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A Model of Supplier Integration into New Product Development*

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In many industries, firms are looking for ways to cut concept-to-customer development time, to improve quality, and to reduce the cost of new products. One approach shown to be successful in Japanese organizations involves the integration of material suppliers early in the new product development cycle. This involvement may range from simple consultation with suppliers on design ideas to making suppliers fully responsible for the design of components or systems they will supply.

While prior research shows the benefit of using this approach, execution remains a problem. The processes for identifying and integrating suppliers into the new product development (NPD) process in North American organizations are not understood well. This problem is compounded by the fact that design team members often are reluctant to listen to the technology and cost ideas made by suppliers in new product development efforts. We suggest a model of the key activities required for successful supplier integration into NPD projects, based on case studies with 17 Japanese and American manufacturing organizations. The model is validated using data from a survey of purchasing executives in global corporations with at least one successful and one unsuccessful supplier integration experience. The results suggest that (1) increased knowledge of a supplier is more likely to result in greater information sharing and involvement of the supplier in the product development process; (2) sharing of technology information results in higher levels of supplier involvement and improved outcomes; (3) supplier involvement on teams generally results in a higher achievement of NPD team goals; (4) in cases when technology uncertainty is present, suppliers and buyers are more likely to share information on NPD teams; and (5) the problems associated with technology uncertainty can be mitigated by greater use of technology sharing and direct supplier participation on new product development teams. A supplier's participation as a true member of a new product development team seems to result in the highest level of benefits, especially in cases when a technology is in its formative stages.

Introduction

Research in new product development (NPD) has shown that an array of different variables is important in creating successful new products. One that is frequently mentioned is customer/supplier integration [12,22,23,34–36,42, 54,56,63]. Although extensive research has focused on integrating *customer* requirements into new product development efforts [23,41,43,63], the area of *supplier* integration has not received as much attention. Congruent with the need to integrate multiple-linked processes in the supply chain, theoretical research advocates that early and extensive supplier involvement results in a faster development process [11,12,17,19,35,49,50,63]. Despite the criticality

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of this subject to managers, business models for successfully involving North American and European suppliers in the NPD process are sparse [22,27,40,51].

To illustrate, many managers characterize the execution processes for integrating suppliers into NPD projects as a "black box" [27,47]. While case studies and anecdotal evidence suggest that the participation of these outside constituents is important, prior research tends to focus on Japanese buyer–seller relationships that are markedly different from those found in North America [2,17,33,45,48]. Although many of the internal processes associated with NPD are well defined, comparatively little information exists on how to integrate third parties (suppliers) into the process [15,29,55].

Issues that arise in supplier integration include tier structure, degree of responsibility for design, specific responsibilities in the requirement setting process, when to involve suppliers in the process, intercompany communication, intellectual property agreements, supplier membership on the project team, and alignment of organizational objectives with regard to outcomes [15,39,47,52].

In this article, we propose that successful supplier integration projects require a *major change to the cross-functional new product development process*. We propose that three critical factors form the foundation for a successful supplier integration effort: (1) understanding the focal suppliers' capabilities and design expertise, as well as the technical risks weighing against them; (2) ensuring that technology and cost information flows between the design team and the supplier; and (3) ensuring that the supplier has an ongoing active role on the design team. We develop a model of supplier integration based on case studies with 17 Japanese and American manufacturing organizations and validate the model using data from a survey of 84 purchasing executives in global corporations with at least one supplier integration experience.

BIOGRAPHICAL SKETCHES

Dr. Kenneth J. Petersen is assistant professor of supply chain management at Arizona State University and research associate at the Center for Advanced Purchasing Studies. Dr. Petersen has published numerous articles in various supply management and business-related journals, including the *Decision Sciences Journal*, *California Management Review*, *Journal of Business Research*, and the *Journal of Supply Chain Management*.

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Model Development

Research on supplier integration into NPD is aligned with several different theoretical perspectives on buyer–seller relationships. Transaction cost economics dictates that the form of governance and the extent of trust may affect the degree of risk of loss perceived by agents of firms in alliances [49,52,61] but that transaction costs do not increase necessarily with an increase in relationship-specific investments [16]. Relational theory furthers this approach by asserting that a relational capability is not a sufficient condition for realizing relational rents [18]. Rather, organizations must establish what knowledge and resource investments are likely to ensure that both parties create joint value in the form of relational rents [17,62]. Organizational design theory also proposes that firms may place resource-based concerns in front of organizational economics when deciding whether or not to engage in interfirm cooperation [13,20,25]. Finally, network governance models suggests that a select, persistent, and structured set of autonomous firms will engage in creating new products or services, based on implicit and open-ended contracts that permit adaptation to environmental contingencies and that safeguard exchanges [20,31,38,50]. All four bodies of theory (transaction cost economics, organizational design, relational theory, and network theory) align with our central thesis that buyer–seller integration (including NPD efforts) require appropriate safeguards and approaches to be successful.

Recent studies of supplier integration into NPD projects typically examine the outputs of the process but rarely examine the dynamics. A variety of benefits are attributable to supplier integration into NPD [37]. First, including suppliers on project teams adds information and expertise regarding new ideas and technology [10] and helps to identify potential problems so they can be resolved early [60]. "Sticky" information can be shared by transferring information from its point of origin to its point of use [58], thereby resulting in improved problem-solving activities. Suppliers also can benefit from "spillover effects" that influence future research and development (R&D) activities downstream [28]. Second, supplier integration provides outsourcing and external acquisition possibilities that reduce the internal complexity of projects [9] and provides extra personnel to shorten the critical path for NPD projects [12,54,57]. Third, it helps coordinate communication and information exchange, thus reducing delays [17,26]. Fourth, it helps eliminate rework because accessibility and production of parts can be considered early [12]. Finally, it improves supplier relationships, which leads suppliers to internalize project concerns and thus allows for a better working relationship [46].

