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External technology integration in product and process development

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Abstract *This paper empirically examines the process of acquiring technology from a source, external to the firm, and incorporating it into a new product or operational process under development. We refer to this key activity in product and process innovation as external technology integration. This paper develops a conceptual model of external technology integration based on organizational information processing theory and a wide range of technology management literature. Field interviews were conducted to evaluate the validity of the model across diverse settings. Our results indicate general support for the conceptual model. We close with a discussion of the implications of this study for both theory and practice.*

Introduction

Limited resources, expertise, and time are forcing many firms to focus on core competencies and functions. As a result of this narrowed focus, firms are finding that internal development of all technology needed for new products and processes is difficult or impossible. They must increasingly acquire technology from external sources. More frequent acquisition and incorporation of technology from external sources leads to more instances of interfaces with external organizations. Managing these interfaces will therefore become much more common, and the nature of these interfaces will vary considerably as the range of externally sourced technologies widens.

We refer to the process of managing the acquisition and incorporation of technology from external sources as external technology integration (ETI). ETI plays an important role in many operational activities, including new product development, new process development, and operational improvement. As such, for many firms, ETI is no longer an occasional activity that can be managed in an ad hoc fashion; rather, it is a recurring process that requires purposeful management supported by a well-developed portfolio of organizational skills.

The following example illustrates some of the issues and difficulties that can arise in ETI (this example is drawn from an earlier study we conducted, see Stock and Tatikonda, 2000; Tatikonda and Rosenthal, 1998). While this example deals with the integration of technology into a new product, similar issues are found in the integration of new technology in other situations, such as the installation of an advanced logistics

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information system or a flexible manufacturing system sourced from an external vendor.

> The subject firm was developing an imagesetter (similar to a very high-end laser printer that writes on film instead of paper) for the professional publishing market. To provide superior technical performance, the firm employed a new laser diode that would have significantly higher resolution capability (in dots per inch) than prior devices. This new product technology worked well in preliminary laboratory tests, so the firm committed itself to the technology and sourced it from the appropriate vendor. But the technology did not work well when implemented in the product system. Resolving this problem led to substantial delays and cost over-runs in the new product development effort. The product that resulted from this effort was a market success, but the firm believes earlier market introduction would have increased revenues substantially. In this case, the firm had had limited interaction with the technology vendor, even though it was a critical technology. Greater interaction with the vendor might have led to better assessment of the riskiness of the technology, faster characterization of the function of the technology, quicker resolution of technical problems, and earlier entry into the marketplace. In contrast, the firm took a different external technology integration approach for the film media to be used in the imagesetter. This particular technology was of a new variety and was relatively unknown to this firm. Here, the firm worked more closely with the vendor to characterize and understand the film as it would be used in the imagesetter, and the result was a more cost-effective, timely integration into the imagesetter product system.

This example shows the importance of purposefully managing ETI processes. Many firms manage every case of ETI in virtually the same way regardless of the nature of the technology to be integrated. However, it stands to reason that different approaches might be needed to integrate different types of technology. A simple upgrade of inventory system software might be accomplished quite effectively with very little interaction between the firm and the software supplier; on the other hand, the installation of an advanced enterprise resource planning system would probably require a very high level of interaction between the software vendor and the firm, particularly if the firm has little experience with this type of information system.

There are multiple challenges in the ETI process: first, the firm must be able to assess the characteristics of the technology relative to the firm's own capabilities and experience; second, the firm must be able to determine the extent to which it must interact with the technology's external source; and third (and possibly most important), the firm must be able to deploy the organizational skills needed to manage the external integration process. Our goal in this paper is to provide theoretical insight and practical guidance on how a firm can effectively address each of these challenges. In earlier research, we developed a theoretically derived conceptual framework of ETI (Stock and Tatikonda, 2000; Tatikonda and Stock, 2003). In this paper, we first summarize the related literature and development of this framework. We then report the findings of a series of field interviews that we conducted to evaluate this framework, and we then discuss the research and managerial implications of our results.

Related literature

The subject of ETI is informed in a fragmented manner by a variety of diverse literatures. ETI results from the movement of a technology between two separate organizations and may therefore constitute a type of supply chain (in particular, a "technology" supply chain). Therefore, the general literature on supply chain management is useful in that it provides definitions of what a supply chain is and considers essential concepts related to this topic (Chopra and Meindl, 2001; Mabert and Venkataramanan, 1998; Maloni and Benton, 1997). Still, the general literature on supply chain management has, to the best of our knowledge, focused on the challenges of managing upstream material and downstream distribution supply chains – for example, the issues involved in managing inventory or configuring transportation networks. The issues involved in managing a technology supply chain would likely be quite different.

ETI also involves interorganizational relationships. Both the strategy and marketing literatures have explored interorganizational relationships in a variety of contexts. For example, prior strategy research has considered such interorganizational forms as strategic alliances, joint ventures, and other collaborative arrangements (Cardinal, 2001; Dhanaraj and Parkhe, n.d.; Kotabe *et al.*, 2003; Rothermael, 2001; Rowley *et al.*, 2000). This literature in some cases considers technology-related issues, such as the relative performance of using strategic technology alliances (Dhanaraj *et al.*, n.d.; Kotabe *et al.*, 2003; Rothermael, 2001; Saxton, 1997). Marketing research also examines interorganizational structures, particularly in the context of marketing channel or buyer-supplier relationships (Jap, 2001; Rindfleisch and Moorman, 2003). However, the focus of these literature streams is not on how an interorganizational relationship should be managed at an operational level to improve the integration of technology from external sources.

