently manage the flow of materials, …coordinate internal activities with those of suppliers and communicate with customers about market requirements" (Vollmann, et al., 1992, p.2). This variable measures IT deployment for manufacturing planning and control (MPC). This technology facilitates what Rockart and Short (1989) say is IT's most important role: enabling firms to manage organizational interdependence. Management of interorganizational interdependence is enabled as well, to the extent that MPC systems span organizational boundaries to include suppliers and customers.

Table 1. Business Complexity

Business complexity--Firm's response to the scale & difficulty of production, supplier-facing and customer-facing processes in the marketplace. (Limited Complexity ↔ Extensive Complexity)

A) Product diversity: Number of products. (Less ↔ More), Cronbach's alpha = 0.8701

1. *Number of products for which sales forecasts are developed (Few ↔ Many)*
2. *Number of products for which production plans are developed (Few ↔ Many)*

B) Product line diversity: Number of product lines. (Less ↔ More), Cronbach's alpha = 0.9257

1. *Number of product lines produced (Few ↔ Many)*
2. *Number of product lines forecast (Few ↔ Many)*
3. *Number of product lines in production plan (Few ↔ Many)*

C) Inventory diversity: Number of part numbers in raw materials and WIP inventories. (Less ↔ More), Cronbach's alpha = 0.6786

1. *Number of part numbers in raw materials inventory(Few ↔ Many)*
2. *Number of part numbers in WIP inventory(Few ↔ Many)*

D) Production volatility: (Less ↔ More), Cronbach's alpha = .6553

1. *% Orders for which customer schedule changes occur after the start of production (Low ↔ High)*
2. *% Orders for which engineering or design changes occur after the start of production (Low ↔ High)*
3. *% Incoming material rejected (Low ↔ High)*

Table 2. IT Infrastructure

Manufacturing IT infrastructure sophistication: the enabling base of shared IT capabilities which "provides common services to a range of applications" including "…information to efficiently manage the flow of materials, …coordinate internal activities with those of suppliers, and communicate with customers about market requirements".

(Less Extensive ↔ More Extensive)
Extent of IT Deployment for
A. sales forecasting *(1 ↔ 5)*
B. production planning *(1 ↔ 5)*
C. production scheduling *(1 ↔ 5)*
D. inventory management *(1 ↔ 5)*
E. purchasing *(1 ↔ 5)*

Supply Chain Coordination Strategy

Supply chain coordination strategy's definition is summarized in Table 3. It describes the "choices made for coordinating economic activity with trading partners and includes…choice of partners and types of relationships developed with them" (Holland & Lockett, 1997, p.479). This construct measures the degree to which relationships with suppliers and customers "…reflect a long-term commitment, a sense of mutual cooperation, shared risk and benefits, and other qualities consistent with concepts and theories of participatory decision making ….[vs.] an arm's length relationship in which the rules of the game are well specified and the failure to deliver on commitments by either party can be resolved through litigation" (Henderson, 1990, p.8). We refer to the first extreme as a relational strategy, and the second extreme as a transactional strategy. In essence, this construct measures the degree of cooperation and trust inherent in a firm's supply chain. Theories that deal with the resource-based view, transaction costs, coordination costs, agency costs, trust and cooperation are relevant.

Table 3. Coordination Strategy

Coordination strategy: "…choices made for coordinating economic activity with trading partners and includes…choice of partners and types of relationships developed with them (Holland & Lockett, 1997, p.479). (Relational ↔Transactional)

A. Measurement Precision: (Low ↔ High), Cronbach's alpha = .7777

Firm has formal measures for:

time standard accuracy(1↔5),	*product design time(1↔5),*
forecast accuracy (1↔5),	*productivity (1↔5) and*
delivery speed (1↔5),	*setup times (1↔5)*
mfg throughput time (1↔5),	

B. Capacity leasing: (Low↔High), Cronbach's alpha = .8715

How often company responds to capacity imbalance by
leasing temporary capacity from others (1↔5) or by
leasing excess capacity to others (1↔5)

C. Number of suppliers/part: (1↔5)

Dependent Variable

Strategic Performance

Strategic Performance is modeled as a formative construct with eight indicators. These indicators measure the respondent firm's comparison with competitors regarding unit manufacturing cost, product quality, throughput speed, delivery speed, delivery reliability, product flexibility, volume flexibility and product design time. These are measured on a one to five scale, with one representing "far worse than competition" and five representing "far better than competitors".