A study of supplier integration practices by Wasti and Liker [60] found that three elements were critical: (1) the extent to which the supplier influences decision-making; (2) the amount of control the buyer retains over the design; and (3) the frequency of design-related communication. This research also supports the proposition that technology uncertainty is related to the need for greater involvement of suppliers. Bensaou [5] also found that in Japan, technological uncertainty drives closer relationships with first-tier suppliers through early involvement in product conception and planning. In the United States, a converse relationship was discovered: Technology uncertainty resulted in lower supplier involvement due to a lack of trust.

Case Studies

In identifying the methods used to integrate suppliers in the North American and European sample, we began by assuming that supplier integration into the NPD process is fundamentally a *social process*, an assumption evoked in other studies of the process [6,21,22]. Putting technical considerations aside, the majority of the engineers interviewed for the study expressed their initial and acute discomfort at having an external supplier participate on an NPD team, where sensitive technical information is being discussed [often referred to as the "Not Invented Here" (NIH) syndrome].

To better understand the critical factors responsible for successful supplier integration efforts, we developed an interview protocol and met with NPD and purchasing managers at manufacturing locations in Japan and the United States [47]. This set of companies was selected based on a list compiled from executives asked to identify companies considered "best in class" in the areas of supplier integration into NPD. The companies visited were in the automotive, electronics, computer, chemical, consumer products, and semiconductor industries. The goal of these interviews was to understand the company's current process for integrating suppliers and to elicit insights into how they had overcome barriers along the way. All notes from the interviews were typed and coded. Based on a review of these notes by multiple participants, we developed a simplified structural equation model that effectively characterized the major activities required to integrate successfully suppliers into the NPD process (see Figure 1).

The structural equation model is based both on theoretical premises as well as the salient variables that emerged from our case studies. The model is consistent with the alignment of network, organizational

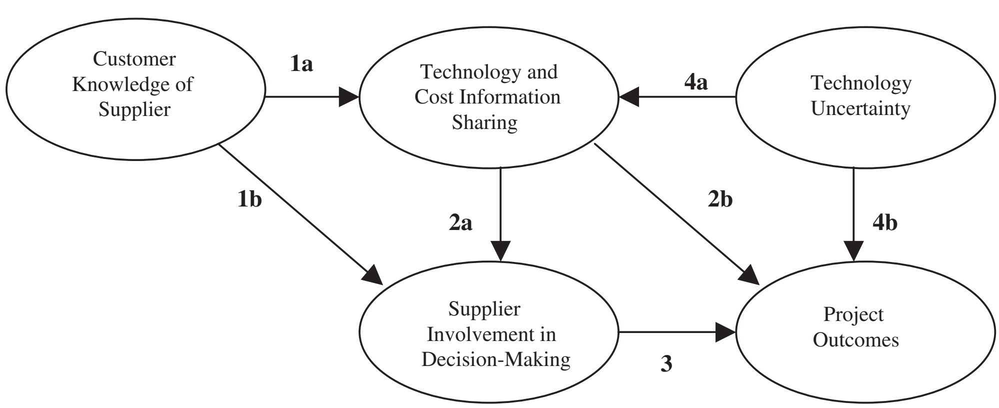


Figure 1. Simplified Structural Equation Model and Hypotheses

design, transaction cost economics, and relational theory assertions that buyer–seller relationships can evolve from business network connection, to mutual dependence and to value creation under conditions of uncertainty in order to reduce the likelihood of loss [13,18,20,31,49,61]. Our case studies also suggested that companies successful at supplier integration employed a *systematic process* for overcoming perceived technology risks. This process was initiated by developing a deep knowledge of the suppliers being considered for involvement. A second requirement of successful companies involved close discussions with suppliers over time to share information in order to create a "bookshelf" of current and emerging technologies that were becoming available to meet future requirements. These discussions also led to a detailed understanding of the cost drivers associated with a given technology. Third, successful supplier integration efforts were managed carefully; managers took the time to ensure that the supplier was included actively in the team decision-making process. Whenever possible, the supplier's insights were considered in decisions, especially when the team confronted technical issues with which they were not familiar. Adhering to these steps was instrumental in ensuring that the buying company fully exploited the value of the supplier's knowledge and capability.

The structural equation model developed reflects these insights and consists of four variables that affect the relative degree of success of NPD projects that integrate suppliers into the process. Other factors mentioned by managers that may impact supplier integration but that were not included in the study included the following: re-engineering the new product development process; detailed make or buy analysis; use of information technology to communicate with suppliers on design characteristics; use of tools such as quality function deployment; use of detailed non-disclosure and proprietary technology agreements; and matrixed product development organizations.

Although we acknowledge that these and other variables may account for variation in the success of supplier integration efforts, we limited our model to the following factors based on the salience of these issues in the case study interviews: (a) Customer Knowledge of Supplier; (b) Technology and Cost Information Sharing; (c) Supplier Involvement in Decision-Making; and (d) Technology Uncertainty (see Figure 1). The structural model assesses the effect of these factors on Project Outcomes. In the next section, we develop a set of hypotheses that establish the relationship between these variables in the structural model based on prior studies and the rationale of product managers interviewed.