The traditional literature on technology transfer specifically considers the movement of technology across organizational or national boundaries. This literature provides a sense of the overall technology transfer process, particularly at the strategic or national level (Contractor and Sagafi-Nejad, 1981; Cusumano and Elenkov, 1994; Reddy and Zhao, 1990). Project work-level details and activities are not generally addressed in detail, particularly with respect to how the technology is eventually incorporated into the targeted product or process in the recipient firm. Furthermore, the technology transfer literature most often addresses the nature of the technology to be transferred in a relatively superficial manner, generally considering only a single technology attribute, if it considers the nature of the technology at all (Davidson and McFetridge, 1985; Howells, 1996).

The nascent literature on early supplier involvement (ESI) attempts to better understand the contemporary blurring of organizational boundaries in product development projects. This literature draws on the well-established "purchasing" literature and integrates those perspectives with new product development management ideas. The ESI literature addresses what traditionally were considered purchasing activities conducted late in the product development process, and provides insights into the role of suppliers to facilitate production rampup and volume manufacturing (Hartley *et al.*, 1997; Ragatz *et al.*, 1997). The ESI literature typically assumes that component specifications are generally well known, that these specifications are given by the developer to a supplier, and that the supplier's development of that component (if there is any development) is triggered by the purchaser. The ESI literature also does not generally consider the nature of the technology embodied in the components being provided by the supplier, and does not generally address the interorganizational processes of a recipient and its supplier in the transfer of already developed "raw" product technologies for use in early product design stages.

ETI includes the incorporation of the transferred technology into a product or process system. The literature on new product development at the project level has progressed to the point where quite a bit of prescription is available regarding how to manage internal aspects of a development project (such as design/manufacturing integration, use of CAD tools, internal project management processes such as phase/gate systems, etc.) (Schilling and Hill, 1998; Ulrich and Eppinger, 2000; Wheelwright and Clark, 1995). Literature on advanced manufacturing technology (AMT) implementation addresses how a recipient firm may prepare for and ramp-up a new technology. This literature focuses on activities *internal* to the implementing organization (the recipient firm) such as organizational change, gaining buy-in, user involvement, personnel training, information systems preparation, planning and executing the implementation project, performance measurement, and post-implementation audits (Chiesa *et al.*, 1996; Fjermestad and Chakrabarti, 1993; Gerwin, 1988; Sambasivarao and Deshmukh, 1995). What is important from our perspective, however, is that the new product development or AMT implementation literatures typically do not consider in detail the interorganizational factors that may be relevant to the incorporation of the technology into a new product or process.

To summarize, prior literature streams provide important foundational contributions but do not adequately address detailed characterization of the type of technology to be transferred and detailed project-level interorganizational (source-recipient) processes in technology integration. Fortunately, there is well-developed organizational theory that does generally describe work-level interfirm interfaces and interactions. We borrow and build on this organizational theory for application in the ETI context. Further, we draw on and synthesize diverse technology management and product innovation studies, both conceptual and empirical, to construct a generalizable technology characterization scheme. In developing and presenting our model of ETI, we incorporate ideas from the literatures discussed above, but focus on presenting new ideas relating to technology type and interorganizational factors.

Organizational theory foundations

Information processing is the purposeful generation, aggregation, transformation and dissemination of information associated with accomplishing some organizational task (Robey, 1986; Tushman and Nadler, 1978). Here, the task of interest is ETI. Although specific subtasks, information sources, and information transformation requirements may differ among technology integration situations, all technology integrations involve some information processing to conduct the transfer. Information processing theory has been employed in prior research in other areas of technology management, such as the information technology (Anandarajan and Arinze, 1998; Jarvenpaa and Ives, 1993) and R&D project management (Sicotte and Langley, 2000). In addition, information processing theory has also guided research in an interorganizational context in the management global new product development (Subramanian *et al.*, 1998) and high technology innovation (Tatikonda and Montoya-Weiss, 2001). Accordingly, it is useful to view technology integration through the lens of organizational information processing theory (OIPT). This theory, which has an inherently contingent perspective, underlies our framework of technology integration. OIPT explains that an organizational task poses information processing requirements to the organization, as an organization must generate, transform, and disseminate information about the task in order to effectively accomplish the task. Certain tasks require more of these activities than others, which in turn represent higher levels of information processing requirements. Various means applied by the organization provide information processing capabilities. The degree to which requirements and capabilities are appropriately matched determines the quality of task outcomes (Galbraith, 1973, 1977). While OIPT has a long history, it has only recently begun to appear in operations management research (Flynn and Flynn, 1999; Tatikonda and Rosenthal, 2000a; Tatikonda and Stock, 2003).

Organizational tasks vary in the degree to which the means to accomplish them are certain. Task uncertainty is "the difference between the amount of information required to perform the task and the amount of information already possessed by the organization" (Galbraith, 1977, p. 36), and represents the quantity of knowledge or information that must be acquired and processed. In addition to the quantity of information that must be processed, the quality (or richness) of the information is important (Daft and Lengel, 1986). Task-related characteristics cause or contribute to task uncertainty. An additional point to be recognized is that task uncertainty is organization-specific: what is certain to one organization may be uncertain to another (Galbraith, 1977; Robey, 1986).

Organizations employ different organizational means to process information and reduce task uncertainty as the task execution progresses. Galbraith (1977, p. 39) explains that "variations in organizing modes are actually variations in the capacity of organizations to process information and make decisions about events which cannot be anticipated in advance". The endpoints of the information processing capacity spectrum have been described as "mechanistic" and "organic" organizations (Burns and Stalker, 1961; Keller, 1994; Tushman and Nadler, 1978). Mechanistic organizations are efficient and effective for lower levels of information processing quantity and quality. Organic organizations are efficient and effective for high levels of information processing quantity and quality. Poor task outcomes occur when requirements and capabilities are not properly matched (Galbraith, 1977; Tushman and Nadler, 1978). When the organization does not have enough information processing capacity to accomplish the task, the task is completed below performance standards, late, and/or over budget. When the organization employs more information processing capacity than is required to accomplish the task, the task is accomplished inefficiently. The contingent perspective is clear: a given level of information processing requirements should be appropriately matched (or fit) to a given level of information processing capacity (or vice versa) in order to achieve effective task outcomes.