This performance measure adds a unique perspective, as it is multi-dimensional and measures a firm's performance on eight different performance dimensions, relative to its competitors. Fisher (1997) distinguishes between transactional and relational supply chain strategies, and their performance dimensions. He suggests that in volatile, rapidly obsolescing, high-margin markets, unit costs are secondary to agility. However, in mature, low-margin markets, cost efficiency is key. Thus, one performance metric is inadequate to measure strategic performance. Also, absolute metrics without comparison to competitors' performance may not illuminate a firm's or supply chain's relative performance, thus not its strategic competence.

Relationships and Hypotheses

Figure 2 represents our research model's hypothesized relationships, which we discuss next. The path numbers refer to research hypotheses.

H1: Business complexity's negative association with strategic performance is mediated by manufacturing IT infrastructure and supply chain coordination strategy.

H2: Business complexity is positively associated with manufacturing IT infrastructure.

H3: Manufacturing IT infrastructure is positively associated with strategic performance.

H4: Business complexity is associated with a transactional supply chain coordination strategy.

H5: Manufacturing IT infrastructure is positively associated with a transactional supply chain coordination strategy.

H6: A transactional supply chain coordination strategy is positively associated with strategic performance.

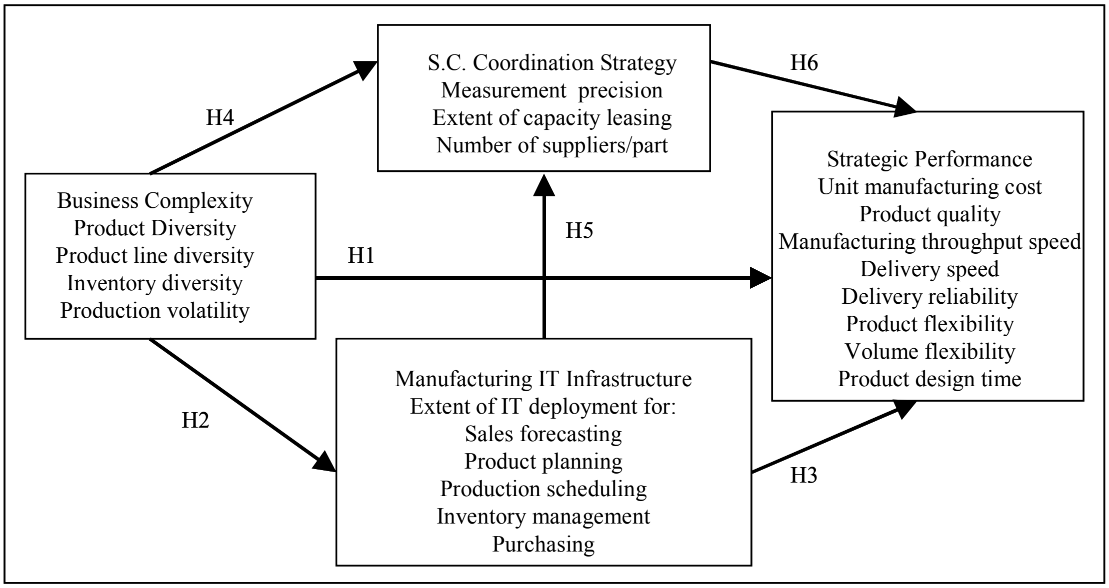


Figure 2. Research Model

Empirical Study

Sample

The Global Manufacturing Research Group (GMRG) data set contains secondary data gathered by operations management researchers. It addresses the general manufacturing context and MPC practices of two specific industries—companies that manufacture small machine tools and those manufacturing non-fashion textiles manufacturing -- and a catchall "Other" category (N= 106). There were 254 U. S. responses from these three categories. Since the "other" category did not control well for extraneous variables and the non-fashion textile industry did not provide a sufficiently large sample (N=37), the study was limited to the U.S. small machine tool manufacturing industry. This sample includes 93 usable responses. Since the data are specific to this single industry, many extraneous variables are thereby controlled. Similarly, our focus on MPC systems minimized problems associated with aggregating all IT applications, in which "…the impacts of effective systems are neutralized by ineffective systems" (Mukhopadhyay, Kekre, and Kalathur, 1995, p.149). This study offers additional insight through its use of "IT deployment" measures of IT, as these include some of the intangible investments made in change management, process reengineering, employee training, etc. that are not captured by considering only IT capital investment figures. Our multi-dimensional performance dependent variable also provides richer modeling of potential performance trade-offs than a single performance metric.