Hypotheses 1a and 1b: Customer Knowledge of Supplier

Prior studies have identified compatibility, reputation, and fit between parties as an important component to any type of joint projects [29,32,49,53]. Increased knowledge of a party has been identified as an important aspect for greater integration. Familiarity with a supplier makes it easier to involve their people on NPD teams, as they are more likely to be considered a "family member," (albeit a distant cousin) and an active team member [6,15,30,42]. An increased comfort level associated with the supplier can lead to technology sharing in pursuit of new products [37,60]. Several companies in our case studies noted the importance of becoming familiar with a supplier prior to involvement. At a major U.S. electronics company, cross-functional commodity teams are tasked with focusing on those suppliers who were open and clear about their strategic focus. Part of this task involved considering capacity, total cost, and technology criteria and ensuring that different product teams do not duplicate effort by separately buying common or duplicate items. Other variables that influenced the team's willingness to include suppliers include their relative level of involvement and record of success in prior efforts, financial health, engineering staff headcount, and other issues. The relative importance of these specific criteria varies from company to company and from project to project. The fundamental objective is to achieve alignment between the buying company's needs and the supplier's capabilities, from both a technical standpoint and a cultural/behavioral standpoint.

H1a: Customer knowledge of a supplier is associated positively with increased technology and cost information sharing.
H1b: Customer knowledge of a supplier is associated positively with increased supplier involvement in decision-making.

Hypotheses 2a and 2b: Technology and Cost Information Sharing

Research-intensive cooperation often involves both the discovery and absorption of tacit knowledge that is not transferable or codifiable easily. Transaction cost savings and immediate returns generally are not as critical as gains in technical capability, tacit knowledge, or understanding of rapidly changing markets [38,56]. Increased technology sharing often can lead to better supplier solutions, which often as not result in lower costs as well. Several organizations in our cases employed "target pricing" methods, which involved joint buyer–seller teams exploring alternative technical solutions to meet a target cost early in the product development cycle [47]. Such efforts often required suppliers to "open their books" and to share their own cost allocation methods—a practice in which they were less likely to engage if the relationship was not well established.

In other interviews, managers noted that suppliers who had participated early in initial technology sharing discussions later contributed to setting goals regarding project outcomes. Suppliers, because of their technical knowledge or expertise, may have more realistic technology goals and information on the tradeoffs involved in achieving particular goals. Such goals are not limited to cost but often include product performance characteristics (such as weight, size, or speed) and project performance measures (such as development time). The buying company will have the ultimate authority in goal setting, but the supplier's involvement can help in setting goals that are aggressive but reasonable and also in assuring the supplier's "buy-in" to the goals.

For example, a leading Japanese firm visits its key suppliers before the detailed design of a new product begins. These visits help the purchaser decide if the supplier can produce an item at the targeted cost and quality levels. The buyer also assesses the supplier's ability to become part of the product development team. After a general discussion about the technology required for the new product, the supplier submits an initial design proposal. Starting with a basic frame and shape based only on broad product requirements, the product design evolves, with engineers from both companies working together to evaluate alternative designs that satisfy product requirements.

Based on these observations, we propose that

H2a: Technology and cost information sharing is associated positively with supplier involvement in decision-making.
H2b: Technology and cost information sharing is associated positively with project outcomes.

Hypothesis 3: Supplier Involvement in Decision-Making

In order to elicit real input on a team, suppliers often are asked to colocate a design engineer on the purchasing company's design team (either full time or part time). Colocation of suppliers in such cases is valued primarily for its impact on the companies' ability to address design problems quickly as they arise in the design process. Companies in our case studies who used colocation found it to be extremely effective for problem-solving during design, ramp-up, and full-volume operations.

In our interviews, we also noted that successful companies often made the focal supplier an active participant on the project team. Our findings suggest that the extent of the supplier's participation was the factor most strongly associated with the achievement of project goals. Supplier representatives do not have to be present necessarily at every NPD team meeting, but the suppliers must be kept apprised of and must participate in decisions that are relevant to their involvement. This is perhaps one of the most challenging elements of supplier integration. One firm suggested that corporate cultural differences were problematic when including suppliers on design and development teams. This firm, which relies heavily on supplier support during the development of process equipment, includes supplier representatives as part of its process design teams to overcome corporate culture issues and establish open lines of dialogue. During one project a major supplier assumed a lead role for developing a process for use by all of the buying company's suppliers. The project required suppliers with different corporate and national cultures, some of whom also were competitors, to work together. This proved to be a challenging task. However, collaboration on the project became much easier when representatives were brought together in a face-to-face environment and were required to resolve their differences.

H3: Supplier involvement in decision-making is associated positively with project outcomes.

Hypotheses 4a and 4b: Technology Uncertainty

The impact of technology uncertainty has been identified as a key variable in research on supplier integration. Many companies are facing an increase in technological risk/uncertainty due to their desire to reduce product development cycle times while at the same time maintaining their level of innovativeness [3,56]. In this situation, organizations find themselves having to commit to technology and design decisions earlier, often with less information. With careful planning and involvement with key suppliers, a firm can control its exposure to technological risk and still can realize the benefits of technological advances.

Our case studies suggest that technological uncertainty/risk comes from several sources: new-to-the-world technologies; new applications of existing technologies; and technologies outside the company's field of expertise. The newer a technology is, the greater the risk associated with applying that technology in a new product. If a technology is new to the company but is not new to the world, the company can mitigate the risk by working with a supplier who has significant experience with the technology or by using it on low-volume products. For example, one automotive company interviewed has used a low-volume product line as a type of test bed for new technology applications. Exposure is limited because of the lower volume, but the company uses the product line as a showcase as well, so suppliers are willing to work with the company on the application of the new technologies.

Previous studies also suggest that technology uncertainty can be mitigated through openly sharing cost and technology information with suppliers [3,25,56]. For example, Hartley et al. [29] identify the degree of component change as a mediating variable affecting the extent to which suppliers are successfully integrated. In Japanese companies, technological uncertainty drove closer relationships with first-tier suppliers through early involvement in product conception and planning [5,59]. Wasti and Liker found evidence of an interaction effect between technology uncertainty and the need for greater involvement of suppliers in their research [60].