A key consideration in our framework is the relationship between the organizations engaged in ETI. The two distinct organizational units (source and recipient) are engaged in a work task (the integration of a technology) where the two units are reliant on each other, to some degree, to accomplish the task at hand. Interdependence theory describes the degree of, and elements of, interorganizational relationships (Adler, 1995; McCann and Galbraith, 1981; Thompson, 1967). It addresses structural and process aspects of relationships between two distinct organizational units. Lower levels of interdependence means that the units can do the work quite independently of each other, and have "little need for interaction, consultation or exchange" (Daft, 1986, p. 153). Greater interdependence means higher relationship intensity. In general, lower interdependence affords greater reliance on planning, while greater interdependence requires more emphasis on problem-solving and communication during the task activity (Daft, 1986). Higher forms of interdependence represent a greater capacity for information processing, both in quantity and quality. Of particular relevance to this paper, we also note that prior literature has examined issues associated with technology management (Harter and Slaughter, 2003) and interorganizational relationships (Chatfield and Yetton, 2000; DeSanctis *et al.*, 1999) from the perspective of interdependence theory.

Conceptual framework

As we noted above, this study is guided by a previously published conceptual framework. We summarize the basic concepts of this framework here, but a more detailed discussion of its development can be found in the work of Stock and Tatikonda (2000) and Tatikonda and Stock (2003). Here, ETI corresponds to the general concept of the organizational work task from OIPT. In the context of ETI, technology uncertainty corresponds to the general OIPT construct of task uncertainty. Greater technology uncertainty leads to greater information processing requirements. Similarly, interorganizational interaction corresponds to the general OIPT construct of organizational mode. Therefore, greater levels of interorganizational interaction lead to greater information processing capacity. Many variables influence the ETI process. This section reduces the multivariate complexity of this phenomenon by synthesizing the many factors into a few overall subdimensions of technology uncertainty and interorganizational interaction. These subdimensions are contributors to technology uncertainty and interorganizational interaction, and in turn are contributors to information processing requirements and capacity, respectively. In addition, we explicitly specify a conceptualization of ETI effectiveness and identify a set of associated subdimensions.

Technology uncertainty

The concept of technology uncertainty has been examined to a limited extent in prior research in product development (Ragatz *et al.*, 2002; Song and Montoya-Weiss, 2001; Tatikonda and Rosenthal, 2000b), although its definition and measurement varies considerably. In this paper, the general OIPT concept of task uncertainty corresponds to *technology uncertainty* when considered in the specific context of ETI. OIPT describes task uncertainty as lack of knowledge about how to accomplish the task. Therefore, technology uncertainty in ETI is defined to be the lack of knowledge of how to acquire and implement the technology of interest. Hence technology uncertainty is the difference between the level of knowledge required by the recipient organization to acquire and implement the technology, and the level of knowledge the recipient actually possesses.

Many factors contribute to technology uncertainty (and in turn increase the information processing requirements). Based on a thorough review of the literature, we synthesize these elements into three subdimensions of technology uncertainty: technology novelty, technology complexity, and technology tacitness. A thorough and detailed development of these subdimensions can be found in the work of

Stock and Tatikonda (2000) and Tatikonda and Stock (2003), but we outline the essential elements of each subdimension here. Technology novelty refers to the degree of prior experience with the technology and the degree of change in the technology relative to prior technologies. Technology complexity includes the level of interdependence between components in the technology, level of interdependence between the technology and elements external to it, and the scope of the technology. The tacitness of the technology refers to the tacitness of the knowledge embodied by the technology, and includes the degree to which the technology is physically embodied, codified, and complete.

The three subdimensions represent largely different concepts; nonetheless, they overlap to some degree because some technological elements influence more than one subdimension. Recall that technology uncertainty is defined to be the difference between the knowledge the recipient firm needs to integrate the technology and the knowledge the firm actually has. Higher levels of each subdimension increase the level of technology uncertainty. For example, a technology that is very new to an organization (which would reflect a high level of technology novelty) would mean the firm has little experience with the technology and would therefore require the firm to gain more knowledge about how to integrate the technology, and would therefore lead to a high level of technology uncertainty. Highly complex or tacit technologies would similarly lead to high levels of technology uncertainty. In general, then, a technology that is more novel, complex, and/or tacit will be more uncertain than a technology that is familiar, simple, or well defined. Moreover, higher levels of technology uncertainty will lead to greater information processing requirements.

Table I(a) lists the set of the factors, and their sources from the literature, underlying each of the technology uncertainty subdimensions. Note also, that like the general OIPT concept of task uncertainty, technology uncertainty is organization-specific. Different levels of experience or absorptive capacity (Cohen and Levinthal, 1990; Glass and Saggi, 1998; Kedia and Bhagat, 1988) may mean that what is highly uncertain to one organization may not be for another.

Interorganizational interaction

The second dimension in ETI framework, corresponding to the general OIPT concept of organizational approach, is *interorganizational interaction*, which characterizes the nature of the interorganizational relationship between the source and recipient. At a detailed level, three essential "components of the relationship" between organizations (Walton, 1966) have been identified:

1. exchange of information in the joint decision process;
2. structure of interunit interactions and decision-making; and
3. attitudes towards the other unit.

In the context of ETI, we refer to these relationship dimensions as communication, coordination, and cooperation between the two organizations.