Various sampling frames and collection methods were used. Generally, in the U. S., small machine tool and non-fashion textile manufacturers listed in business directories were selected by SIC code, then mailed a survey with cover letter, some preceded by a phone call. The available response data for this secondary data set are aggregated for the three industry categories, and we were not provided a separate response rate for just the manufacturers of small machine tools. However, approximately 250 responses were received from about 1570 U.S. surveys sent, yielding a 16% overall response rate (personal correspondence from Gyula Vastag, August, 1998). As we don't have access to the mailing list, nor the respondents' contact information, we are unable to test for non-response bias. We thus characterize this study as exploratory.

Research Methods

Descriptive Statistics and Measurement Properties of Multiple-Item Scales

Means, standard deviations, and ranges for the latent variables are reported in Table 4. To test for unidimensionality, the indicators were factor analyzed using principal components analysis, followed by a promax rotation. This oblique rotation method was selected, as our factors are likely correlated, and our results will be further analyzed using the partial least squares (PLS) modeling package, PLSGraph, which does not assume independence of factors. Missing cases were replaced with the mean. The resulting factors were then tested for reliability. Those items shown to reduce reliability for the composite indicator were excluded. All variables' Cronbach's alphas exceed 0.60. While the minimum reliability is usually 0.70, lower reliabilities are acceptable for exploratory research (Hair, et al. 1992, p.449). Unidimensional, reliable variables were then formed by taking the mean of these items (with the exception of measurement precision, which is the sum of seven nominal items). These mean values were then transformed to conform to a one to five scale, then standardized and used in PLS (PLSGraph, Version 3.0, 100 iterations) analyses (Wold, 1980).

The pattern and factor correlation matrices for these factors are provided in Tables 5 and 6. Business complexity factors cumulatively explain 74.67% of the variance, and they are not significantly correlated with one another. Table 5 shows that only one manufacturing IT infrastructure factor was extracted. This single factor explained 62.59 % of the variance. In addition to the composite indicators shown in Table 5, coordination strategy also has a single item indicator, number of suppliers/part that did not load reliably with any of the other factors, but was deemed theoretically relevant. These factors cumulatively explained 94.73% of the variance, which is satisfactory for social science research (Hair, et al., 1992).

Summary of Reliability and Validity Analyses

Our factor analyses yielded expected factor structures. This provides evidence of measurement validity and unidimensionality. All factors showed adequate reliability, with Cronbach's alpha values larger than 0.60. The intercorrelations between the independent and mediating variables are shown in Table 6.

Model Evaluation

All latent variables in our study were modeled as formative, since their indicators are construed to "add up" to the latent variable's essence, with each measuring a subset of the total latent variable, rather than each being a different correlated measure of the same property. Thus, our estimates' stabilities are examined using a jackknifing re-sampling procedure (Chin, 1998).

Our PLS model is shown in Figure 2. The path coefficients show the degree of association between latent variables, while indicator weights show the extent to which items are related to the latent variable. A two-tailed adjusted t test was used to assess significance of the path connecting business complexity with supply chain coordination strategy, as we can only hypothesize an association, not whether the association is positive or negative. One-tailed adjusted t tests were used to assess significance of all other latent variables' indicators and the paths connecting them, as our hypotheses postulate positive and negative associations (for indicators' associations with latent variables, as well as latent variables' relationships to each other), based on theory.

Results

A preliminary PLS analysis of a simple model including only business complexity and strategic performance showed a significantly negative relationship between these constructs. Figure 2 demonstrates that, in this study, business complexity's negative association with strategic performance is indeed mediated by manufacturing IT infrastructure and supply chain coordination strategy (supporting Hypothesis1). Business complexity is associated with deployment of a more extensive manufacturing IT infrastructure (supporting Hypothesis 2). This extensive manufacturing IT infrastructure is associated (though not significantly) with lower strategic performance (not supporting Hypothesis 3). Business complexity is not significantly associated with coordination strategy (not supporting Hypothesis 4). An extensive manufacturing IT infrastructure enables a transactional supply chain coordination strategy (supporting Hypothesis 5), which is associated with heightened strategic performance (supporting Hypothesis 6).