Our interviews suggest that by effectively creating a "bookshelf" of potential untested technologies, companies are able to access and to apply better these technologies in new products when there is a good match. The ability to tap the knowledge and expertise of suppliers, for design as well as for manufacturing, is likely to lead to better technology decisions and ultimately to better products. When confronted with technological uncertainties, organizations often approached key suppliers to influence the direction of their technology development efforts and ultimately to reduce development costs. For example, one electronics company has established an "Advanced Technology Group" charged with managing the development and adoption of new technologies for the company's products. This group monitors the supply market for new technologies and also takes a proactive role in developing technologies called for by the company's product line teams. As such, we propose that in situations when high-technology uncertainty exists, organizations will increase the sharing of technology and cost information to aid this process.

H4a: Technology uncertainty is associated positively with technology and cost information sharing.

We also acknowledge the difficulty in managing technology uncertainty and the potential negative effect on project goals. Several companies reported major increases in costs and project delays due to technologies that never worked out due to complexities that were unforeseen during the concept stage. For example, in the computer industry, a key challenge lies in the timing of application of new technology. In some cases, a supplier can provide a promising new technology that is not yet robust and not cost competitive. Over time, this situation may change as costs are lowered and as technological performance also improves. The decision over whether to transition a new technology into the product cycle can be very challenging, since the technology may be untested or substandard, yet other producers already are using it. On the downside, if it is not incorporated, suppliers run the risk of being late to market with a new feature or technology.

H4b: Technology uncertainty is associated negatively with project performance goals.

Methodology

Measurement Development

To ensure face validity, all measures were examined thoroughly by a group of industry executives and subject area experts prior to mailing of the survey [14]. All of the items used in the measurement model were new scales, although based in part on previous work on supplier integration [29,30,39]. The scales were pretested in the case study interviews and were reworded accordingly to improve comprehension.

Data Collection and Sample

A survey instrument was prepared and was distributed to members of the Michigan State University Global Procurement and Supply Chain Electronic Benchmarking Network (GEBN) in 1996. Members of the GEBN agreed to participate in a series of benchmarking surveys conducted each year as part of a larger research initiative. An initial prequestionnaire fax was sent to all 210 members, asking them to indicate whether they currently were integrating suppliers into their NPD process. All 210 companies responded, and 84 of the 210 companies (40 percent) indicated they had involved suppliers in their NPD efforts to some extent and would respond to the survey. The remaining faxed responses from other members (60 percent) indicated they were not able to complete the survey because they currently were not involving suppliers in NPD but would like to have a copy of the results so as to plan this initiative for the future.

For the 84 companies with an experience in supplier integration, a survey was sent to the primary contact, typically a high-level purchasing executive within the company (the director or vice president). This executive then coordinated the completion of the survey, requiring input from purchasing managers, engineers, and designers involved in the supplier integration effort. The questionnaire asked for detailed information regarding the business unit's experience in two specific cases of supplier integration into NPD. The two cases about which the respondents were asked were those that the business unit considered to be its ''most successful'' and ''least successful'' cases of supplier integration. Each of these cases focused on the integration of the supplier of a single commodity, purchased item, subsystem, or system. It was left to the respondents to determine which of their experiences was the most and least successful.

The complete set of 84 companies that participated is shown in Table 1 and represented the following industries (all numbers following industries are given in percentages): automotive/transportation (18); petroleum/mining (16.67); industrial products (13.25); consumer products (12); telecommunications (9.6); electronics (9.6); aeronautical/aviation (4.8); computers (4.8); pharmaceuticals (3.6); packaging (2.4); textiles (1.2); chemicals (1.2); semiconductors (1.2); and office furniture (1.2). Approximately 79 percent of the responses were from North American companies, 20 percent European, and 1 percent Australian. Of the 84 companies, only 44 completed the questionnaire for both most successful and least successful suppliers, leaving a final sample of 88 paired responses.

The use of covariance structure analysis requires that the data to be analyzed are free from any missing values [8]. As noted earlier, the respondents in the final sample provided a response for a most successful and a least successful supplier integration experience, for a total potential sample of 88 (44×2). Cases/questions contributing too heavily to the overall degree of missing data were discarded. This procedure

Table 1. Companies Participating in Survey

A. Ahlstrom	* Intel
Air Products	Jefferson Smurfitt
* Alcatel	* Johnson & Johnson
* ALCOA	Kerr McGee
* Allied Signal	* Kraft
Amoco	* Lexmark
Amway	Libbey Owen Ford
* Arvin Exhaust	Liquid Carbonic
Atlantic Packaging	Mack Trucks
Avon	* Mattel
* Bell Atlantic	Merck
BellSouth	* Natural Gas Pipeline
BHP	Ontario Hydro
* Black & Decker	Owens Corning
BMW	* Pacific Bell
* British Telecomm (3)	* PBR
BTR Engineering	* PPG Industries
* Caradon MK Electric	* Phelps Dodge
* Caterpillar	Philips Consumer
Champion	* Prince/JCI
* Chevron	Sasol
* DaimlerChrysler	SEW
* Compaq	Shell Internationale
* Cummins Engine	Siemens
* Cyprus	* Siemens Bordnetze
* Deere & Company	SmithKline Beecham
* Delco	Southcorp Packaging
Detroit Edison	* Sprint
Dupont	STATOIL
Eaton	Steelcase
Eureka	Tandem
Exxon	* The Interlake Corporation
Fluke	* Texas Instruments
* Ford	* The Post Office
* Ford of Australia	* Thomson Consumer
* Frigidaire	TRINOVA/Aeroquip
* Hamilton Standard	TRINOVA/Vickers
Henkel	* Unisys
Hewlett Packard	US West
* Honeywell	* Walt Disney
* ICL	* Whirlpool
* INCO	* Zenith

Note: While all companies listed above participated in this research, only those companies marked with an (*) were included in the data analysis presented in this article.

resulted in a data set that contained no missing data among the measures of the dependent construct and a 0.054 percent rate of missing data rate among the measures of the independent constructs. The missing data values among the independent measures then were replaced using a simple mean imputation [1] calculated across all remaining responses to a given question. The final sample size was 88 NPD projects.