An in-depth development of these subdimensions of interorganizational interaction can be found in the work of Stock and Tatikonda (2000) and Tatikonda and Stock (2003), but we provide a concise review here. Communication includes the methods of communication, magnitude and frequency of communication, and nature of information exchanged. Coordination refers to the nature of the planned structure and

Subdimension	Underlying factors	Representative literature
(a) Technology uncertainty subdimensions		
Novelty	Technological familiarity	Adler (1992), McDonough and Barczak (1992) and Yoon and Lilien (1985)
	Technology newness	Barnett and Clark (1996), Brooks (1987), Davidson and McFetridge (1985) and Tatikonda and Rosenthal (2000b)
	Radical/incremental innovation	Ettlie *et al.*, (1984) and Green *et al.* (1995)
	Discontinuous change	Ehrnberg and Jacobsson (1997), Schumpeter (1942) and Tushman and Anderson (1986)
	Platform/derivative innovation	Tatikonda (1999) and Wheelwright and Clark (1992a, b)
Complexity	Internal system interdependence	Henderson and Clark (1990), Khurana (1999), Singh (1997) and Tatikonda and Rosenthal (2000b)
	External system interdependence	Brooks (1987) and Tushman and Rosenkopf (1992)
	Scope	Clark and Fujimoto (1991), Griffin (1997) and Shenhar (1998)
Tacitness	Tacit knowledge	von Hippel (1994), Howells (1996), Madhavan and Grover (1998) and Polyani (1967)
	Physical embodiment	Lam (1997) and Tsang (1997)
	Codification	Dutta and Weiss (1997), Kogut and Zander (1993), and Mascitelli (1999)
	Invisibility	Brooks (1987)
	Structuredness	McKeen *et al.* (1994), Naumann *et al.* (1980) and Tait and Vessey (1988)
(b) Interorganizational interaction subdimensions		
Communication	Communication methods	De Meyer (1991), Gibson and Smilor (1991) and Stock *et al.* (1996)
	Magnitude and frequency of communication	Ghoshal and Bartlett (1988) and Rebentisch and Ferretti (1995)
	Nature of information exchanged	Gibson and Smilor (1991), Gray (1989), von Hippel (1987) and Rebentisch and Ferretti (1995)
Coordination	Quantity of planning	Bailetti and Callahan (1993)
	Relationship formality and structure	Cooper (1983), Eisenhardt and Tabrizi (1995) and Van de Ven and Ferry (1980)
	Length of time horizon	Adler (1995) and Rogers (1995)
Cooperation	Trust	Corsten (1987), Das and Teng (1998) and Hagedoorn (1990)
	Willingness to share information	Heide and Miner (1992), Schrader (1991) and Wong (1999)
	Goal congruence	Geisler, (1997), Hagedoorn (1990), Turner *et al.*, (1994) and Wong (1999)
	Commitment	Geisler (1997), Holm *et al.* (1996) and Johnson (1999)

Table I. ETI model subdimensions

process of interactions and decision-making between source and recipient (Parkhe, 1991). Cooperation is the “willingness of a partner to pursue mutually compatible interests rather than to act opportunistically” (Das and Teng, 1998, p. 492). The subdimensions are conceptually different; nonetheless, they overlap somewhat. For example, a higher level of cooperation would result in a greater willingness to share information and would likely result in higher levels of communication, both in the frequency of the communication and in the richness of the information that is communicated. Higher levels of each of these subdimensions reflect higher levels of interorganizational interaction, and higher levels of interorganizational interaction provide higher levels of information processing capability. Table I(b) provides a detailed set of the underlying factors, and their sources in the literature, for each of the interorganizational interaction subdimensions.

ETI effectiveness

The final dimension of our conceptual framework is technology integration effectiveness. The interorganizational activities in technology integration may be seen as constituting a project. Key elements of project operational effectiveness are time, cost and technical performance (Meredith and Mantel, 1995). These elements apply readily to the technology integration context, making up three subdimensions of ETI project effectiveness: the functional operation of the technology (analogous to technical performance), ETI-related costs, and the time taken to complete the ETI project. In this paper, we focus primarily on tactical, project-related outcomes associated with the ETI process. We also note that there are other dimensions of ETI effectiveness, including some which are described as strategic outcomes. For example, the recipient firm may very well find that an ETI project has increased its knowledge about a particular technology, even though the project itself was not judged to be a success by traditional project performance measures. This increased knowledge, which represents technological learning, may be of great benefit to the recipient firm in the long run. We discuss such a learning perspective in more detail below, but learning outcomes *per se* are outside the scope of the conceptual framework guiding this study and are therefore considered primarily in the context of future research.

The fit between technology uncertainty and interorganizational interaction

The underlying proposition in our conceptual framework follows from a straightforward application of OIPT to the specific dimensions identified in ETI. Task uncertainty results in information processing requirements. The form of interorganizational interdependence provides information processing capacity. An appropriate match of requirements and capabilities leads to effective performance of the task. Technology uncertainty corresponds to the general theory construct of task uncertainty; interorganizational interaction corresponds to the general theory construct of organizational approach; and technology integration effectiveness corresponds to task effectiveness. By adapting the general OIPT principles to the specific context of technology integration, we can argue that the level of technology uncertainty posed by the technology that is transferred should be appropriately matched with the level of interorganizational interaction (provided through the form of interorganizational interdependence) between source and recipient (and vice versa). An appropriate match, or fit, between technology uncertainty and interorganizational interaction will result in effective technology integration. This application of the general theory of OIPT to the technology integration context is shown in Figure 1. Appropriate matches of technology uncertainty and interorganizational interaction are shown along the diagonal of the ETI matrix shown in Figure 2.

