J PROD INNOV MANAG 2003;20:444–467

THE JOURNAL OF
PRODUCT
INNOVATION
MANAGEMENT

Product Technology Transfer in the Upstream Supply Chain

Mohan V. Tatikonda and Gregory N. Stock

This article addresses the transfer of new product technologies from outside the firm for integration into a new product system as part of a product development effort. Product technology transfer is a key activity in the complex process of new product development and is the fundamental link in the technology supply chain. Product technology transfer too often is dealt with in an ad-hoc fashion. Purposeful management of the product technology transfer process leads to more effective transfers in terms of timeliness, cost, functional performance, and competence building. Better management of product technology transfer gives firms access to a greater variety of new technology options, improves a firm's ability to offer significantly differentiated products, deepens the firm's competitive competencies, and positively influences sustained product development success. The central objective of this article is to gain insight into product technology transfer so that companies can manage this process more successfully and so that researchers can investigate this critical activity further.

This article describes the technology supply chain as a unique form of a supply chain that poses a set of managerial challenges and requirements distinguishing it from the more traditional component supply chain. Because a single product technology transfer project is the fundamental piece in the technology supply chain, understanding this piece well is key to leveraging the extended technology supply chain and to improving overall product development performance. This article integrates literatures on new product development, supply chain management, and technology management and builds on organizational theory to present a conceptual model of determinants of product technology transfer success. The core proposition is that product technology transfer effectiveness is greatest when companies carefully match (or "fit") the type of technology to be transferred (the "technology uncertainty") with the type of relationship between the technology supplier and recipient (the "interorganizational interaction").

A quite detailed framework characterizing technology uncertainty along the dimensions of technology novelty, complexity, and tacitness is presented to help in assessing the challenges associated with transferring a particular product technology. This article also considers detailed elements characterizing the interorganizational interactions between the technology source and recipient firms. This helps firms consider the appropriate means to facilitate the interfirm process of technology transfer. Overall, this article provides practical insight into characterizing technologies and into improving the product technology transfer process. This article also provides a strong theoretical foundation to aid future research on product technology transfer in the technology supply chain.

Address correspondence to Mohan V. Tatikonda, Kelley School of Business, Indiana University, 801 W. Michigan St., Indianapolis, IN 46202-5151. Phone: (317) 274-2751; E-mail: tatikond@iupui.edu.

Introduction

Companies often incorporate new product technologies in their product designs to help achieve distinctive new products. Companies rarely rely solely on internal research and development (R&D) for the initial development of all the new product technologies they will employ in a new product system (Wheelwright and Clark 1992). Accordingly, careful integration of product technologies from external organizations, called the ''product technology transfer process'' here, is an essential competence for new product development organizations. Companies skilled in the product technology transfer process have access to a vastly greater array of technological options and can ration their scarce R&D resources better (Miller 1995; Noori 1990).

It has been reported that product technology transfer frequently is difficult to conduct (Iansiti 1998). This process often is fraught with unanticipated problems and excessive risk, leading to product development efforts that are unsuccessful due to time delays in market introduction, cost overruns, and technical functionality problems. It is acknowledged that product technology transfer is conducted regularly in an ad-hoc manner (Sheridan 1999). As an example of the importance of product technology transfer, consider the experiences described to the authors by managers of a truck engine manufacturer when this firm first incorporated an electronic control module (ECM) in the design of a new truck engine:

> *The ECM technology was very new (it had never been used in this firm or by any truck engine manufacturer), it was very complex, and it existed only as a set of high-level design requirements (much less a tangible component or even a finished design). The interaction with the firm selected to be the source of the ECM was characterized by ineffective communication, poor or absent coordination of design activities, and a generally adversarial relationship. As a result, an entire year was lost in the project when the two firms finally realized that they were both working on the design of the ECM without realizing it. The two firms essentially had to restart the project from scratch, but in this second product technology transfer project there was a high degree of communication, effective coordination, and a cooperative relationship for this novel, complex, and uncodified new product technology. The ECM was successfully incorporated into the new truck engine, which was subsequently a very successful product for the firm.*

Given the difficulty of product technology transfer, the importance of obtaining new technologies from external sources, and the need for purposeful management of this process, this article aims to answer the following types of questions:

- How should firms go about transferring new product technologies?
- Does the nature of the technology that is transferred matter?
- What forms of interorganizational relationships are most appropriate?

BIOGRAPHICAL SKETCHES

Dr. Mohan V. Tatikonda is associate professor of operations management at the Kelley School of Business at Indiana University. He holds a B.S. in electrical engineering, an M.S. in manufacturing systems engineering, and an M.B.A., all from the University of Wisconsin. He received his D.B.A. in operations management from Boston University. He holds the NPDP certification from PDMA and the CFPIM certification from APICS. Dr. Tatikonda also has served on the faculty at the University of North Carolina at Chapel Hill and at Boston University. He currently teaches the core operations management course in the M.B.A program. Dr. Tatikonda's primary research interests lie in new product and service development, technology implementation, and supply chain management. His doctoral dissertation received the ''best dissertation award'' from the Production and Operations Management Society, and he has received research awards from the Marketing Science Institute and The Manufacturing Roundtable. He has consulted for The World Bank and SAP and has engaged in collaborative research with Agfa, General Electric, and Motorola. His research has been published in leading journals including *Journal of Product Innovation Management*, *Management Science*, *Journal of Operations Management*, and *IEEE Transactions on Engineering Management*. He authored three chapters in the recent book *New Directions in Supply Chain Management*.

Dr. Gregory N. Stock is assistant professor of operations management in the College of Business at Northern Illinois University in DeKalb, where he teaches operations management and supply chain management. He received his B.S.E. and M.S. degrees in electrical engineering from Duke University and his Ph.D. degree in business administration from the University of North Carolina. Prior to beginning his academic career, he held design and development engineering positions in a variety of high-technology industries, including computer graphics, data communications, and wireless telecommunications. He also has served on the faculties of the University of Hartford, Arizona State University West, and Hofstra University. His research interests include technology management and supply chain management, and his work has been published in the *Journal of Product Innovation Management*, *IEEE Transactions on Engineering Management*, *Journal of Operations Management*, *Journal of High Technology Management Research*, *Technovation*, *International Journal of Operations and Production Management*, *International Journal of Physical Distribution and Logistics Management*, and *Production and Inventory Management Journal*. Dr. Stock is a member of the Product Development and Management Association, the Academy of Management, the Decision Sciences Institute, the Production and Operations Management Society, APICS, and IEEE.

- Which organizational competencies should firms nurture to enable consistent and routinely successful transfers?

General Characteristics of a Supply Chain

A supply chain is a network of organizations involved from beginning to end in transforming and transporting materials and information in order ultimately to create and to deliver valued products to end customers.[1] In turn, "supply chain management" is the purposeful integration of these organizations and activities in order to achieve greater customer responsiveness and lower overall costs (see also Handfield and Nichols 1999; Poirier and Bauer 2000; Simchi-Levi et al. 2000). Several aspects of these definitions are to be emphasized. First, both information and materials flow up and down the supply chain. Second, each organization in the supply chain creates, delivers, and adds value to the ultimate product. Third, the supply chain is a network, constellation, value chain, web, or even ecosystem of organizations; that is, individual organizations must interrelate and must interact in order to add value.

Two general categories of supply chains have been identified: upstream, or incoming materials, and downstream, or outgoing distribution (Handfield and Nichols 1999). Further, within the category of upstream supply chains, the technology supply chain and component supply chains have been identified (Ettlie and Reza 1992; Deck and Strom 2002; Melnyk and Swink 2002).

The Technology Supply Chain

A technology source firm (the supplier) and a technology recipient firm (the firm conducting a new product development effort) comprise a dyad engaging in interfirm interactions to accomplish product technology transfer. This defines a classic supply chain in that the two firms are organizational players in the supply chain who interact with each other, and an entity (the product technology and associated knowledge about the product technology's function and interfaces) flows along the supply chain.[2] The product technology transfer process is the essential, elemental link in the technology supply chain. A complex technology supply chain would comprise many links in a variety of configurations; hence, many product technology transfer processes across supply echelons.

The technology supply chain is different from the more widely studied component supply chain in a number of significant ways (see Figure 1). First, incoming component supply chains have relatively regular, continuous flows of materials in nontrivial volumes. In contrast, the technology supply chain problem is highly episodic, with the occasional transfer of a single product technology. Second, incoming components (for a manufacturer) typically enter into either the manufacturing rampup or the volume production phases of a product life cycle. In comparison, the product technology typically enters into the early product design phase. Third, in the component supply chain the manufacturer customarily provides detailed, prespecified component specifications to established supply sources. In the technology supply chain, the technology is not prespecified necessarily. The product technology initially may be developed independently by the source firm and then may be selected and integrated by the recipient firm. Hence, a technology recipient can be opportunistic in scanning the environment for technological opportunities. Fourth, in the incoming component supply chain, the entity typically is well established—that is, highly specified and with little uncertainty as to its nature. In contrast, in the technology supply chain the incoming technology is often risky—it is not always understood fully by the recipient firm and may require considerable characterization and refinement before incorporation into a new product system.

Links, Series, and Hubs in the Technology Supply Chain

In all, it is clear that the technology supply chain has unique characteristics and as a result poses unique

[1] Although different authors present slightly varying conceptualizations of supply chains, most authors converge on definitions similar to the ones posed here.

[2] Indeed, the technology supply chain may be considered to be a knowledge supply chain (Tornatzky and Fleischer 1990), because the technology transferred embodies knowledge and because associated with the technology there is knowledge about its technical function and the technology's potential ability to interface with other technological elements. Hence the product technology that is transferred actually is a technology/knowledge package.