Results

Univariate Distributions

All univariate distributions were examined and were found to be free from excessive skewness, kurtosis, and outliers. Mardia's coefficient [44] was employed as a measure of multivariate kurtosis and provided an indication that the data were slightly multivariate kurtotic (Mardia's coefficient=2.04).

External Validity of Outcome Measures

The descriptions of the measures for each of the independent constructs are summarized in Appendix A. *Project outcomes* were measured by the degree of overall satisfaction with the performance outcomes and whether the project achieved established goals. The correlations of this construct also were compared to other performance outcomes (cost reduction, quality, concept to customer cycle time) to assess their validity. The correlations in each case were positive and significant. A summary of the range of different project outcomes described by the companies is shown in Table 2. A correlation matrix showing the correlations of subjective measures of satisfaction with actual performance outcomes is shown in Table 3. All of the actual performance outcomes were correlated significantly with the subjective measures (except for market share and quality, which had a low correlation with degree of overall satisfaction). A correlation matrix of all latent variables used in the analysis is shown in Table 4.

Table 2. Self-Reported Results of Supplier Integration

Percent Improvement of NPD Projects When Suppliers Were Integrated (Median)

Project	%
Cost	11
Cycle Time	20
New Product Development Time	42
Quality Improvement	14
Technology Access	40

Range of Reported Performance Improvement Results from Selected Companies

Performance Improvement	Result
Quality	0 to 52% annual improvement (25 firms)
Cost	0 to 47% annual dollar cost reduction (21 firms)
Cycle Time	0 to 191% annual improvement (20 firms)

Confirmatory Factor Analysis

Confirmatory factor analysis (CFA) was used to validate the measurement model (Table 5). This measurement model was tested using EQS with maximum likelihood [7] estimation. All latent constructs in this measurement model are reflected by either two or three manifest variables. Although at least five measures were developed initially for each construct, the CFA resulted in several of the manifest variables being dropped. These variables were dropped as a result of the fact that these manifest

Table 3. Correlations between Project Outcome Measures and Other Performance Outcomes

		Cost	Quality	Design Cost	Market Share	Market Volume	Profit/ROI
SATISFAC	Pearson Correlation	0.18	0.11	0.28	0.17	0.22	0.25
	Sig. (2-tailed)	0.10*	0.30	0.01*	0.12	0.04*	0.02*
	N	88	88	87	87	87	86
ACHIEVE	Pearson Correlation	0.20	0.27	0.23	0.22	0.22	0.26
	Sig. (2-tailed)	0.06*	0.01*	0.03*	0.04*	0.04*	0.01*
	N	88	88	87	87	87	86

*=Significant at the p=0.1 level
Survey Question: For each of the following results categories, please rate its importance as a measure of the OVERALL SUCCESS of the project. Rate each dimension from 1 (not important at all) to 7 (critically important).

Table 4. Correlation Matrix of Latent Variables

	INFOSHAR	OUTCOME	KNOW	SUPINVL	TECHUNC
INFOSHAR		0.475	0.333	0.493	0.539
OUTCOME			0.411	0.580	0.204
KNOW				0.402	0.064
SUPINVL					0.392
TECHUNC					

Table 5. Confirmatory Factor Analysis, Reliability, and Fit Statistics

	Factor	Standardized Solution			Reliability (alpha)
		Lambda	Delta	T-Statistic	
TECHSHARE	INFOSHAR	0.875	0.484	5.448	
COSTSHARE	INFOSHAR	0.891	0.455	5.572	0.861
SATISFAC	OUTCOME	0.979	0.202	6.136	
ACHIEVE	OUTCOME	0.816	0.578	4.867	0.873
SUPFREQ	KNOW	0.567	0.824	3.119	
SUPFAM	KNOW	0.961	0.278	4.108	
SUPASSESS	KNOW	0.612	0.791	3.198	0.726
MEMBERSHIP	SUPINVL	0.664	0.748	4.957	
PARTICIPATE	SUPINVL	0.879	0.478	6.314	
COMMUNICATE	SUPINVL	0.685	0.728	5.067	0.766
TECHCOMPLX	TECHUNC	0.833	0.553	3.525	
TECHNEW	TECHUNC	0.765	0.644	3.400	
TECHSTAB	TECHUNC	0.604	0.797	3.174	0.778
Chi-Square	70.08/60 d.f. (p=0.175)				
BBNFI	0.871				
BBNNFI	0.972				
CFI	0.978				
RMSEA (90%)	.045 (0, 0.082)				

Note: BBNFI: Bentler-Bonett Normed Fit Index; BBNNFI: Bentler-Bonett Nonnormed Fit Index; CFI: Comparative Fit Index; RMSEA: Root Mean Square Error of Approximation.