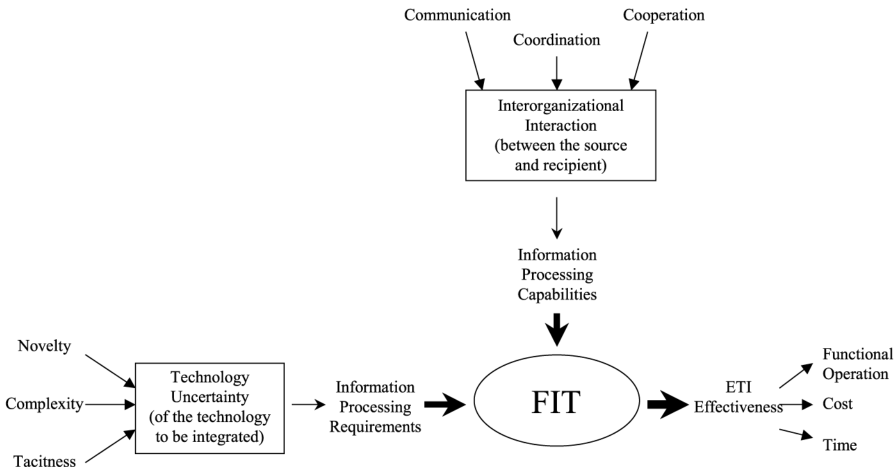

Figure 1.
OIPT applied to ETI

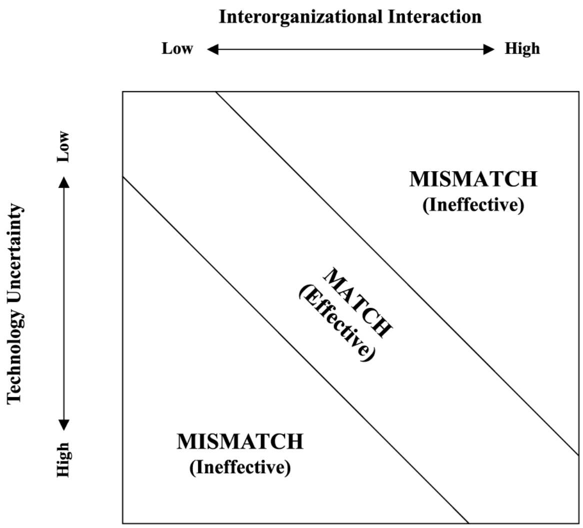

Figure 2.
The ETI matrix

Methodology

We evaluated our proposed framework through a series of in-depth field interviews with managers who were involved in ETI. We selected a case study methodology because this study was the initial empirical evaluation and confirmation of the conceptual framework. Case research is often an appropriate strategy for studying a phenomenon that is broad and complex, as case studies provide the opportunity to analyze relationships between constructs in a more detailed manner than would a larger scale approach such as a survey (Benbasat *et al.*, 1987). In addition, these in-depth interviews allowed us to refine the conceptualization of the framework's constructs, which would be used in the construction of a questionnaire to be used in future survey research. It should be noted, however, that this study employs a small-sample confirmation of a previously developed conceptual framework, rather than a cross-case exploratory theory-building approach.

These managers were selected from five different firms encompassing a broad range of industries and technologies. The population to be considered would be those firms that conduct ETI projects, so the first requirement for selection was that the firm had conducted an ETI project (or multiple ETI projects). The firms were also selected to provide variation across the types of technology (product and process; hardware and software) and across types of products (services and manufacturing). All of the firms in our sample are located in the Midwest United States. Table II provides a summary of relevant information about the firms in our sample, including their primary business, the nature of the projects we investigated, their annual corporate sales, and the number of employees in each firm. We have disguised the names of these firms and withheld more detailed information about them to preserve confidentiality. In each company, we interviewed from one to three managers. These managers held positions at relatively high organizational levels, typically director or division head. Most had technical backgrounds and had been with their firms for more than 15 years. The interviews covered a total of 17 ETI projects. Technologies ranged from relatively simple desktop PC software to more advanced enterprise resource planning (ERP) systems and

Firm	Business description	ETI projects	Sales (million US$)	Employees
Firm A	Operator of college bookstores and wholesale book supplier	A1: Point of sale (POS) system – source 1	1,733	10,000
		A2: POS system – source 2		
		A3: Internet bookstore		
		A4: EDI format translation system		
		A5: Desktop office software		
Firm B	Maintenance, repair, and operating supplies provider	B1: ERP system	4,644	15,236
		B2: Paperless warehouse system		
		B3: Desktop office software		
Firm C	Human resource outsourcing and consulting firm	C1: Internet portal software	2,031	15,000
		C2: Report writer software		
		C3: Single sign-on environment software		
		C4: Collaboration software		
Firm D	Truck manufacturer	D1: Warehouse management system	7,340	14,020
Firm E	Heavy equipment manufacturer	E1: ECM – source 1, phase 1	20,152	68,990
		E2: ECM – source 2, phase 1		
		E3: ECM – phase 2		
		E4: Computer aided earth moving system		

Table II.
Sample firms and ETI projects

truck engine electronic control modules (ECMs). Semi-structured interview protocols and data triangulation techniques were employed (Yin, 1994).

Results

The interviews provided considerable insight into the ETI process. The ETI projects covered a broad range of technologies and experiences in the various dimensions of technology uncertainty, interorganizational interaction, and project outcomes. Figure 3 shows the location of the different projects on the ETI matrix. We followed a standard assessment procedure (using the dimensions of technology uncertainty and interorganizational interaction) in order to mitigate subjectivity regarding placement of each project. For each project, managers were asked to describe the technology. Following a review of notes and transcripts of the field interviews, the authors used these descriptions to determine individual assessments of the novelty, complexity, and tacitness of the project's technology. These evaluations of the individual subdimensions were then combined to estimate an overall level of the uncertainty of the technology. A similar approach was employed to assess the communication, cooperation, and coordination between the source and recipient, which was used to estimate the overall level of interorganizational interaction for the project.