Dimension of Difference	Component Supply Chain	Technology Supply Chain
Regularity of Activity	Regular and continuous flow of materials	Highly episodic, occasional transfers
Transfer Volume	Non-trivial volumes of common parts in batches	Single product technology
Product Life Cycle Phases Impacted	Primarily volume manufacturing, but also manufacturing ramp-up phases	Early product design phase
Specifications	Typically highly pre-specified component technical specifications	Typically not highly pre-specified or well-established technical specifications
Technology Risk	Very low	Ranges from low to very high
Adaptation and Integration Work Required after Receipt	Generally low adaptation/integration requirements since the component, and the product system it goes into, are pre-specified	Ranges from low to very high characterization, refinement and integration activity before the transferred technology works effectively in the new product system
Key Management Objectives (or Performance Measures)	Primarily tactical, operational performance measures (e.g., component cost, delivery, quality, inventory cost)	Tactical: Transfer project and development project performance measures (e.g., time, budget, technical performance of the technology in the new product system) Strategic: Competence-building regarding the technology and organizational skills.

Figure 1. The Component versus Technology Supply Chains

management challenges. The unit of observation in this article is the one essential, elemental link in a technology supply chain: the product technology transfer process. This process comprises elements and interactions of the source-recipient dyad. Insight into this link can be leveraged to consider more complex comprehensive technology supply chain network configurations.

For example, there can be a sequence of product technology transfers, where a recipient in one transfer is also the source in another transfer, referred to here as "links in a series". Consider a product technology that enters into a new product system (product system A), where product system A is itself a product technology that enters into another new product system (product system B). For example, a product technology (e.g., a laser diode) is transferred from Firm 1 to Firm 2 where that technology is integrated into a laser printer product developed by Firm 2. The laser printer product then is transferred to Firm 3, which designs, develops, and markets medical diagnostics equipment. From the perspective of Firm 2, the laser printer product is an end product, but from the perspective of Firm 3, it is a raw product technology. Firm 3 incorporates the laser printer device as a central product technology module (whose function is to provide diagnostic output in hardcopy form) in its new product (product system C). The diagnostic machine then could be incorporated by another organization (Firm 4) into some even greater product system, such as a multifunctional medical diagnostic and monitoring machine (product system D). The many sequential links in the chain become apparent.[3]

[3] In traditional supply chain management terminology, these sequential links represent multiple echelons, or tiers of organizational players.

In addition, any given new product development project can involve several or even many product technology transfers because the new product system may incorporate multiple transferred technologies. This single-recipient/multiple-sources situation represents a hub where there are many links for a single development effort, and so this is referred to as ''links in a hub''. Consider Firm 2 in the previous example. In addition to the laser diode technology that must be transferred (product technology transfer 1), Firm 2 also needs to transfer central processing unit (CPU) technology (product technology transfer 2), computer operating system technology (product technology transfer 3), and data storage technology (product technology transfer 4) as part of the development of the laser printer product (product system B).

Figure 2 illustrates both links-in-a-series and links-in-a-hub attributes of this technology supply chain example. Technology supply chains of larger scale and scope can be represented by more complex configurations of links, series, and hubs.

The conceptual model in this article focuses on the essential, elemental link in the technology supply chain: the product technology transfer process, which is a dyadic relationship between a technology source firm and the technology recipient firm. In the following two sections, foundational literature informing the product technology transfer problem is reviewed, and theoretic notions of information processing are applied, because technology transfer is an information processing exercise.

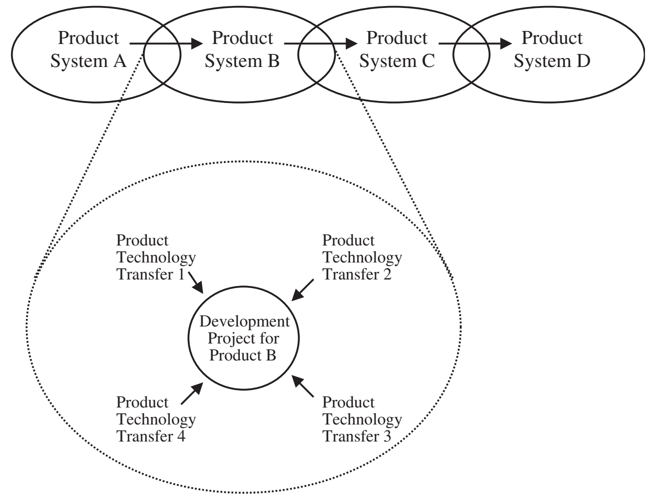

Figure 2. Links, Series, and Hubs in the Technology Supply Chain

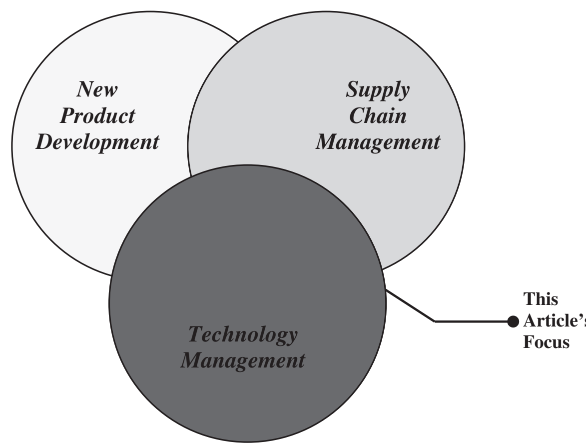

Figure 3. Integration of Three Literatures

Related Literature

The subject of source-recipient interfirm links in the technology supply chain is informed by a variety of literatures (see Figure 3). The central contributions and limitations of the technology management, new product development, and supply chain management literatures are addressed briefly now as they apply to the problem of project-level product technology transfer.

The traditional literature on technology management addressing technology transfer provides a sense of the overall transfer process, particularly at the strategic level. For example, the contractual nature of the transfer mode often is considered at the firm level (e.g., Reddy and Zhao 1990; Tsang 1997), and transfer outcomes often focus on firm level performance, such as improved competitiveness (Zhao and Reisman 1992). However, project work-level details and activities generally are not addressed (Cusumano and Elenkov 1994). This literature typically considers only a single technology attribute of the technology to be transferred.[4] Examples include the tacit knowledge embedded in the technology (Howells 1996), the embodiment of the technology (Reddy and Zhao 1990), or the functional area in which the technology is to be used (e.g., R&D, engineering, or manufacturing) (Zhao and Reisman 1992).

The new product development literature at the project level provides substantial prescription on how to manage internal aspects of a development project [such as design/manufacturing integration, use of

[4] There are limited exceptions. For example, Souder and Padmanabhan (1989) consider multiple characteristics of the technology by addressing perceived complexity and fragility of the technology.

computer-aided design (CAD) tools, internal project management processes such as phase/gate systems, etc.] (Ulrich and Eppinger 2000). This literature also contributes characterizations of the technology that is to be developed by a new product organization (Griffin 1997). But the product innovation literature is preliminary in describing what permeates and integrates interfirm organizational boundaries of a new product development effort.

The literature on supply chain management provides definitions of what a supply chain is and considers essential concepts related to this topic (Handfield and Nichols 1999; Poirier and Bauer 2000; Simchi-Levi et al. 2000). As such, it provides an important topical lens to study the technology supply chain. This literature generally focuses on upstream components and downstream distribution supply chains rather than on the technology supply chain. The recent work on early supplier involvement (ESI), joint specifications development, and co-development do aim to understand better the contemporary blurring of organizational boundaries in product development projects. The nascent 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 (see Hartley et al. 1997; Ragatz et al. 1997). The ESI literature typically assumes that component specifications generally are 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.[5] The ESI literature generally does not consider the nature of the technology embodied in the components being provided by the supplier and does not 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. Recent studies go beyond that perspective by considering when co-development is appropriate for new products that employ "revolutionary" technology (Neale and Corkindale 1998), as well as considering the conditions under which co-development should be chosen over joint ventures as the preferred mode of collaborative product development (Tao and Wu 1997).

[5] The literature on joint specifications development and joint component design, which is more typical of Japanese source-recipient relationships, is a small exception (e.g., Handfield et al. 1999; Kamath and Liker 1994; Sobek et al. 1998).

The prior literature provides an essential foundation for this study (see Figure 3). This article draws on and synthesizes diverse product innovation, technology management, and supply chain management studies, both conceptual and empirical, to make several contributions. First, through a highly integrative consideration of these literatures, a detailed conceptual characterization of the type of product technology (and its associated knowledge) to be transferred is constructed. Second, by integrating the three literatures and by considering organizational theories of information processing and interdependence, project-level interorganizational interactions between the technology source and recipient in the transfer are detailed. The issue of interorganizational relationships in technology transfer is made much richer when also considering the multidimensional nature of the transferred technology. Third, based on the literature, organizational theory, and the authors' prior field experience, it is posited here that understanding and configuring the appropriate combination of the technology type and source-recipient relationship is a key determinant of product technology transfer success in new product development.

The Concept of "Fit"

Product technology transfer entails movement of the product technology (and knowledge about it) from source to recipient; the evaluation, experimentation, refinement, and adaptation of the technology; and the final functional incorporation of that product technology into a new product system (Bozeman 2000; Souder 1987; Tornatzky and Fleischer 1990). Therefore, the technology transfer process begins at the point of commitment to a specific technology by the recipient firm and concludes when that technology has been incorporated satisfactorily into the recipient's new product.[6]

Product technology transfer is a dyadic process between source and recipient firms. The conceptual

[6] There are a number of activities prior to transfer. These include the recipient firm's initial recognition of the potential need for (or availability of) a technology solution; technology scanning, comparative evaluation of alternative technologies, and strategic and economic justification of a given technology; and the recipient's actual commitment to a specific technology. The quality of activities prior to technology transfer very well could influence technology transfer effectiveness; however, pre-transfer activity is beyond the scope of this paper.

model in this article considers this dyadic relationship from the recipient's perspective. The model begins temporally when a technology to transfer has been chosen and has been committed to by the recipient firm.