This model's results more specifically suggest that firms having many product lines deploy more IT for inventory management. This IT deployment for inventory management is significantly associated with increased measurement precision, increased use of capacity leasing, and with having more suppliers per part. These three factors are significantly associated with better strategic performance with regard to manufacturing throughput speed, delivery reliability and flexibility to change output volume, but lower strategic performance on delivery speed.

Table 4. Descriptive Statistics

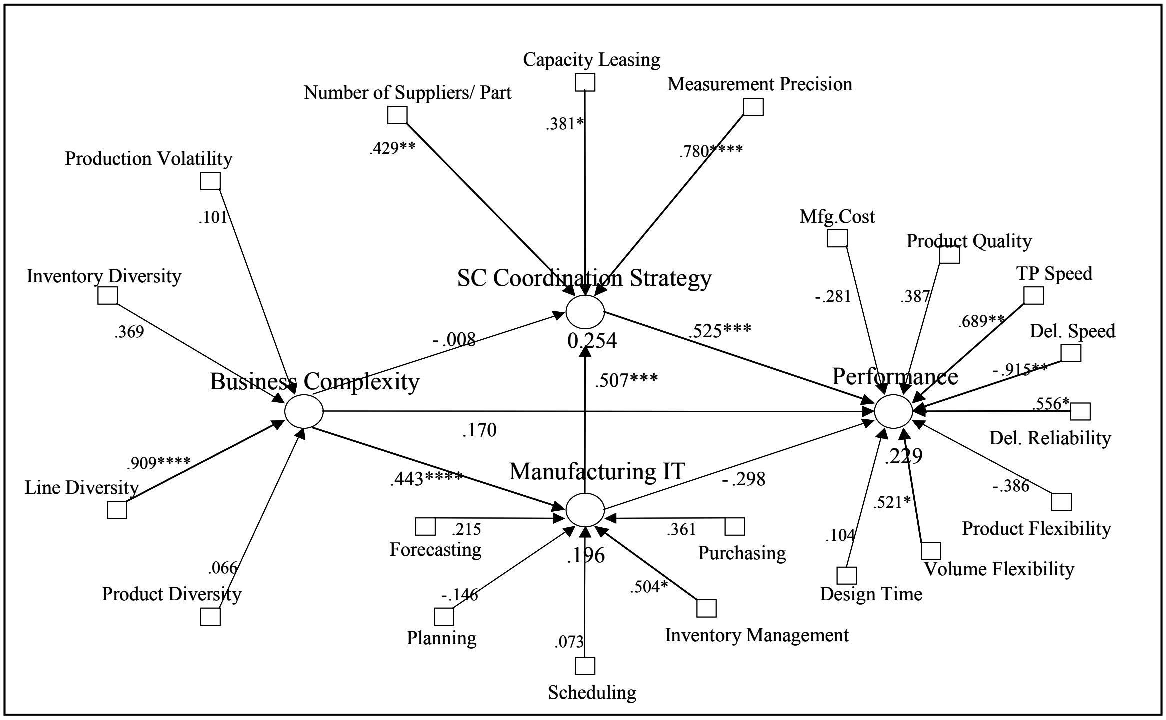
Constructs	Variables	Items	Min	Max	Mean	Std.Dev
Business Complexity						
	Product diversity		1.00	5.00	1.35	0.98
		Number of products for which sales forecasts are developed	1.00	5.00	1.35	0.81
		Number of products for which production plans are developed	1.00	5.00	1.32	0.75
	Product line diversity		1.00	5.00	1.59	0.94
		Number of product lines produced	1.00	5.00	1.02	0.91
		Number of product lines forecast	1.00	5.00	1.28	1.12
		Number of product lines in production plan	1.00	5.00	1.08	1.07
	Inventory Diversity		1.00	5.00	1.20	0.61
		Number of product numbers in raw materials inventory	1.00	5.00	1.19	0.65
		Number of product numbers in WIP inventory	1.00	5.00	1.21	0.76
	Production volatility		1.00	4.83	1.66	0.84
		% Orders for which customer schedule changes occur after the start of production	1.00	5.00	1.12	1.50
		%Orders for which engineering or design changes occur after the start of production	1.00	5.00	0.88	0.95
		% Incoming material rejected	1.00	5.00	1.00	1.01
Manufacturing IT						
		Extent of computer use for sales forecasting	1.00	5.00	2.31	1.29
		Extent of computer use for production planning	1.00	5.00	3.12	1.44
		Extent of computer use for production scheduling	1.00	5.00	3.27	1.45
		Extent of computer use for inventory mgt.	1.00	5.00	3.63	1.47
		Extent of computer use for purchasing	1.00	5.00	3.46	1.40
S.C. Coordination Strategy						
	Measurement precision	Firm has formal measures for forecast accuracy, delivery speed, mfg. throughput time, product design time, productivity, setup times	1.00	5.00	3.06	1.26
	Capacity leasing		1.00	5.00	2.43	1.39
		How often company responds to capacity imbalance by leasing temporary capacity from others	1.00	5.00	2.33	1.35
		How often company responds to capacity imbalance by leasing excess capacity to others	1.00	5.00	2.59	1.62
	# suppliers/part:		1.00	5.00	1.07	0.44
Strategic Performance						
		How firm compares with competition on unit mfg. cost	1.00	5.00	3.36	0.98
		How firm compares with competition on product quality	1.00	5.00	4.27	0.65
		How firm compares with competition on mfg throughput speed	1.00	5.00	3.66	0.91
		How firm compares with competition on delivery speed	1.00	5.00	3.80	0.95
		How firm compares with competition on delivery as promised	1.00	5.00	3.79	0.97
		How firm compares with competition on flexibility to change product	1.00	5.00	4.18	0.92
		How firm compares with competition on flexibility to change output volume	1.00	5.00	3.86	1.06
		How firm compares with competition on product design time	1.00	5.00	3.60	1.07