The results show general support for our conceptual framework. For each project, the interview subjects were asked to assess the extent to which the ETI project met its objectives on schedule, cost, and functional performance. The authors then used these individual project performance assessments to arrive at an estimate of overall project performance. In fact, there were only two projects (A1 and E1) that were located far from the diagonal, which indicated a large deviation from a fit between technology uncertainty and interorganizational interaction. And in fact, these two projects had the poorest outcomes. The remaining projects, which are located closer to the diagonal running from the top left to the bottom right (indicating a better match between technology uncertainty and interorganizational interaction), tended to result in better project outcomes.

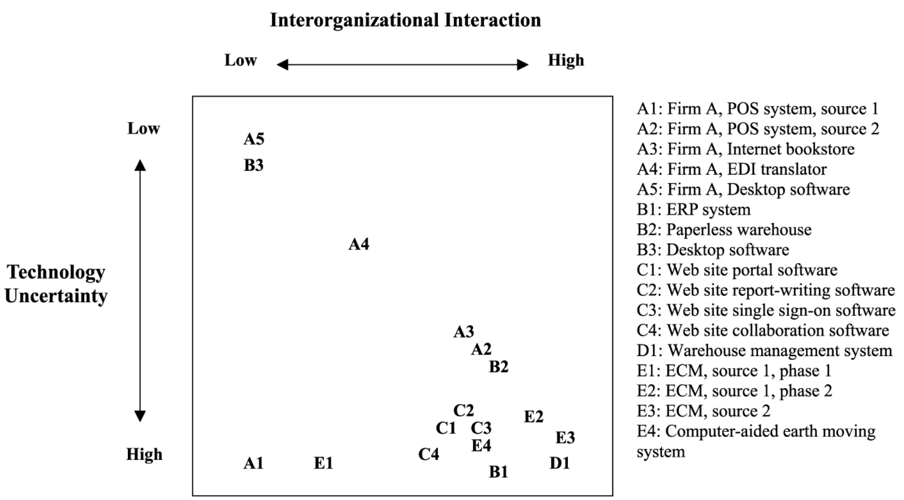

Figure 3.
Locating ETI projects on the ETI matrix

The scope of this paper does not allow the detailed description of each ETI project covered in these interviews. However, below we discuss two projects that were particularly insightful. The projects we describe below were selected to provide examples of ETI for a process technology (an ERP system) and for a product technology (an ECM for a heavy truck engine). These two cases provide rich and detailed illustrations of the underlying propositions in our conceptual framework.

ERP system

Firm B is a materials, replacement, and operating (MRO) supplies provider. It is the leader in its market, and it recognized the need to improve its business information systems as it modified its business processes to deal with new competitive challenges. Therefore, Firm B decided to acquire and implement an ERP software system. An ERP system is a very complex software package that encompasses many business processes within an organization. The source of this technology was a leading provider of ERP systems. The level of technology uncertainty was very high. Firm B had no experience with ERP systems, so it was very high in technology novelty. The system itself was very complex, as it has a large number of modules and countless interactions between these components and between different organizational units. In addition, because the ERP system had no physical embodiment and needed some modification before installation, it was assessed to be relatively high on the tacitness dimension as well. Although this ERP system included the standard modules common to ERP systems installed in other organizations, it still required extensive modification and customization for use in Firm B.

The level of interorganizational interaction was very high as well. There was substantial communication, cooperation, and coordination between Firm B and the source of the ERP system. The project lasted approximately 18 months, and engineers and consultants from the ERP source were located within Firm B, working together with Firm B's technical professionals, for a good part of that time. The manager in charge of the overall project even went so far as to characterize the relationship as having essentially one organization working together. This project is coded as "B1" on Figure 3. The project was deemed a success, for the most part. The ERP system achieved its technical, functional, and budgetary goals at the time it was "turned on." At this time, the system worked properly from the perspective of the implementation team.

However, users of the system had difficulties in some types of processes. The manager overseeing the project explained that an ERP system such as this one requires the redefinition of existing business processes to fit the functions of the software. However, system users often attempted to find "work-arounds" to make some of these newly defined business processes be more like old processes. As a result, the system in these instances was not used properly, with corresponding problems in functional outcomes. These post-installation problems were attributed to inadequate training in how to use the system. Therefore, although the project was successful by and large, additional interaction in the form of training users of the system in its operation would have increased the effectiveness of the project even more. The fit between technology uncertainty and interorganizational interaction was good, but could have been slightly better, which limited the ultimate success of the project somewhat.

ECM for heavy truck engines

Firm E is a heavy equipment and engine manufacturer. The ETI projects studied here were part of the development of two generations of ECM used in diesel truck engines. In the first project, coded as "E1" on Figure 3, Firm E recognized the need for its next generation of trucks to be electronically controlled. However, the firm had no experience or expertise in this technology, so managers made the decision to source the ECM from an external organization. For this first generation of ECM, a source was selected that had experience in developing electronic engine control components for automotive engines. However, this source had limited experience with truck engines. The ECM was to control virtually every function in the truck engine, so the technology was very complex. Its application in truck engines was new in general, and Firm E had no experience with electronic control, so its novelty was very high as well. Finally, the ECM had to be designed, developed, and manufactured "from scratch." It was not yet in a completed form, and in fact existed only as a set of conceptual functional requirements when the project began. Accordingly, the technology was quite tacit.