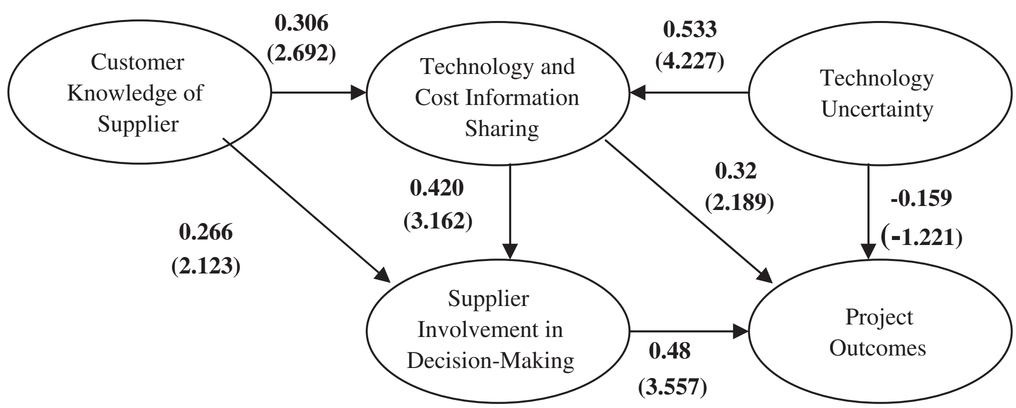
variables demonstrated (1) correlated error terms; (2) lack of convergent validity; or (3) lack of discriminant validity. We recognize that this limitation to the study likely is due to the fact that the measures were new and that no previous measures of supplier integration had been tested formally for convergent validity.

The overall fit of the measurement model provided a chi-square of 70.08 (60 d.f.; p=0.175). Furthermore, the Bentler-Bonett nonnormed fit index was 0.972; the comparative fit index was 0.978; and the root mean square error of approximation (90 percent) was 0.045 (0, 0.082). We may conclude that the overall fit of the measurement model is satisfactory [4]. All factor loadings were of sufficient magnitude and were significantly different from zero at the p=0.05 level. Standard tests of discriminant and nomological validity supported the measurement model as adequate to employ in the testing of the structural model.

Structural Model

The structural equations (see Appendix B) were estimated using the EQS 5.6 structural equation modeling software package [7]. The structural model with standardized solutions and t-statistics is shown in Figure 2. All structural relationships were assessed by estimating the structural and measurement models simultaneously (Table 6).

All parameter estimates in the model were significant (with the exception of the path from Technology Uncertainty to Project Outcomes) and were in the expected direction and were of the expected magnitude. The overall fit of the revised structural model was indicated by a chi-square of 62.14 (57 d.f.; p=0.298). The Bentler-Bonett nonnormed fit indices for each of the models were 0.985; the comparative fit index was 0.989; and the root mean square error of approximation (90 percent) was 0.034 (0; 0.075). We may conclude that the



() – T statistic
χ^2 = 62.14 (57 d.f., p = 0.298).
BBNNFI = 0.885
BBNNFI = 0.985
CFI = 0.989
RMSEA (90%) = 0.0034 (0, 0.075)

Total Effects
Customer Knowledge → Supplier Involvement = 0.394
Customer Knowledge → Project Outcomes = 0.291
Information Sharing → Project Outcomes = 0.528
Technology Uncertainty → Project Outcomes = 0.014

Figure 2. Standardized Solution—Structural Models

Table 6. Structural Model

	Factor	Standardized Solution		
		Lambda	Delta	T-Statistic
TECHSHAR	INFOSHAR	0.902	0.431	8.379
COSTSHAR	INFOSHAR	0.859	0.511	*
SATISFAC	OUTCOME	0.951	0.539	*
ACHIEVE	OUTCOME	0.842	0.825	8.015
SUPFREQ	KNOW	0.565	0.825	*
SUPFAM	KNOW	0.965	0.261	4.493
SUPASSESS	KNOW	0.609	0.793	4.604
MEMBERSHIP	SUPINVL	0.653	0.757	*
PARTICIPATE	SUPINVL	0.891	0.455	5.995
COMMUNICATE	SUPINVL	0.676	0.737	5.317
TECHCMPLX	TECHUNC	0.783	0.622	*
TECHNEW	TECHUNC	0.810	0.586	6.146
TECHSTAB	TECHUNC	0.610	0.792	5.167

* Indicates that the value of this lambda in the structural equation model was not estimated.

overall fit of each of the structural models is satisfactory [4].

Discussion

Figure 2 shows the standardized solution from the model tested with the total effects of the variables shown below this figure. In interpreting the results of the structural model, a number of interesting examples from the case studies have been used to illustrate their application for managers.

Hypotheses 1a and 1b: Customer Knowledge of Supplier

The tested model supports the hypotheses that increased knowledge of a supplier is more likely to result in greater information sharing as well as in greater involvement of the supplier in the decision-making process. The total effect of Customer Knowledge on Supplier Involvement (through Information Sharing) was 0.394. This result emphasizes that a prior relationship with a supplier likely is to be especially important in building harmonious teams when technology-sharing strategies are used. Internal team members are often dubious about having an external party participate in the NPD process, citing such problems as lack of trust. This fact also was supported by the significant total effects of Customer Knowledge on Project Outcomes (0.291).

The results validate many of the observations from our qualitative study. Generally speaking, every company we visited had some form of supplier assessment system in place. While standard supplier performance measurement systems are necessary to provide some assurance that the potential supplier can deliver a quality product on time at a reasonable price, they are not a sufficient condition that guarantees a successful integration project. Moreover, a number of other criteria must be considered in determining whether the supplier should be involved in an NPD project, including (1) ability to hit targets; (2) ramp-up capability; (3) innovation and technical expertise; (4) required training of personnel; and (5) resource commitment on the part of supplier's top management team. Although this data were not considered in this survey, future studies should include these criteria in assessing which elements are more important in different situations. A risk assessment also should consider the contingency plans required in the event the supplier cannot perform their role in the process.