Table 5. Measurement Properties of Multiple-Item Scales

Constructs	Variables	Items	Eigenvalue	Loading	Missing N	% Variance	Cronbach's α
Business Complexity						74.05%	
	Product diversity		1.445			14.45%	.8812
		Number of products for which sales forecasts are developed		.873	36		
		Number of products for which production plans are developed		.872	31		
	Product line diversity		2.451			24.51%	.9151
		Number of product lines produced		.865	5		
		Number of product lines forecast		.883	27		
		Number of product lines in production plan		.826	32		
	Inventory diversity		2.075			20.75%	.6786
		Number of product numbers in raw materials inventory		.883	18		
		Number of product numbers in WIP inventory		.841	18		
	Production volatility		1.497			14.97%	.6553
		% Orders for which customer schedule changes occur after the start of production		.887	3		
		% Orders for which engineering or design changes occur after the start of production		.669	4		
		% Incoming material rejected		.694	6		
Manufacturing IT			3.219			62.59%	.8490
		Extent of computer use for sales forecasting			0		
		Extent of computer use for production planning			0		
		Extent of computer use for production scheduling			1		
		Extent of computer use for inventory mgt.			1		
		Extent of computer use for purchasing			1		
Supply Chain Coordination Strategy						60.01%	
	Measurement precision	Firm has formal measures for time standard accuracy, forecast accuracy, delivery speed, mfg throughput time, product design time, productivity, and setup times.	0.945	.998	0	22.79%	.7777
	Capacity leasing		1.812			45.29%	.8715
		How often company responds to capacity imbalance by leasing temporary capacity from others		.942	0		
		How often company responds to capacity imbalance by leasing excess capacity to others		.939	6		
	# Suppliers/ part	Number of suppliers for each part	1.032	1.000	3	25.80%	

Table 6. Intercorrelations of Indicators (*denotes p< .05, ** denotes p< .01, using Spearman correlation coefficient, one-tailed test)