From the outset, the relationship between the source and Firm E was plagued with problems. There was very little communication, and there was little coordination in scheduling and assignment of development activities. Moreover, the level of cooperation between the two organizations was very low and could even be characterized as adversarial in many ways. A turning point in the project, one that precipitated a dramatic change in its organization and management, was the realization that both organizations were attempting to design the product independently. The interorganizational interaction was not only at a low level, but it had become dysfunctional and harmful to the development of the ECM. The manager in the recipient firm characterized the interaction as one of "blaming" each other for the problems with the project. At this point, which we have termed the end of "phase 1" with this source, top management in the two firms took a dramatically different approach. The end of the phase 1 project was judged to be a nearly complete failure. The project was far behind schedule and the technology did not function as specified. Moreover, from an organizational point of view, the relationship between the source and recipient had deteriorated into one of mutual dislike and distrust.

We consider phase 2 in the development of the ECM, which we have labeled "E2" (ECM – source 1, phase 2) on Figure 3, to be a separate ETI project because at this point the development of the ECM, and in particular the relationship between the source and recipient, was planned and managed in a completely different manner. A new schedule and new objectives were formulated at this point as well, further indicating a distinctly new project. Top management in both firms took an active role in directing joint meetings between engineers in the two firms. Development tasks were more explicitly allocated and scheduled. More information was shared, and the frequency of communication increased as well. Overall, there was more cooperation, communication, and coordination in the management of this ETI project, which resulted in a very high level of interorganizational interaction. In addition, the recipient firm had gained some learning about the technology, so the technology uncertainty decreased somewhat as well. In this project, the fit between technology uncertainty and interorganizational was quite good, and the phase 2 ETI project was very successful in each dimension (cost, time, and technical functionality).

The phase 2 ETI project was also very successful overall. However, managers in the recipient firm decided that it would be necessary due to competitive reasons to upgrade the ECM technology in the next generation of truck engines to be developed. They determined that the original source either did not have the capability or the inclination to develop the technology further. Therefore, the recipient firm chose a different source for this ETI project. This project is labeled as "E3" (ECM – source 2) on Figure 3. The technology embodied in this generation of the ECM was considerably more advanced and more complex than in the previous ECM. It was in an unfinished and largely conceptual state as well when the project began. Therefore, despite the recipient's experience and greater understanding of ECM technology gained from the first two projects, this project was characterized by a very high level of technology uncertainty. From the start, the relationship between the source and recipient was structured and managed as what one senior manager described as a "partnership." There were very high levels of cooperation, communication, and coordination. In this project, there was a good fit between technology uncertainty and interorganizational interaction, and the project met its objectives for time, cost, and technical functionality.

Theoretical implications

The generalizability of our study is limited somewhat by the field interview method used and the smaller sample size associated with this method. Nonetheless, we can draw some tentative conclusions. The first conclusion we can draw is theoretical in nature. Our conceptual framework, which is based on organizational information processing theory, was supported by the field interview results. This study demonstrates the application of this general theory to the specific operational task of ETI. Information processing theory's prior application to and empirical confirmation in operations contexts have been relatively limited (Flynn and Flynn, 1999; Tatikonda and Rosenthal, 2000a). Our study provides additional support for its use in other areas of operations management.

We have limited the scope of this paper to an examination of the specification and management of the relationship between the source and recipient organizations in an ETI project, and as a result, there are a number of opportunities for future research. Prior research has explored interorganizational relationships, particularly in the fields of strategy (Kotabe *et al.*, 2003; Rothermael, 2001; Rowley *et al.*, 2000), marketing (Jap, 2001; Rindfleisch and Moorman, 2003), and supply chain management (Chopra and Meindl, 2001; Mabert and Venkataramanan, 1998; Maloni and Benton, 1997). However, very little, if any of this prior literature examines these issues in the context of ETI. Therefore, the directions of future research we discuss here would broaden the domain of this existing literature. We noted above the importance and difficulty of assessing the uncertainty of a particular technology to be transferred. One direction for future study is the development of technology assessment tools that would enable a firm to carry out this activity in a structured manner across a wide range of technologies.

We also noted the importance of developing competencies in managing interorganizational relationships, in particular ETI relationships. However, most firms have little or no expertise in developing these sorts of managerial skills, and are often likely not even to understand their own capabilities in this area. A second avenue for future research, then, is the "parallel" development of tools that would allow a firm to more accurately assess its competencies (and those of potential technology source firms) in managing interorganizational relationships.

A third direction for future research is a more detailed exploration of the effects of learning in ETI. In particular, what would be especially useful is a determination of whether there is a learning curve associated with this activity. The presence of such a learning effect would allow firms to integrate external technology more efficiently and effectively over time, even technology that is relatively complex and novel. Chew *et al.* (1991) have noted that a firm that is able to implement more advanced technology with fewer problems is essentially acquiring that technology "at a discount" (with its concomitant cost advantage) and therefore should have a competitive advantage. What would be especially interesting in this line of study would be an explicit exploration of the relative importance of technological learning versus learning about the management of the interorganizational relationship (or the interaction of the two types of learning).

The conceptual model explored in this paper focused on two key dimensions: technology uncertainty and interorganizational interaction. Other important antecedent and contextual variables could influence both these variables and ETI effectiveness. Such variables include:

- processes that occur before the ETI project that could influence technology integration (e.g. the selection of the technology and the source organization of that technology);
- critical foundational characteristics of the source-recipient relationship that set up the context for the technology integration (e.g. ex-ante dyad characteristics between the source and recipient organizations);
- a variety of organizational resources and experiences that are enablers of interorganizational interaction (e.g. ETI experience in general, integration resources such as the availability of key personnel with such experience);
- non-dyadic variables in the technology integration process that could materially influence ETI success (e.g. some aspects of integration resources such as the availability of personnel with the appropriate level of technical expertise).