Matching Technology Type and Interorganizational Relationship

Technologies to be transferred come in many forms: Some are physically large or small; some may be based on the latest scientific principles while others are "old hat;" or some may be incorporated easily into a product system while others require many modifications before successful integration. The incremental/radical dichotomy (Nord and Tucker 1987) that is applied commonly to differentiate technologies, although helpful in some applications, does not guide rich theory building regarding execution of product technology transfer. And although it is easy to discuss anecdotally how technologies differ, for deep insight into technology transfer it is necessary to have a more complete and generalizable characterization scheme for the variety of technologies that conceivably might be transferred.

Once it is known what type of technology is to be transferred, the recipient organization can work with the source organization to accomplish the technology transfer most effectively. A wide variety of interorganizational forms are available. For example, the technology could be "tossed over the wall," or the two firms could engage in some type of colocation to conduct the transfer. As with characterizing the technologies, it is necessary to determine the different forms of interorganizational interaction between the source and recipient firms that are available.

As an example of the match of technology and interorganizational form, consider that a simple, well-known (highly certain) technology would require only limited collaboration (low interorganizational interaction) between the source and recipient firms. Similarly, a highly novel or complex technology (highly uncertain) might benefit from high levels of collaboration (high interorganizational interaction) to achieve the technology transfer. In short, the greater the technology uncertainty associated with a given technology, the greater the interorganizational interaction between technology source and recipient that is required for technology transfer success. Technology uncertainty and interorganizational interaction should be matched appropriately. By itself, more interorganizational interaction is not always better: For example, greater interorganizational interaction would be excessively costly for the transfer of a relatively simple technology. Accordingly, the core proposition of this article is as follows:

> *The highest product technology transfer success accrues when the optimal match of technology uncertainty and interorganizational interaction is employed.*

Figure 4 presents the core model of the article and also illustrates the core proposition of fit.

The notion of "fit," also commonly referred to as congruence or a contingency relationship, is grounded in well-established organizational theory. We now address two theories that underlie our three-variable core model.

Organizational Theory Foundations

Information processing theory. Information processing is the purposeful generation, aggregation, transformation, and dissemination of information associated with accomplishing some organizational task with the intention to reduce the uncertainty about how to accomplish that task (Tushman and Nadler 1978). All product technology transfers inherently involve some level of information processing. Information processing theory explains that organizational tasks pose task uncertainty to the organization. Task uncertainty in turn poses information processing requirements to the organization, since information processing is required to resolve the task uncertainty. Various means applied by the organization provide information processing capabilities. The degree to which requirements and capabilities are matched appropriately determines whether

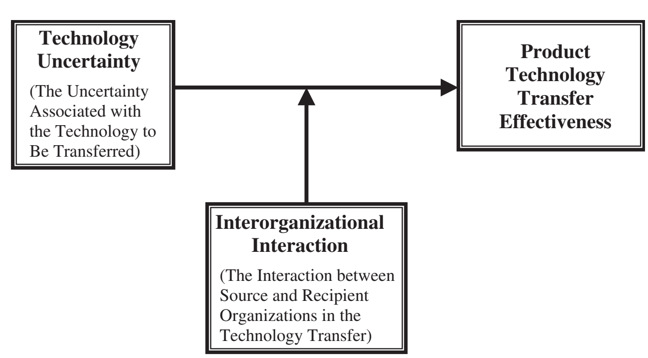

Figure 4. Core Model of Product Technology Transfer

sufficient information processing is conducted to resolve the task uncertainty and in turn determines the quality of task outcomes (Galbraith 1977).

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 and quality of information that must be processed (Daft and Lengel 1986). Task uncertainty is organization-specific: What is certain to one organization may be uncertain to another. Task-related characteristics cause or contribute to task uncertainty (Galbraith 1977). The task context of interest here is the integration of an external product technology into a new product system under development by the recipient firm. This task poses some level of uncertainty to the recipient organization.

Organizations employ different organizational means to process information and to reduce task uncertainty as the task execution progresses. Galbraith (1977) 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" (p. 39). The endpoints of the information processing capacity spectrum have been described as "mechanistic" and "organic" organizations (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 information processing requirements and capabilities are not matched properly (Galbraith 1977). 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 matched appropriately (or fit) to a given level of information processing capacity (or vice versa) in order to achieve effective task outcomes.

Interdependence theory. The source and recipient engaged in the product technology transfer are reliant on each other, to some degree, to accomplish the task. Interdependence theory addresses structural and process aspects of relationships between two distinct organizational units (Adler 1995). Four forms of interunit interdependence (pooled, sequential, reciprocal, and team interdependence) have been identified and represent increasing levels of an interorganizational relationship (Thompson 1967; Van de Ven et al. 1976). A lower level 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). In general, lower interdependence affords greater reliance on planning and reflects a more mechanistic organization. Greater interdependence means higher relationship intensity and requires more emphasis on problem solving and on communication during the task activity (Daft 1986). Higher forms of interdependence represent a greater capacity for information processing, both in quantity and quality, and are typical of a more organic organization.

Combining the theories. There is value in combining the organizational information processing and interdependence theories. Task uncertainty causes information processing requirements. The form of interorganizational interdependence provides information processing capacity. Appropriate match of requirements and capabilities leads to effective performance of the task. By adapting the general information processing and interdependence theory principles to the specific context of product technology transfer, it can be stated that the type of technology uncertainty (posed by the technology that is to be integrated into a new product system) should be matched appropriately with the type of interorganizational interaction (provided through the form of interdependence) between source and recipient firms (and vice versa). See Figure 5.

Explication of the Three-Variable Core Model: A Roadmap

The next three sections build on the core theoretical notions of the information processing and interdependence theories, namely task uncertainty and interorganizational interdependence. Each of the three sections addresses one variable in the core model (Figure 4). The first section in the series develops a detailed, generalizable characterization scheme identifying dimensions and elements of task uncertainty (that is, technology uncertainty) in product technology transfer. The second section in

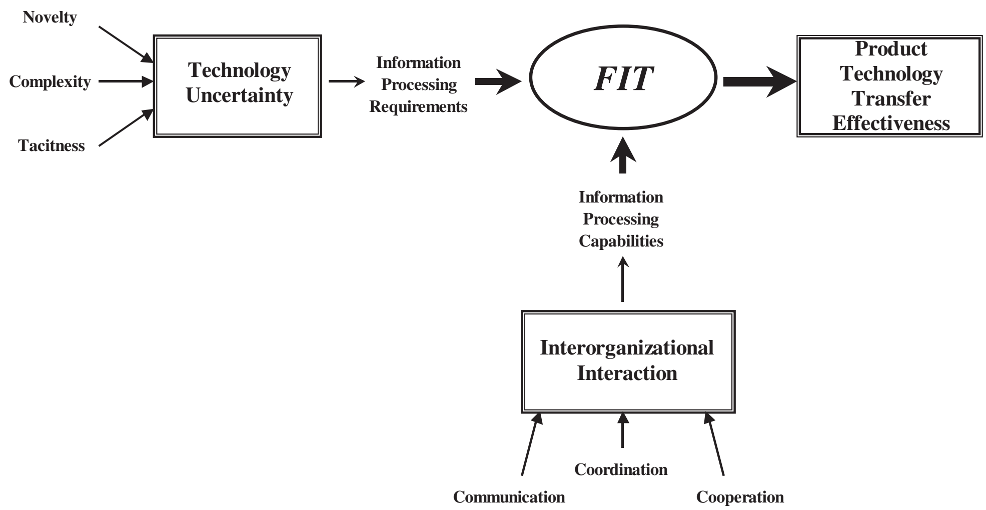

Figure 5. Information Processing and Interdependence Theories Applied to Product Technology Transfer

the series presents a detailed, generalizable characterization scheme identifying dimensions and elements of interorganizational interaction in product technology transfer. The third section in the series addresses the meaning of transfer effectiveness or success in the product technology transfer context. See Table 1 for a summary of the dimensions and elements of each variable.

Characterizing Technology Uncertainty

This section addresses technology uncertainty, the first variable in the core model. Different technologies, and different product technology transfer situations, vary in the level of technology uncertainty that must be dealt with by the recipient organization during technology transfer. Technology uncertainty is the differential between the level of knowledge required by the recipient organization to integrate the technology and the level of knowledge the recipient actually possesses at the start of the technology transfer. Greater technology uncertainty implies a need for greater learning about, experimentation with, and/or adaptation of the technology by the recipient organization before that technology can be incorporated successfully into a new product system. Therefore, greater technology uncertainty leads to greater information processing requirements.

Dimensions of Technology

Souder (1987) notes, "What is a technology? This should be an easy question to answer. Yet it is not." He continues, "[The] difficulty in defining and measuring technologies is their multidimensional nature" (p. 199). That is the central problem. There are many elements, characteristics, dimensions, facets, and factors the literature employs to define a technology and attribute contributors to technology uncertainty. In reading the literature, the authors have come across no single, deep, comprehensive, multidimensional framework for analyzing the uncertainty associated with a given technology.