Hypotheses 2a and 2b: Technology and Cost Information Sharing

The results supported the hypothesized effect of technology sharing on the level of supplier involvement in the NPD projects and the project outcomes. Access to a supplier's insights on emerging new technologies often leads to creative solutions that significantly improve not only internal team dynamics but also effectively leads to interorganizational exchanges between the buying and supplying enterprises. In addition, outcomes related to overall satisfaction and achievement of established goals were found to be associated significantly with information sharing strategies.

Our field visits uncovered various methods used by companies to share technology and cost information. The most common form was known as a "technology roadmap," which refers to the set of performance criteria and undiscovered products and processes an organization intends to develop and/or manufacture within a specified or unspecified time horizon. Many companies define their technology roadmaps in terms of the next decade, while others employ a horizon of 50 years or even a century.

One of the high-technology companies we examined shares its technology roadmaps regularly with the supplier of one of its critical product systems, which is an industry standard item. Through discussions and long-term planning with the supplier's designers, the company has been able to influence the features included in the industry standard. By driving the leading edge of the standard, the company best is able plan its own product platforms and is often first to market with new product introductions—a key competitive advantage in this industry. In addition, suppliers frequently meet with buying company engineers to offer insights into new products.

Hypothesis 3: Supplier Involvement in Decision-Making

Project outcomes were found to be associated significantly with greater supplier involvement with the NPD team. Supplier involvement can occur either through a formalized entry point in the company's product development process or through informal channels. For example, supplier involvement in basic research in the laboratory stage at one company is conducted through joint meetings with suppliers, beginning with top management in order to gain commitment. Suppliers are approached and are asked if they are willing to work on development for a future product. For such basic technologies, the R&D group primarily is involved in approaching and evaluating suppliers. For incremental products however, manufacturing and procurement primarily are involved in selection and negotiation.

The physical colocation of a supplier engineer at a buying company increasingly is becoming a part of the normal NPD structure. One company operates what it calls a "guest engineer" program through which it invites key suppliers to place an engineer in the buying company's facility for a short period of time (two to three weeks) in the very early stages of product development. During this period, the firms develop product/design requirements specifications and assign responsibilities for development. A different buying company colocates its personnel and the supplier's personnel at a neutral site due to union rules. The result is the same: a focused and closely integrated team that works together throughout the duration or just during critical stages of the development project.

One high-technology company has a "core" team for each product development project and forms subteams to work on each of the major components or systems of the product. The core team is internal company personnel, only including engineering/design, manufacturing engineering, manufacturing planning, quality assurance, and procurement. Suppliers participate as members or even lead the subteams for the product system with which they are involved, giving the suppliers an active role but still maintaining a high level of confidentiality for the overall project.

Hypotheses 4a and 4b: Technology Uncertainty

Our results indicated that in cases when technology uncertainty was present, companies were more likely to share information with suppliers. However, the results did not support the hypothesis that technology uncertainty necessarily affects project outcomes (a negative but not significant structural coefficient was found in our analysis).

These results must be interpreted in light of the total effects shown at the bottom of Figure 2. When the indirect effects of Technology Uncertainty through Information Sharing and Supplier Involvement were included, the total effects of Technology Uncertainty on Project Outcomes (0.014) were of a lower magnitude than the direct effect of Technology Uncertainty on Project Outcomes (−0.159). This suggests that *the performance outcome problems associated with technology uncertainty can be mitigated by greater use of technology sharing and direct supplier participation on the new product development team*. This is an important result, as it supports key propositions in the theoretical literature [24,53] but goes beyond the recent empirical findings in this area [19,30].

Our field studies suggest that companies used a variety of different supplier integration strategies in cases where technology uncertainty existed. For instance, technologies with short product life cycles and for which performance ceilings were rapidly rising often were delayed as much as possible in order to capture the latest technology in the product once released. For these types of products, the supplier was integrated on a one-time basis. In the next product cycle, the buyer often returned to the pool of suppliers to determine whether any new innovative technologies had evolved. In other cases, suppliers had technologies on their roadmaps that were not yet robust enough or cost effective to be integrated into existing technologies. In such cases, the technology was "bookshelved" and was revisited in the next new product cycle.

In cases when the supplier possessed high levels of expertise in a technology that needed to be adapted to a particular product development initiative, companies were integrating suppliers very early in the development cycle to take advantage of their expertise situation. Suppliers in such cases often worked closely in buying company design engineers to solve problems related to manufacturability, integration of the technology, cost reduction, and product performance. In cases where the supplier was providing a fairly standard technology involving limited innovation and expertise, companies integrated the supplier at a variety of different stages. Some companies decided to integrate the supplier early in order to work on achieving significant target cost objectives. Other suppliers were integrated at varying points in the cycle, depending on how the specific technology affected other components or subsystems in the product and affected cost, product release, quality, ramp-up, or other new product goals.

Because of the diverse set of strategies found to exist, we believe this to be a very fruitful avenue for further research. There is clearly no single best method to integrate suppliers into new product development, and the relative point at which the supplier should become involved clearly is dependent on the level of technology uncertainty present.