Variable	Product diversity	Prod.. line diversity	Inv. diversity	Prod. volatility	Forecasting	Planning	Sched.	Invy mgt	Purch.	Meas. precision	Leasing	Suppliers/ parrt	Mfg cost	Prod quality	Mfg TP speed	Del. speed	Del. reliability	Prod. flex	Vol. flex.	Design time
Product diversity	1.000																			
Product line diversity	-.022	1.000																		
Inventory diversity	-.066	.093	1.000																	
Production volatility	-.227*	-.098	.292**	1.000																
Forecasting	-.117	.241*	-.063	-.036	1.000															
Planning	.033	.397**	.214*	.042	.557**	1.000														
Scheduling	-.076	.300**	.317**	.118	.369**	.741**	1.000													
Inventory mgt.	.157	.237*	.228*	-.014	.355**	.590**	.602**	1.000												
Purchasing	-.091	.168	.286**	.143	.313**	.535**	.528**	.585**	1.000											
Meas. precision	-.050	.203*	.062	-.054	.377**	.407**	.420**	.278**	.261**	1.000										
Capacity leasing	.022	.080	.147	.171	.113	.199*	.241*	.167	.089	.125	1.000									
# Suppliers/ part	-.078	.131	-.089	.135	.121	.091	.107	.029	.108	.002	-.054	1.000								
Unit Mfg.Cost	-.085	-.005	-.166	.021	.142	-.041	-.074	-.027	.071	.000	-.247**	.125	1.000							
Product quality	-.058	-.057	-.112	.188*	-.013	.003	-.024	-.052	.062	.127	-.025	.124	.089	1.000						
Mfg. TP time	-.081	.120	-.171	.053	.189*	.047	.039	.019	-.043	.188*	-.072	.153	.475**	.212*	1.000					
Delivery speed	-.055	.079	-.239*	-.038	.023	.033	-.053	.100	.079	.094	-.224*	-.077	.344**	.287**	.602**	1.000				
Delivery reliability	-.045	.024	-.189	-.027	.065	.027	.-.058	.095	-.069	.168	-.102	-.038	.206*	.383**	.518**	.727**	1.000			
Product flexibility	.136	.151	.025	-.107	.029	-.042	-.028	.006	-.111	-.091	-.018	.205*	.283**	.266**	.341**	.167	.315**	1.000		
Volume flexibility	.032	.242*	.023	-.129	.127	.025	.094	.090	.066	.166	-.015	.233*	.180*	.150	.225*	.189*	.160	.482**	1.000	
Design time	-.188	.057	-.206*	.033	.062	-.121	.026	-.179*	-.104	.043	-.028	.194*	.477**	.219*	.425**	.253**	.185*	.443**	.449**	1.000



* p< .10. ** p< .05, ***p< .01, ****p<.001, one-tailed test

Figure 2. Model

Implications for Theory

This research was able to empirically test theoretical frameworks (c.f., Das, et al., 1991; Holland and Lockett, 1997; Patnayakuni, et al., 2002) suggesting that the degree of fit between an organization's complexity level, and/or its supply chain coordination strategy and its manufacturing IT infrastructure determines elements of its strategic success. This result is consistent with Markus and Soh (1993), who say that IT infrastructure, rather than directly impacting aggregate firm performance, may instead support critical processes that improve firm performance. Our results also confirm Brynjolfsson and Yang's (1997) assertion that tangible IT investments must be leveraged by complementary investments in intangibles, such as strategy adjustments and process reengineering. It supports Bhaskaran's (1998) suggestion that IT leveraged by supply chain coordination improves strategic performance.

Implications for Practice

Managers must analyze IT deployment in terms of desired, sometimes conflicting, performance impacts; using relevant, sometimes non-financial, measures; and in terms of complementary investments, some of which are intangible. We found that firms supporting more product lines deployed more inventory management IT, but without complementary deployment of transactional supply chain coordination strategy, they experienced equivocal strategic performance. However, with these complementary investments, they reaped significantly better strategic performance.

If manufacturing throughput speed, delivery reliability and volume flexibility are critical, IT deployment for inventory management must be coupled with transactional supply chain coordination strategies, i.e., with more suppliers/part, increased capacity leasing and measurement precision. The ability to consider the total situation, to ask the correct questions, to measure the critical outcomes, as well as apply the relevant technologies will confer competitive advantage.

Limitations

This study uses secondary data, collected by others, back in 1994 and 1995. We relied upon GMRG members' generosity in providing the data. We don't know the companies contacted, those surveyed, or those that responded. We thus have no good way to check for non-response bias. Also, since the variable operationalizations are constrained to data available in the data set, explanatory power and generalizability of the results may be low, so we characterize this study as exploratory.

Future Research

This analysis could be extended to an industry sector that ideally relies upon a relational supply chain strategy, and the results compared. We would also like to follow up this study with one considering newer IT infrastructures, e.g., B2B exchanges. Will exchanges serving the auto industry continue to support transactional coordination strategies or will the new technologies be better leveraged with relational strategies? Do the optimal strategies differ with regard to the respondent firm's tier?

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