Such a framework is essential to guide understanding of what a technology is and the uncertainty it poses to players in the technology supply chain. Souder (1987) concurs, stating that "the nature of a technology can significantly affect the success or failure of an innovation project" (p. 199). It is believed here that a major contribution of this article is the original, conceptual synthesis of these many technology elements. Technology, and therefore contributors to technology uncertainty, is characterized into three macro-dimensions: technology novelty, technology complexity, and technology tacitness. These three dimensions were settled on for a variety of reasons:

1. In reading the diverse literature streams, no element was found that contributes to technology uncertainty that does not logically fall into one of these three dimensions. The three dimensions, which are conceptually unique, seem collectively to capture the great range of technology characteristics that potentially influence technology uncertainty.

Table 1. Variables, Dimensions, and Key Elements

Legend:

Variable
Dimension
- Key Element

1. Technology Uncertainty
Novelty
- Technology Newness
- Technological Change

Complexity
- Internal Technological Interdependence
- External Technological Interdependence
- Scope

Tacitness
- Physical Embodiment
- Codification
- Completeness

2. Interorganizational Interaction
Communication
- Methods
- Magnitude and Frequency
- Nature of Information Exchanged

Coordination
- Administrative Planning
- Process Formality
- Relationship Time Horizon

Cooperation
- Trust
- Goal Congruence
- Commitment

3. Transfer Effectiveness
Operational Outcomes
- Functional Performance
- Time Duration
- Cost

Competence-Building Outcomes
- Technology-Oriented
- Intraorganizational Skills
- Interorganizational Skills

2. It is acknowledged here that the terms technology novelty, technology complexity, and technology tacitness are not new. The general notions of these three dimensions are in the extant literature. However, no single framework has been seen that integrates all three dimensions. It is notable that literature associated with different disciplinary streams of work tends to emphasize, and similarly to disregard, particular dimensions. The new product development literature commonly addresses aspects of technology novelty, occasionally addresses aspects of technology complexity, and generally does not address technology tacitness. The technology management literature, particularly the work on technology strategy and technology transfer, greatly emphasizes technology tacitness but does not in general address technology novelty or complexity. The supply chain management literature for the most part does not address intrinsic technology characteristics. In presenting the three dimensions as a set, these diverse literatures and thought-streams are integrated into a single, workable, generalizable framework that helps to define technology and to assess technology uncertainty levels.
3. Based on factor analysis of a survey administered to 48 engineers, Souder (1987) found technology factors that define a technology. The factors are "state of the art," which roughly corresponds to "technology novelty;" "connectedness," the extent to which the technology is integrated with other technologies, which roughly corresponds to "technology complexity;" and "accessibility," the level of codification of the technology and the ease in which the technology can be explained, which roughly corresponds to "technology tacitness." The three dimensions here parallel the technology factors elucidated by Souder's research.[7]

The remainder of this section describes essential, generalizable technology characteristics that contribute to greater technology uncertainty. This characterization scheme may be employed to assess the level of technology uncertainty associated with a given product technology. The many factors that contribute to technology uncertainty into the technology novelty, technology complexity and technology tacitness dimensions are synthesized here. These three dimensions represent largely different concepts; nonetheless, in practice they overlap to some degree because some technological elements influence more than one dimension. Higher levels of each dimension increase the level of technology uncertainty and lead to greater information processing requirements.

Novelty

Technology novelty has two related elements: (1) the degree of prior experience the recipient organization

[7] A fourth factor Souder (1987) presents, "impact," refers to the societal impact of a technology. This is not related directly to technology uncertainty for players in the technology transfer dyad and is beyond the scope of this paper.

has with the technology to be transferred (resulting in the "technology newness" posed to the recipient organization); and (2) the degree of change in the technology relative to prior technologies ("technological change").[8]

The technology newness element is quite organization-specific, because a given technology may pose different levels of technology newness to different recipient organizations. For example, a newly available more efficient electric motor likely would pose a low degree of technology newness to a firm having a good deal of expertise and experience in incorporating motors into its products (e.g., a developer of laser printers). However, the same motor technology might pose a very high level of technology newness to a developer of garden appliances if this developer previously incorporated only small gasoline motors into its products. Accordingly, different levels of experience or absorptive capacity (Cohen and Levinthal 1990; Glass and Saggi 1998) may mean that what is highly novel to one organization may not be for another. Greater experience with a given technology, or related technologies, decreases the technology novelty.

Some describe technology newness as the degree of familiarity or experience the recipient organization has with the technology (Adler 1992; McDonough and Barczak 1992; Tatikonda and Rosenthal 2000; Yoon and Lilien 1985). The "familiarity matrix" of Roberts and Berry (1985) captures three levels of technology newness: base, new-familiar, and new-unfamiliar. One dimension of Abernathy and Clark's (1985) "transilience matrix" represents technology newness in terms of the organization's experience with the given technology. They state that newer technologies may require new knowledge, skills, organizational procedures, capital equipment, and organizational relationships with vendors. Bohn's (1994) framework of the stages of technological knowledge (ranging from complete ignorance to complete knowledge) provides fine granularity of technology newness and recognizes that newer technologies pose lower ease of transfer.

Within the broad technology management literature, technology newness also sometimes is characterized as the magnitude of technological change (Barnett and Clark 1996) or, in a similar vein, as the radicalness of the technology (Green et al. 1995). In both of these similar approaches, the technology is classified in terms of how it has changed relative to technologies previously sourced, developed, or manufactured by an organization. There is a much larger body of literature that examines in more general terms the concept of technological change. Most of this literature characterizes technologies in terms of incremental or radical change (Dewar and Dutton 1986; Ettlie et al. 1984; Henderson and Clark 1990; Nagarajan and Mitchell 1998), while some of it addresses discontinuous (otherwise known as disruptive, destructive, or revolutionary) change (Iansiti 1995; Kuhn 1962; Schumpeter 1942; Tushman and Anderson 1986).

Many intermediate forms exist between the extreme incremental and radical categories of technological change and commonly occur in practice. For example, in the product development context, Wheelwright and Clark (1992) present four categories of change ranging from "incremental change" to "new core technology." They collapse overall product and process technology change into three classifications: derivative, platform, and breakthrough changes. Others provide related classifications (Henderson and Clark 1990; Menor et al. 2002; Meyer and Roberts 1986; Tatikonda 1999). Griffin (1997) measures the percentage of change in the new product relative to its predecessor product, terming this percentage the level of "product newness" (what has been defined here as technological change). Those who study single industry contexts quite specifically address, for example, variations in product technology newness (Barnett and Clark 1996; Firth and Narayanan 1996; Meyer and Roberts 1986; Meyer and Utterback 1995) or software technology newness (Brooks 1987; Deutsch 1991).

Complexity

Technology complexity has three core elements: (1) level of internal technological interdependence; (2) level of external technological interdependence; and (3) the scope of the technology.

The interdependence of a technology manifests itself in two ways: interactions among elements within the technology system (internal interdependence) and interactions between the technology system and its

[8] The technology newness and technological change literatures overlap considerably, with most articles not making clear conceptual distinctions between technology newness and technological change. In addition, these literatures do not adopt a consistent unit of analysis. The technological change literature tends toward a societal or corporate unit of observation, while the technology newness literature generally considers a more operational level.

surrounding, operating environment (external interdependence). One characterization of internal interdependence would be the extent to which the technology is "systemic, [has] multiple interactions, and [is] nondecomposable" (Singh 1997, p. 340). "Systemic" means that the technology is composed of a set of components or elements, often organized into hierarchical subsystems. "Multiple interactions" means that there are many relationships and interactions between components, both at the same hierarchical level or subsystem and across levels and subsystems. "Nondecomposable" means the technology cannot be separated into its components without significantly decreasing its capabilities or performance. The systemic notion has been studied by researchers who define different product and system architectures (Smith and Reinertsen 1998; Ulrich 1995); modular (localized) versus architectural (systemic) technological changes and impacts (Henderson and Clark 1990; Sanchez 1996); interdependencies among technical components (Eppinger 1991; Krishnan 1996; Tatikonda and Rosenthal 2000); and interactions between elements within a technological system (Perrow 1994).

External interdependence addresses the degree to which the technology of interest must conform to an existing interface or process or must be adapted to fit the needs of a particular extant system (Rosenthal and Salzman 1990; Tatikonda and Lorence 2002). Examples include situations where the technology of interest is intended to become part of a physical product system, or an existing hardware or software system. External interdependence aspects have been captured by the terms "conformity" (Brooks 1987) and "interface adversity" (Deutsch 1991) to describe the number of interfaces (external constraints) to which the technology must conform to and operate in conjunction with. Tushman and Rosenkopf (1992) link the notions of internal and external interdependency through a hierarchical conceptualization of technological complexity that considers interactions between components within individual products or systems as well as interactions between these individual systems.

Technology scope (also called size or scale) captures the relative or absolute quantity of internal elements of the given technology. Clark and Fujimoto (1991) define the "complexity of internal product structure," which essentially measures the technology development project's size in terms of number of people working on and functional areas represented in the development effort. Griffin's (1997) definition of complexity is the number of technical functions embodied in a product technology. Meyer and Utterback (1995) use the phrase "technology integration" to capture the number of component technologies in an overall technology. Clark (1989) takes a slightly different perspective, describing "project scope" as the percentage of development effort conducted in-house (by the recipient) versus by suppliers (the technology source). This can be construed in the product technology transfer context to mean the degree to which the recipient organization must conduct additional refinement or adaptation of the technology. Shenhar (1998) describes "system scope" as an important descriptor of different technology situations, where scope varies in terms of the number of elements within the technology of interest and the geographical/physical dispersion of these elements. The system scope of a technology ranges from low (e.g., a lithium battery) to moderate (e.g., a new manufacturing plant) to high (e.g., a mass transportation system). Literature on software technology also characterizes complexity aspects. Brooks (1987) explains that complexity includes the total number of elements in the technology and the number of unique elements in the technology. Deutsch (1991) describes software project size as an element of "project adversity", and Meyer and Curley (1991) refer to "technological complexity" as the depth and scope of the technical activities required in developing an information system.