Conclusions

The results of the research point to some important lessons for managers and academic researchers. First, the results suggest that customer/supplier integration on an NPD project requires a detailed formal evaluation and selection of potential suppliers prior to consideration for involvement. Only trusted suppliers with a proven track record should be approached (at least initially) to participate. Some of the important criteria to consider include the supplier's relative level of experience and capability in new product development as well as their relative level of expertise with a given technology. Second, sharing of technology and cost information early in the process effectively can enable the product development team to begin active discussion of technology options that can meet market requirements. Withholding this information may delay the process—which in turn can lead to a lower probability of target project outcome success. Third, project outcome objectives should be shared and explicitly should be understood by all parties involved. Although a number of barriers exist at the project team level when it comes to acceptance of suppliers in the process, direct supplier participation in team meetings (whether through simple consultation on design issues or via a detailed design proposal) can make the difference between a successful or an unsuccessful outcome. Fourth, supplier involvement on project teams seems to be even more important when the technology is complex or when the buying company does not have a high level of internal expertise in the area. Our results support the notion that project teams attempting to apply unique and complex technologies can benefit by including suppliers on teams and by sharing technology information early on to be able to capture external expertise early in the process.

Limitations

We acknowledge a number of limitations to this study. First, this study was limited to focus on the role of only four variables on supplier integration outcomes; these were selected based on the fact that managers mentioned them frequently during our field interviews. Further, results suggest that they plan an important role in exploring the variance in project outcomes. Second, quantified performance outcomes measures were not included, nor were there quantified measures of supplier involvement. We did, however, examine the correlations between subjective measures of performance and actual performance outcomes. Third, the effects of multiple industry respondents were not controlled for, and future studies should assess whether industry in fact does contribute to the variance in our results. Fourth, we relied on only two or three items for each construct, which is unlikely to capture the full domain of these concepts. We recognize this limitation to the study likely is due to the fact that the measures were new and that no previous measures of supplier integration had been tested formally for convergent validity. We recognize that using new measures is always a risk, but we felt it was important to capture the key variables that emerged from the case studies and had to rely on developing new scales. Researchers pursuing work in this area may use our scales as a starting point for developing a stronger set of measurement items.

Future Research

The results obtained from this study clearly show the importance of supplier integration but also generate a set of new and interesting research questions. A set of additional issues that build on our empirical approach include the following:

- What are the key dimensions of explicit and tacit capabilities of suppliers that can predict the likelihood of a successful supplier integration effort? For example, how should managers weigh the relative strengths and weaknesses of various suppliers in areas such as technological knowledge, manufacturing capabilities, length of relationship with the supplier, degree of trust, and alignment of technology roadmaps with future products?
- What are the key variables an NPD team should consider in measuring the relative alignment of a supplier's technology roadmap with its customer's product requirements? What are the means to gain access to and to assess the degree of alignment of supplier technology roadmaps across multiple industries on a global basis? This type of research would involve understanding the nature of product development organizational structures, as well as an assessment of the role of advanced technology groups and technology boundary spanners.
- In cases when a future required product/process technology does not exist in the market, what are the key variables to consider whether to redirect a supplier's technology roadmap (outsource technology development) or to undertake the development of a new technology in-house (insource technology development)? This line of thinking takes the concept of technology uncertainty a step further by proposing that supplier involvement always may not be the best solution, as a firm may outsource a critical technology to an external party. (Consider the case of IBM outsourcing the

development of chips to Intel and its operating system to Microsoft!)

These questions represent challenges for the next decade; we believe they can benefit from prior insights derived from the literature on purchasing management, engineering management, and marketing. In order to understand fully how supplier integration will unfold, we further believe that the focus should not be limited to single buying/supplying organizational units but should extend both up and down the supply chain. This framework would represent better the vision of the future, wherein entire supply chains of customers and suppliers will compete against similarly aligned chains, with the objective of creating the maximum value up and down the chain.

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Appendix A. Measures

Technology and Cost Information Sharing (IS)

TECHSHAR: Please indicate the extent to which technology sharing was used in your supplier integration case (1=no use; 7=extensive/significant use).

COSTSHAR: Please indicate the extent to which cost information sharing was used in your supplier integration case (1=no use; 7=extensive/significant use).

Project Outcomes
SATISFAC: Degree of overall satisfaction with results (1=very low; 7=very high).

ACHIEVE: Overall degree of achievement of the established goals (1=results far worse than goals; 7=results far better than goals).

Customer Knowledge of Supplier
SUPFREQ: How frequently had this supplier been involved in new product/process/service design projects with your firm prior to this project (1=never before; 7=very frequently)?

SUPFAM: How familiar was your business unit with this supplier's capabilities prior to their integration in this project (1=not familiar at all; 7=very familiar)?

SUPASSESS: How extensive was your firm's formal assessment of the supplier's capability and performance prior to the decision to involve the supplier in this project (1=not very extensive; 7=very extensive)?

Supplier Involvement in Decision-Making
SUPMEM: Please indicate the extent to which supplier membership/participation on the buying company product/project team was used in your supplier integration case (1=no use; 7=extensive/significant use).

SUPPART: How extensive was the supplier's participation on your firm's project team for this project (1=no participation at all; 7=very high participation)?

SUPCOMM: How much direct cross-functional/intercompany communication (for example, engineer to engineer) took place between your firm and the supplier's firm during the project (1=no such communication at all; 7=very high degree of communication)?

Technology Uncertainty
TECHCMPLX: What was the level of complexity of the technology involved in this new product/process/service development project (1=relatively simple technology; 7=very complex technology)?

TECHNEW: What was the level of "newness" or uncertainty of the technology involved in this new product/process/service development project (1=well-established, known technology; 7=very new technology)?

TECHSTAB: How rapid and uncertain versus stable and predictable are product/process/service technology shifts at your business unit for your supplier integration case (1=very stable/predictable; 7=very rapid change and uncertain)?

Appendix B. Structural Model Equations

SUPINVL	=	INFOSHAR + KNOW + D1
INFOSHAR	=	KNOW + TECHUNC + D2
OUTCOME	=	INFOSHAR + SUPINVL + TECHUNC + D3