Deeper consideration of these antecedent and contextual variables is beyond the scope of this paper. Nonetheless, comprehensive consideration of the ETI process should consider such variables as well and should therefore be explored in future research.

Managerial implications

We now turn to the managerial implications of this study. First, we consider whether the ETI conceptual framework is managerially valid. From the summary results shown in Figure 3, as well as the more detailed descriptions above, our interpretation is that the framework does hold. An appropriate match between technology uncertainty and interorganizational interaction tends to result in better ETI project outcomes. What is also noticeable about Figure 3 is that the firms in our sample were successful in avoiding the upper right-hand corner of the ETI matrix. This result is not surprising. The firms we interviewed appeared to rarely overestimate the uncertainty of the technology, so it is unlikely they will engage in too great a level of interaction with the technology's source organization. If the unsuccessful projects were not located in the upper right quadrant, then we are left with ETI projects located in the lower left corner. In these projects, the source and recipient organizations have structured a relationship in which the level of interorganizational interaction is lower than what was required for successful integration of the technology. The question, then, is how does one stay out of the lower left corner?

We found in our interviews that ineffective projects of this type generally result from one of two causes. In the first, the recipient organization has underestimated the level of technology uncertainty and then structured the integration relationship to have an inadequate level of interorganizational interaction. Recall that the level of technology uncertainty is organization-specific. A technology that is well understood within one organization may be new to another company and well beyond its current level of technical expertise. This situation was in fact the case for Firm A in project A1. This company had no experience in point of sale systems, and structured the relationship with too little interaction. By definition, a high level of technology uncertainty implies that the recipient organization would not have the information needed to incorporate the technology into its product or process. However, there is an additional risk – the recipient organization may not know enough about the technology to even be able to assess the technology accurately – and that may lead to a disastrous ETI experience. In other words, the recipient may not even know what it does not know (or even what kind of information it must acquire).

Is it hopeless then to attempt ETI with a very uncertain technology? The answer is no – recall the successful cases located in the lower right corner of the ETI matrix shown in Figure 3. The keys appear to be a willingness to learn and a commitment of resources to building a learning capability. Although learning was not included as an explicit component of out conceptual framework, the results of our interviews indicated that learning was important, both during an individual project (particularly when technology uncertainty is high) and across multiple projects. An effective learning technique is the project audit (Burgelman *et al.*, 1998), where the project team at the conclusion of an ETI project would formally review the management process of that project to identify lessons that might be applied to future projects. Firm B, for example, employs project audits as a standardized concluding step in their ETI projects (including the ERP system project described above). Moreover, each ETI project should provide technical experience that builds expertise, both with the specific technology and with the ability to assess technologies that will be acquired in the future. Greater expertise with a technology reduces its uncertainty in the first place, and allows a more accurate assessment of its uncertainty. This in turn should allow the recipient to structure the proper level of interorganizational interaction to the integration relationship. The end result should be a more effective ETI project.

The second cause of a lower left corner ETI project would be the ineffective management of the integration relationship, even if the technology has been accurately assessed and there is an appropriate intended match of technology uncertainty and interorganizational interaction. Therefore, the problem is one of execution, not assessment and planning. The level of interorganizational interaction that actually occurs during the ETI project is not as high as it was intended to be. Here, the key seems to be cooperation. Cooperation involves working together toward compatible goals, and it involves a high level of trust and willingness to share information. Without a high degree of cooperation, it is unlikely that coordination and communication will occur, because both of these dimensions of interorganizational interaction require a considerable information sharing. A key to the effective management of ETI projects that require a high level of interorganizational interaction, then, is the establishment of an effective cooperative relationship at the start of the project. Such a level of cooperation may run counter to the cultures of many organizations, and as such may require an active role by top management. Project E1 was an example of this type of ineffective management of interorganizational interaction. The source and recipient did not necessarily intend to have a relationship characterized by poor coordination and communication. However, the lack of a cooperative approach to the project led to a very low level of interaction, and the project was unsuccessful. Top management involvement to establish cooperation was critical to the subsequent successful projects in Firm E (projects E2 and E3) described above.

A firm might also take a longer view of the ETI process in assessing the effectiveness of a particular project. The traditional project performance dimensions of cost, time, and functional effectiveness generally will have a primary importance, but the learning perspective discussed above can be important as well. A project that is a "failure" by conventional criteria may provide an opportunity for learning about a new technology that will lead to success in the future. This cycle of failure, learning, and success has been observed in the management of internal new product development projects (Maidique and Zirger, 1985). In addition, ETI projects also can allow an organization to build organizational competencies in managing inter-firm relationships that concern activities other than ETI. In fact, both Firm B (the ERP system) and Firm E (the truck engine ECM) viewed these ETI projects as learning opportunities. Firm E, in particular, was able to create a learning capability across its three ECM projects (projects E1, E2, and E3), which led to better outcomes for project E2 as well as a subsequent project with the next generation of this technology (project E3).

Summary and conclusions

This paper has highlighted the importance of ETI as a key activity in the complex processes of product development, process development, and operational improvement. ETI is an activity too often dealt with in an ad hoc fashion. Purposeful, structured management of the ETI process should lead to successful products, processes, and operations.

For years the focus of business teaching and practical attention has been on managing the internal organization and its processes. However, contemporary business realities require firms to focus on interorganizational processes as well. Indeed, for some firms in dynamic markets, the ability to manage interorganizational processes is their distinctive competitive competence. ETI is a particularly important interorganizational process that calls for multiple forms of competencies in collaboration. These competencies include the ability to assess the technology that crosses organizational boundaries, as well as skills in working with the technology source to most effectively integrate the technology into the firm's products or processes. We hope this paper helps firms manage this increasingly important activity.

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