Tacitness

Technology tacitness captures the degree to which the technology is (1) physically embodied; (2) codified (textually or graphically); and (3) complete (the degree to which the technology can be defined in its final form).

Tacit knowledge (Polyani 1967) is "non-codified, disembodied know-how" (Howells 1996, p. 92). Madhavan and Grover (1998) describe it as "knowledge that cannot be explicated fully even by an expert" (p. 1). In this case, the technical knowledge is simply in someone's head. A very tacit technology lacks physical embodiment and has not been codified (that is, it has not been reduced to paper in the form of textual or graphical representation such as blueprints, procedures, algorithms, etc.). Tacit knowledge is difficult and time consuming to learn. von Hippel

(1994) refers to such technologies as being "sticky," since the knowledge is particularly difficult to transfer. Technology that has a greater level of tacit knowledge is more difficult to transfer (Madhavan and Grover 1998), and the tacitness of technical knowledge has emerged as a key variable in recent research in technology transfer (Kogut and Zander 1993; Lam 1997; Tsang 1997) and other technology management fields (Dutta and Weiss 1997; Lei 1997).

In describing software technology, Brooks (1987) refers to its "invisibility characteristic", describing the technology as being "unvisualizable," "not inherently embedded in space," and having "no ready geometric representation." Other software technology development researchers (McKeen et al. 1994; Naumann et al. 1980; Tait and Vessey 1988) refer to the degree of "structuredness" of the software technology, or the lack of structure to represent the parts in the software system. These elements evoke tacitness aspects such as the lack of codification, physicality, and representation of the technology.

Another aspect of tacitness is the degree to which the technology development has been completed by the source organization. An incomplete technology is one that still actively is under development by the source organization, or one that has not and will not reach development completion by the source organization (for any variety of reasons). The degree of completion of the technology is reflected in its degree of physicality, codification, and repeatability/predictability of its technical functionality and outputs. Hence, this is referred to as the stability, predictability, or maturity of the technology (Ulrich and Ellison 1998). A completed technology could be described as well defined, highly structured, having high representedness, or as being a finished or static technology. An incomplete technology could be described as poorly defined or undefined; loosely structured if structured at all; lacking in representation (physical embodiment or codification); or as being an unfinished or dynamic technology. For example, a technology that is designed by the source for off-the-shelf use by the recipient is quite complete, while a technology that is designed by the source for highly customized application at the recipient location is more incomplete.

When the knowledge embodied in the technology is quite explicit, there is typically a lower level of technology uncertainty, and movement and eventual incorporation of that technology would be simpler. In particular the movement aspect of the transfer is highlighted. When the technology embodies a great degree of tacit knowledge, it may be difficult for the recipient to be sure that all of the technology's embodied knowledge has been acquired.

Characterizing Interorganizational Interaction

This section addresses interorganizational interaction, the second variable in the core model. Interorganizational interaction captures the nature of the relationship between the source and recipient during the technology transfer. Greater interorganizational interaction provides more information processing capability, which in turn reduces technology uncertainty. The previous section provided a framework of contributors to technology uncertainty. Per the core proposition, given knowledge of the technology uncertainty level posed by a given product technology, choices then can be made regarding what level of interorganizational interaction to employ in order to achieve successful technology transfer.

Dimensions and Endpoints of Interorganizational Interaction

Many factors contribute to interorganizational interaction. These factors are synthesized into three dimensions of interorganizational interaction: communication, coordination, and cooperation between the two organizations. These dimensions parallel the three essential "components of the relationship" identified by Walton (1966): (1) exchange of information in the joint decision process; (2) structure of interunit interactions and decision making; and (3) attitudes toward the other unit. The dimensions are conceptually different; nonetheless, in practice they can overlap somewhat. Higher levels of each dimension increase information processing capability.

The different levels of interorganizational interaction possible in practice constitute a continuous spectrum from very low to very high. For the theoretical development of the core model, it is important to view interorganizational interaction as a continuous range of relationship forms. However, for practical understanding, it may be helpful to recognize that the lowest endpoint on the spectrum is some form of an arm's-length market purchase transaction. For example, a recipient firm travels to a Radio Shack to purchase a standard AA battery for a consumer electronics application under development. Here, the degrees of communication, coordination, and cooperation in this interorganizational relationship are low.

In contrast, the highest endpoint on the interorganizational interaction spectrum is some form of co-development. For example, consider a case where the recipient and source firms work hand in hand, on site, or at least highly virtually colocated, over some nontrivial period of time, to develop a new electronic battery for a unique consumer electronics application (a robotic dog pet). In this co-development case, the degrees of communication, coordination, and cooperation between recipient and source firms are so high that it may even be difficult to distinguish between the firms—the high integration results in a single, highly fused, temporary organization (Stock and Tatikonda 2000). In these examples, the degrees of communication, coordination, and cooperation to apply are managerial decision variables, and the configuration of these three dimensions leads to the relative location on the interorganizational interaction spectrum.

Communication

Communication is the exchange of information (Rogers 1995). Important elements of communication in the technology transfer context are: (1) communication methods; (2) communication magnitude and frequency; and (3) the nature of the information that is exchanged. In all, higher levels of communication are reflected by communication that is more interpersonal, has greater magnitude and frequency, and transmits information that is richer and more complex.

Communication methods describe how the information is exchanged, that is, the media used, such as face-to-face communication, written mail, telephone, facsimile, or electronic methods such as videoconferencing and email (Cutler 1989; De Meyer 1991; Stock et al. 1996). These methods also can be categorized as synchronous (e.g., phone or face-to-face communication) or asynchronous (e.g., mail) (Gibson and Smilor 1991). The method of communication also considers the characteristics of the individuals who are communicating, particularly when the information to be exchanged is technical in nature. In this respect, technical gatekeepers or liaisons who actively manage the communication aspect of the transfer are especially important (De Meyer 1991; Irwin and More 1991).

Communication magnitude and frequency refers to how much and how often information is exchanged between the source and recipient organization. This ranges from sporadic and limited to frequent and dense information exchange. Frequent and dense exchange of information provides greater information processing capacity and is more likely to be effective for transfer of uncertain technologies (Ghoshal and Bartlett 1988; Rebentisch and Ferretti 1995).

The information that is exchanged may be highly technical and may relate specifically to the technology to be transferred, or it may be less technical and may relate more to the coordination aspects of the transfer itself. Information to be exchanged also may be described as routine or nonroutine (Rebentisch and Ferretti 1995) or as important or unimportant (Gray 1989). And the nature of the information may range from poorly codified, poorly structured, and highly tacit in nature to very specific, detailed, organized, and unambiguous (Schrader 1991; von Hippel 1987).

These three factors are related and tend to be found in similar combinations. The method of communication to a great extent determines the magnitude and frequency of information that is exchanged, as well as the nature of the information that can be exchanged. For example, person-to-person communication allows information that is richer and more tacit in nature to be transmitted more effectively than communication through written mail. Moreover, certain methods of communication provide the ability to transmit information more frequently than other methods. For example, email or physical colocation allows for information to be exchanged almost continuously if desired. Similarly, the requirement to communicate a particular type of information would necessitate the use of certain methods to result in effective communication (Gibson and Smilor 1991; Rebentisch and Ferretti 1995).

Coordination

Coordination represents the nature of the planned structure and process of the interactions and decision-making between source and recipient (Parkhe 1991). Important elements of coordination include (1) substantiveness of administrative planning; (2) level of formality in the organizational process of technology transfer; and (3) the length of time horizon of the relationship.

Administrative planning captures the degree to which the source and recipient have worked together in planning their joint work activities. This includes dual schedule development and planned sharing of resources (Bailetti and Callahan 1993). Administrative planning captures the degree of both executive-level and personnel-level planning and interactions.

The formality of the interorganizational relationship is represented by the degree to which the steps and stages in the technology transfer are preplanned, are structured, and are rigid (Van de Ven and Ferry 1980). Such formality sometimes is specified clearly in contracts or is specified less clearly but generally still is understood by the two parties. The contracts or preplans might specify joint planning and execution meetings, joint development of schedules, formal progress reviews, constraints (sanctions) on interactions between personnel from the two units, and centralized communication flows and hierarchical organizational structure in the management of the transfer project. Or the contracts or preplans may allow (if not clearly stated, then possibly by default) that the planning and day-to-day interactions can be quite informal, autonomous, and decentralized. Some level of formality is thought to be effective for many organizational processes since it provides structure and specified steps (Clark and Fujimoto 1991; Cooper 1983). Still, excessive formality can be highly constraining (Eisenhardt and Tabrizi 1995; Rosenthal 1992), which in turn diminishes the quantity and quality of information processing.

The expectation of a longer time horizon of the relationship between source and recipient leads to greater interorganizational interaction in general and to greater coordination in particular. An emphasis on interaction solely in the early stages of the transfer process relationship suggests less interactivity, while emphasis on interactions both in early and late stages of the transfer process relationship shows a higher degree of organizational interaction (Adler 1995; Rogers 1995).

Cooperation

Cooperation between organizations is "the willingness of a partner firm to pursue mutually compatible interests … rather than to act opportunistically" (Das and Teng 1998, p. 492). Several key elements underlie interorganizational cooperation: (1) trust; (2) goal congruence; and (3) level of commitment.

Trust is described as an expectation that one party will perform an action that is desirable to the other party, particularly in a situation that involves some element of risk. Trust is important because it can reduce transaction costs and tentativeness in interorganizational relationships, which therefore increases the likelihood of cooperation (Das and Teng 1998). The willingness to share information is also an aspect of cooperation and trust between firms (Heide and Miner 1992; Schrader 1991; Wong 1999), and trust has been found to enhance the process of technology transfer (Bidault and Fischer 1994; Hagedoorn 1990).

Goal congruence (Spinelli and Birley 1998; Turner et al. 1994) is the extent to which the objectives of the two organizations are compatible. Sometimes objectives may be the same or similar (Geisler 1997; McDaniel et al. 1992) or may be complementary (Hagedoorn 1990). Whether the goals of the two organizations are similar or different, what is important to the level of cooperation is that the attainment of one organization's goals does not interfere with the attainment of the other organization's goals (Wong 1999).

Level of commitment between organizations includes the belief in and acceptance of organizational goals, the willingness to work toward those goals, and belief in the importance of the relationship to the extent that the necessary effort is justified to maintain the relationship (Johnson 1999). Greater levels of commitment have been shown to result in more effective interorganizational relationships in general (Holm et al. 1996; Moore 1998), and empirical studies have shown that greater commitment relates to more effective transfer in particular (Feller et al. 1987; Geisler 1997). Higher levels of commitment indicate higher levels of cooperation.

Characterizing Transfer Effectiveness

This section addresses the third variable in the core model. The notion of technology transfer effectiveness is complex. It poses both definitional and assessment difficulties. Consistent approaches to measuring effectiveness are not in use, and different perspectives of effectiveness arise given the technology-source or technology-recipient, the time frame for assessment evaluation, and the unit of observation (Bozeman 1991; Spann et al. 1995). In the product technology transfer context, effectiveness should be assessed as a function of the firm's objectives for that specific transfer. Certainly different product technology transfers necessarily have different objectives and differential emphasis on the objectives (MacDonald 1993); therefore, each transfer project has a unique set of importance weights on the different transfer objectives.[9]

The degree to which the transferred product technology fulfills the firm's objectives regarding that technology directly indicates the degree of effectiveness. The most fundamental objective is successful incorporation of that product technology. The product technology must work as anticipated in the new product system. This indicates achievement of the functional performance intent. In addition, the firm desires achievement of functional performance within reasonable time duration and cost expenditures. Functionality, time, and cost represent the core project-level operational objectives (Meredith and Mantel 1995) for a product technology transfer project. They also represent performance metrics that can be assessed at the end of the transfer project; hence, they are operational outcomes.

The firm may have intentions beyond the one-time integration of the technology into a new product system, suggesting a longer-term perspective. Such intentions include developing and obtaining greater internal human resources capabilities (e.g., improved design engineering ability with respect to that product technology); more skill and experience in interorganizational interaction; greater dyadic experience with a given technology source firm; or greater product technology transfer experience in general (Lei 1997; Lynskey 1999). These represent competencies gained and so are competence-building outcomes. The competence-building outcomes can be categorized as relating to the technology itself, to intraorganizational skills, or to interorganizational skills. Such outcomes may reduce technology uncertainty in future applications; may facilitate the modification, enhancement, and utilization of the given product technology in a wider array of applications; may increase the general ability of the firm to conduct future transfer processes; may increase the firm's ability to conduct various dyadic activities; and increase overall new product marketing and competitive opportunities (Reddy and Zhao 1990; Wheelwright and Clark 1992).

It is important to note that product technology transfer effectiveness is not the same as new product development success. A given product technology transfer is simply one project within the meta-project that is a new product development effort. As noted in the discussion of links and hubs in the technology supply chain, there can be multiple product technology transfers in a single development project, where each transfer results in different success outcomes. Accordingly, a single product technology transfer is one of many activities, processes, and factors that influence overall product development success (typically measured by market and financial outcomes; see Montoya-Weiss and Calantone 1994; Tatikonda and Montoya-Weiss 2001). The authors here believe that effective product technology transfer is an important determinant of product development success in dynamic markets; however, new product development is a complex business process, and there certainly are additional important influences on success.[10]

Implications

Earlier product technology transfer was identified as the essential, elemental link in the technology supply chain. Considerable depth also was provided on the three variables of the core model of product technology transfer effectiveness. Effective management of the technology supply chain starts first with effective management of individual dyadic links in the chain, that is, individual product technology transfer projects. And effective management of individual links and more complex webs of links (e.g., see Figure 2) lead to greater overall product development success.

This section develops a set of propositions (summarized graphically in Figures 6 and 7) that follow from the core model. Then a discussion follows of how the propositions may guide practice and future research, particularly with respect to new

[9] As part of the technology selection process (which occurred before commencement of the technology integration phase), the firm decided upon the levels or targets of the operational and competence-building objectives for that specific product technology transfer. At this time the firm determined the relative importance of operational versus competence-building objectives and also decided its differential emphasis on the specific operational objectives—that is, the relative importance of functionality, time, and cost. For example, some projects may emphasize speed, others functional capability, and others a more balanced approach. We also note that the formality with which objective setting is done in practice varies considerably across cases.

[10] These include appropriate choice of the target market (Urban and Hauser 1993), wise selection of product specifications (Smith and Reinertsen 1998), and sufficient marketing promotion (Crawford and Di Benedetto 1999).

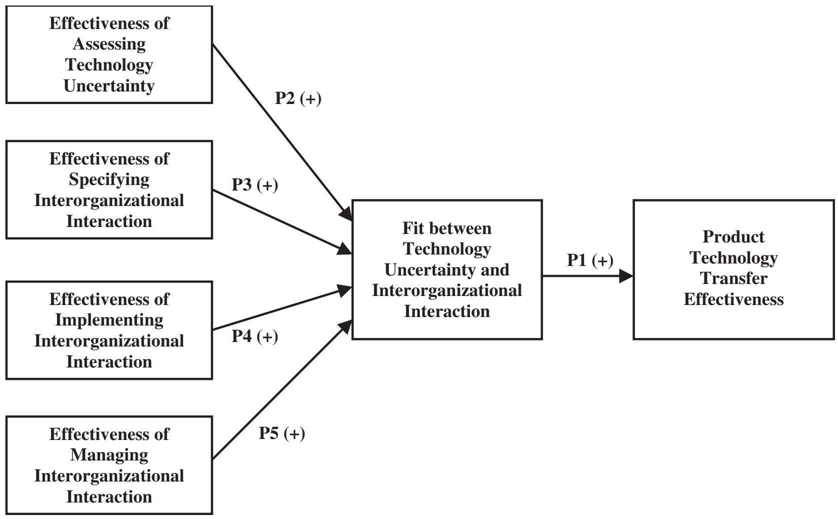

Figure 6. Graphic Summary of Proposed Relationships in Product Technology Transfer

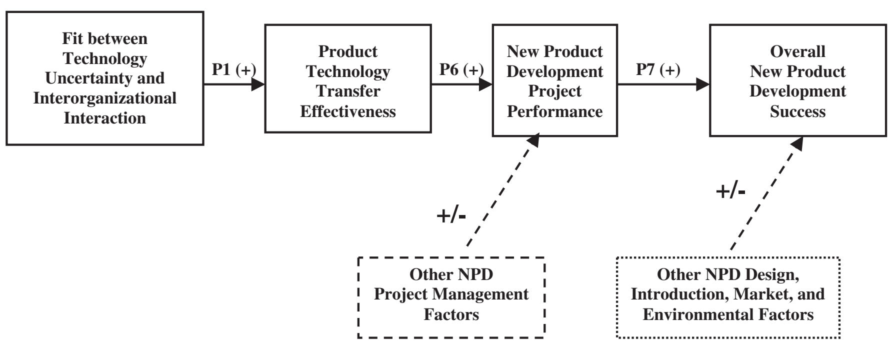

Figure 7. Graphic Summary of Proposed Relationships in Product Technology Transfer

product development and the technology supply chain.

Propositions

The core proposition of the product technology transfer model relates transfer effectiveness to the fit between technology uncertainty and interorganizational interaction. This proposition, restated here, provides the underlying logic of the model:

P1: Higher levels of fit between technology uncertainty and interorganizational interaction will result in higher levels of product technology transfer effectiveness.

Turning now to additional propositions that follow from the core proposition, the recipient firm must match the level of interorganizational interaction (to be conducted with the source firm) to the level of technology uncertainty in order to achieve the necessary fit. To achieve proper fit, it first is necessary for the recipient firm to assess accurately the level of uncertainty associated with the technology. Therefore,

P2: More accurate assessment of technology uncertainty will result in higher levels of fit between technology uncertainty and interorganizational interaction, ceteris paribus.

Having accurately assessed the technology uncertainty, the recipient firm then must define the structure of the relationship with the source firm. This structure represents the level of interorganizational interaction between the recipient and source. To achieve the appropriate fit, the recipient therefore must specify the proper level of interorganizational interaction given the level of technology uncertainty. Therefore,

J PROD INNOV MANAG 461
2003;20:444–467

P3: More effective specification of interorganizational interaction will result in higher levels of fit between technology uncertainty and interorganizational interaction, ceteris paribus.

After specifying the design of the structure of the relationship between recipient and source, it then is necessary that this specified level of interorganizational interaction be implemented. The recipient firm must identify and must put into use the organizational mechanisms necessary to provide the appropriate levels of communication, coordination, and cooperation between the recipient and source that will result in a good fit between technology uncertainty and interorganizational interaction. Therefore,

P4: More effective implementation of interorganizational interaction will result in higher levels of fit between technology uncertainty and interorganizational interaction, ceteris paribus.

In addition to the specification and implementation of the structure of the interorganizational relationship between the source and recipient, the recipient firm must manage the interorganizational interaction during the product technology transfer project so that the specified level is maintained properly over the course of the transfer project. This in turn will result in greater realized fit between technology uncertainty and interorganizational interaction. Therefore,

P5: More effective management of interorganizational interaction over the course of the transfer project will result in higher levels of fit between technology uncertainty and interorganizational interaction, ceteris paribus.

Fit and product technology transfer effectiveness are not ends in themselves. Inherent in the framework here is the goal of improving the outcomes of new product development in a firm. Earlier it was explained that a product technology transfer instance is simply a single project within the larger meta-project that is the overall product development project. Also, product technology transfer operational effectiveness was characterized as the extent to which the transfer project achieves its objectives along three dimensions: timeliness, cost, and functional performance of the technology in its intended application. Achieving these objectives also should lead to better performance of the overall new product development project along the dimensions of timeliness, cost, and product quality. Therefore,

P6: Higher levels of product technology transfer effectiveness will result in higher levels of new product development project effectiveness, ceteris paribus.

There can be many distinct product technology transfer projects in one overall new product development project. Each technology transfer may involve a technology that is quite different from the other technologies in terms of its technology uncertainty level. The recipient firm then must apply a different level of interorganizational interaction to each transfer project in order to obtain the best fit for each transfer project. Companies therefore must develop and must maintain skills in managing multiple levels of interorganizational interaction. Those firms better able to manage multiple levels likely will achieve more consistent and high levels of transfer effectiveness across transfer projects and in turn will enjoy higher levels of overall new product development success. Therefore,

P7: The ability to manage a wide range of interorganizational interaction levels effectively will result in higher overall new product development success ceteris paribus.

Recommendations for Managing Product Technology Transfer in New Product Development

The aforementioned propositions provide a set of explicit recommendations for managing product technology transfer during new product development. In general, managing product technology transfer begins with an understanding of the underlying logic between the relationship of transfer effectiveness and the fit between technology uncertainty and interorganizational interaction (P1). The product technology transfer process starts with an accurate assessment of the uncertainty of the technology (P2), followed by the specification of the appropriate level of interorganizational interaction between the source and the recipient (P3). Managers then must translate this specification of interorganizational interaction into a set of organizational mechanisms that will provide the specified levels of communication, coordination, and cooperation with the source (P4).

During the transfer project, the process must be managed continually to maintain the level of interorganizational interaction appropriate for the technology that is being transferred (P5). To this end, the detailed description of the constituent elements comprising technology uncertainty, interorganizational interaction, and transfer effectiveness in turn should enable the development of detailed measures that can be used to control the project at the process level. For example, it should be possible to construct measures of communication or coordination between the source and recipient as well as to determine appropriate target values for those measures. Periodic assessment of the performance on those dimensions and comparison to the targets should enable better process management and control of the transfer project. Better product technology transfer performance should lead to better new product development project performance (P6). The ability to manage multiple levels of interorganizational interaction, and in turn a portfolio of product technology transfer projects, also should lead to better overall new product development success (P7).

Developing Transfer Competencies

A firm should develop specific organizational competencies that will allow it to conduct product technology transfer effectively across a wide range of technologies. First, effective assessment of technology uncertainty is an especially important (but admittedly difficult) competence to develop. The technology uncertainty characterization scheme provided decomposes uncertainty into more accessible pieces.[11]

Second, given that the recipient organization identifies the appropriate level of interorganizational interaction necessary for a given transfer, then the company actually must execute that interorganizational interaction in a high quality manner. Not all companies are capable of executing the more challenging high levels of interorganizational interaction that clearly require greater and more complex skills. If the recipient organization anticipates the need to employ different interorganizational interaction levels for different transfers, then the firm must develop interorganizational interaction competencies at each level. For firms in dynamic markets, the ability to manage such interorganizational processes is a distinctive competitive competence (Fine 1998).

Awareness that skills in product technology transfer are indeed valuable organizational competencies puts the onus on managers to structure purposeful processes to capture learnings from and about product technology transfer projects (e.g., via post-project audits). Making these learnings available via accessible knowledge management frameworks allows diffusion of transfer knowledge, supports continuous improvement of the transfer process, and deepens the firm's competencies in product technology transfer.

Sustained Technology Supply Chain and Product Development Success

Long-term technology supply chain and new product development success is dependent on a firm initially mastering the management of an individual link in the chain: the individual product technology transfer project. First, if a firm can understand and can manage a single link well, then they can repeat this capability over many transfer instances over time. This has long-term implications for the routine use of advanced technologies in the firm's products. Second, if a firm can manage single links well, then it will be prepared to take on and to manage more complex and extended technology supply chains. Third, if a firm's organizational competencies allow that firm to manage technology transfer relationships effectively over a wide range of interorganizational interaction levels, then that firm has the flexibility to employ a wide range of technologies. Similarly, if a firm is not able to implement and to manage high levels of interorganizational interaction, then the firm would need to avoid using high-uncertainty technologies in its products (or else develop the required interorganizational interaction capabilities). There are potential benefits from choosing to transfer the types of technologies that are most compatible with the interorganizational interaction skills present, easily attained, or competitively advantageous. In all, from the firm's point of view, the technology supply chain functions well when product technologies from outside the firm are incorporated routinely and cost effectively into a firm's portfolio of new products.

Technology versus Component Supply Chains

The two types of upstream supply chains, the technology supply chain and component supply

[11] Tools that help in assessing various dimensions of technology uncertainty include Bohn's (1994) work on levels of process knowledge, which can aid in evaluating product technology novelty. Measurement frameworks in the software development/information technology arena may help in assessing some aspects of technology complexity (Matson et al. 1994). An approach to measuring tacitness in the context of technology transfer can be found in Kogut and Zander (1993).

chain, now are revisited to discuss whether one type can inform the other and whether competencies can be shared across both types. It was noted earlier that the nature of incoming technology in the early design and prototype phases of a product development effort is quite different from the nature of incoming materials during manufacturing rampup and full-scale production.

For companies whose new product development efforts include new technology development and integration, effective product technology transfer processes in the technology supply chain well may be a temporal precursor to component supply chain activity. When the technology that is transferred is incorporated successfully into the new product system, then the essential management characteristics and objectives shift from managing the technology supply chain to managing the component supply chain (see also Figure 1). The "technology" changes to a "material" or "component". The transferred entity is now significantly more proven, stable, and generally fully prespecified (so its technology uncertainty is quite low), and large volumes now are sourced with relatively regular, continuous flows with strong material cost-control imperatives (rather than with episodic, single-unit flows with strong functional imperatives). Successful management of the technology supply chain in product development in turn allows quicker transition to component supply chain processes and more routine, trouble-free application of component supply chain processes. In this sense, effective management of the technology supply chain enables a more effective component supply chain and faster transition to downstream phases in a given new product development project. This in turn helps achieve faster, lower cost product development efforts with greater marketplace potential.

In reverse, can effective management of the component supply chain inform the management of the technology supply chain? Perhaps the component supply chain's structured routines for vendor selection, certification, quality assurance, and dyadic communication can be modified and can be adapted, at least in part, to the technology supply chain. This would help bring more repeatability and manageability to the otherwise often ad-hoc process of product technology transfer. Still, it is noted that the technology supply chain and component supply chain have quite different characteristics and management objectives (particularly with respect to the level of technology uncertainty), so component supply chain routines cannot and should not be imported without substantial modification to the technology supply chain context.

Directions for Future Research

The core model and propositions presented above outline a set of relationships which merit empirical test and confirmation. In-depth conceptual development of the three central constructs, technology uncertainty, interorganizational interaction, and product technology transfer effectiveness, of the core model was provided. This level of conceptual detail should aid in development of sound, theoretically grounded measures of these constructs, in turn enhancing the reliability and validity of future empirical tests. Tests of this model are encouraged through a variety of methodologies ranging from qualitative case studies of a few firms to large-sample survey studies.

Future research should develop and should test practical tools to reliably and holistically assess technology uncertainty. Future research also should explore detailed processes for execution of interorganizational interdependence. For example, to what degree could "phase-gate" and related approaches currently applied to new product development process management be modified and applied to product technology transfer processes? Currently phase-gate processes generally focus on management internal to the firm, while technology transfer permeates company boundaries. Future research also should guide theory and practice regarding effective organizational learning and knowledge management processes for product technology transfer to improve development of transfer competencies and to improve transfer effectiveness.

Product technology transfer is a complex process that lends itself to consideration via a variety of theoretical perspectives. Future research could apply transaction cost theory, the resource-based view of the firm, theories of organizational learning and knowledge management, or social network theory to provide insights that complement those derived from information processing theory in the core model. The complexity of the product technology transfer process also calls for consideration of additional variables (beyond the scope of this article) that may influence transfer success. These include factors antecedent to the given technology transfer instance (e.g., the nature of the source-recipient history prior to the transfer) and contextual factors (e.g., the quantity and quality of organizational resources applied to the transfer by the recipient firm). Figure 7 also shows the presence of other factors that may affect the success of the overall new product development process positively or negatively. These factors, which are examined extensively in the new product development literature, also are beyond the scope of this article.[12]

Finally, future research should investigate and should elaborate on the core model within the context of an extended technology supply chain (see Figure 2). Product technology transfer was conceptualized as the key transformational activity in the technology supply chain—the essential, elemental link in the technology supply chain. Future research should move beyond the single instance dyadic case to consider series of links in the chain, multiple incoming technologies at a hub, and multiparty transfers (three or more organizations involved in a single transfer).

Conclusions

This article describes product technology transfer as a key activity in the complex process of new product development. This article also explored the concept of the technology supply chain and explained that the individual product technology transfer project is the essential, elemental link in the technology supply chain. Product technology transfer is an activity too often dealt with in an ad-hoc fashion. Purposeful, structured management of the product technology transfer process should lead to more effective transfers and in turn to sustained product development success.

This article described the technology supply chain as a unique form of a supply chain that poses a set of managerial challenges and requirements that distinguish it from the more traditional component supply chain. This article integrates literatures on new product development, supply chain management, and technology management, along with organizational theory, to present a model of determinants of product technology transfer success. This model emphasizes the need for fit between the technology uncertainty of the technology to be transferred and the interorganizational interaction between technology source and recipient firms. A quite detailed technology uncertainty framework was presented to aid researchers and practitioners in conceptualizing the challenges associated with transferring a particular product technology. The model helps firms consider appropriate means to facilitate the interfirm process of technology transfer. This article also presents propositions drawn from the model to guide future research and practice in the management of product technology transfer in the technology supply chain.

[12] For example, see Krishnan and Ulrich (2001) and Brown and Eisenhardt (1995) for reviews of the broader product development literature.

References

Abernathy, W.J. and Clark, K.B. (1985). Innovation: Mapping the Winds of Creative Destruction. *Research Policy* 14(1):3–22.

Adler, P.S. (1992). Strategic Management of Technical Functions. *Sloan Management Review* 33(2):19–37.

Adler, P.S. (1995). Interdepartmental Interdependence and Coordination: The Case of the Design/Manufacturing Interface. *Organization Science* 6(2):147–167.

Bailetti, A.J. and Callahan, J.R. (1993). The Coordination Structure of International Collaborative Technology Arrangements. *R&D Management* 23(2):129–146.

Barnett, B.D. and Clark, K.B. (1996). Technological Newness: An Empirical Study in the Process Industries. *Journal of Engineering and Technology Management* 13(3–4):263–282.

Bidault, F. and Fischer, W.A. (1994). Technology Transactions: Networks over Markets. *R&D Management* 24(4):373–386.

Bohn, R.E. (1994). Measuring and Managing Technological Knowledge. *Sloan Management Review* 36(1):61–73.

Bozeman, B. (2000). Technology Transfer and Public Policy: A Review of Research and Theory. *Research Policy* 29(4–5): 627–655.

Bozeman, B. (1991). Evaluating Technology Transfer Success. *Technology Transfer Society Proceedings*. Chapman and Sharp (eds.), June 9–11, Denver, June 9–11.

Brooks, Jr., F.P. (1987). No Silver Bullet: Essence and Accidents of Software Engineering. *IEEE Computer* 20(4):10–19 (April).

Brown, S.L. and Eisenhardt, K.M. (1995). Product Development: Past Research, Present Findings, and Future Directions. *Academy of Management Review* 20(2):343–378.

Clark, K.B. (1989). Project Scope and Project Performance: The Effect of Parts Strategy and Supplier Involvement on Product Development. *Management Science* 35(10):1247–1263.

Clark, K.B. and Fujimoto, T. (1991). *Product Development Performance*. Boston, MA: Harvard Business School Press.

Cohen, W.M. and Levinthal, D.A. (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly* 35(1):128–152.

Cooper, R.G. (1983). A Process Model for Industrial New Product Development. *IEEE Transactions on Engineering Management* 30(1):2–11.

Crawford, C.M. and Di Benedetto, C.A. (1999). *New Products Management*. New York: Irwin/McGraw-Hill.

Cusumano, M.A. and Elenkov, D. (1994). Linking International Technology Transfer with Strategy and Management: A Literature Commentary. *Research Policy* 23(2):195–215.

Cutler, R.S. (1989). A Comparison of Japanese and U.S. High-Technology Transfer Practices. *IEEE Transactions on Engineering Management* 36(1):17–24.

Daft, R.L. (1986). *Organization Theory and Design*. St. Paul, MN: West Publishing.

Daft, R.L. and Lengel, R.H. (1986). Organizational Information Requirements, Media Richness, and Structural Design. *Management Science* 32(5):554–571.

Das, T.K. and Teng, B. (1998). Between Trust and Control: Developing Confidence in Partner Cooperation in Alliances. *Academy of Management Review* 23(3):491–512.

De Meyer, A. (1991). Tech Talk: How Managers Are Stimulating Global R&D Communication. *Sloan Management Review* 32(3):49–58.

Deck, M. and Strom, M. (2002). Model of Co-development Emerges. *Research Technology Management* 43(3):47–53.

Deutsch, M.S. (1991). An Exploratory Analysis Relating the Software Project Management Process to Project Success. *IEEE Transactions on Engineering Management* 38(4):365–375.

Dewar, R.D. and Dutton, J.E. (1986). The Adoption of Radical and Incremental Innovations: An Empirical Analysis. *Management Science* 32(11):1422–1433.

Dutta, S. and Weiss, A.M. (1997). The Relationship between a Firm's Level of Technological Innovativeness and Its Pattern of Partnership Agreements. *Management Science* 43(3):343–356.

Eisenhardt, K.M. and Tabrizi, B.N. (1995). Accelerating Adaptive Processes: Product Innovation in the Global Computer Industry. *Administrative Science Quarterly* 40(1):84–110.

Eppinger, S.D. (1991). Model-Based Approaches to Managing Concurrent Engineering. *Journal of Engineering Design* 2(4): 283–290.

Ettlie, J.E., Bridges, W.P. and St.O'Keefe, R.D. (1984). Organization Strategy and Structural Differences for Radical versus Incremental Innovation. *Management Science* 30(6):682–695.

Ettlie, J.E. and Reza, E.M. (1992). Organizational Interaction and Process Innovation. *Academy of Management Journal* 35(4): 795–827.

Feller, I., Madden, P., Kaltreider, L., Moore, D. and Sims, L. (1987). The New Agricultural Research and Technology Transfer Policy Agenda. *Research Policy* 16(6):315–325.

Fine, C.H. (1998). *Clockspeed: Winning Industry Control in the Age of Temporary Advantage*. Reading, MA: Perseus Books.

Firth, R.W. and Narayanan, V.K. (1996). New Product Strategies of Large, Dominant Product Manufacturing Firms: An Exploratory Analysis. *Journal of Product Innovation Management* 13(4): 334–347.

Galbraith, J. (1977). *Organization Design*. Reading, MA: Addison-Wesley.

Geisler, E. (1997). Intersector Technology Cooperation: Hard Myths, Soft Facts. *Technovation* 17(6):309–320.

Ghoshal, S. and Bartlett, C.A. (1988). Creation, Adoption, and Diffusion of Innovations by Subsidiaries of Multinational Corporations. *Journal of International Business Studies* 19(3): 365–388.

Gibson, D.V. and Smilor, R.W. (1991). Key Variables in Technology Transfer: A Field Study-Based Empirical Analysis. *Journal of Engineering and Technology Management* 8(3–4):287–312.

Glass, A.J. and Saggi, K. (1998). International Technology Transfer and the Technology Gap. *Journal of Development Economics* 55(2):369–398.

Gray, B. (1989). *Collaborating: Finding Common Ground for Multiparty Problems*. San Francisco, CA: Jossey-Bass.

Green, S.G., Gavin, M.B. and Aiman-Smyth, L. (1995). Assessing a Multidimensional Measure of Radical Technological Innovation. *IEEE Transactions on Engineering Management* 42(3):203–214.

Griffin, A. (1997). The Effect of Project and Process Characteristics on Product Development Cycle Time. *Journal of Marketing Research* 34:24–35.

Hagedoorn, J. (1990). Organizational Modes of Inter-firm Cooperation and Technology Transfer. *Technovation* 10(1):17–30.

Handfield, R.B. and Nichols, E.L. (1999). *Introduction to Supply Chain Management*. Upper Saddle River, NJ: Prentice Hall.

Handfield, R.B., Ragatz, G.L., Petersen, K.J. and Monczka, R.M. (1999). Involving Suppliers in New Product Development. *California Management Review* 41(1):59–82.

Hartley, J.L., Meredith, J.R., McCutcheon, D. and Kamath, R. (1997). Suppliers' Contributions to New Product Development: An Exploratory Survey. *IEEE Transactions on Engineering Management* 44(3):258–267.

Heide, J.B. and Miner, A.S. (1992). The Shadow of the Future: Effects of Anticipated Interaction and Frequency of Contact on Buyer–Seller Cooperation. *Academy of Management Journal* 35(2): 265–291.

Henderson, R.M. and Clark, K.B. (1990). Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms. *Administrative Science Quarterly* 35(1):9–30.

Holm, D.B., Eriksson, K. and Johanson, J. (1996). Business Networks and Cooperation in International Business Relationships. *Journal of International Business Studies* 27(5):1033–1053.

Howells, J. 1996. Tacit knowledge, innovation, and technology transfer. *Technology Analysis & Strategic Management* 8(2): 91–106.

Iansiti, M. 1995. Technology integration: Managing technological evolution in a complex environment. *Research Policy* 24(4): 521–542.

Iansiti, M. (1998). *Technology Integration*. Boston, MA: Harvard Business School Press.

Irwin, H. and More, E. (1991). Technology Transfer and Communication: Lessons from Silicon Valley, Route 128, Carolina's Research Triangle, and Hi-Tech Texas. *Journal of Information Science* 17(5):273–280.

Johnson, J.P. (1999). Multiple Commitments and Conflicting Loyalties in International Joint Venture Management Teams. *International Journal of Organizational Analysis* 7(1):54–71.

Kamath, R.R. and Liker, J.R. (1994). A Second Look at Japanese Product Development. *Harvard Business Review* 72(6):155–170.

Kogut, B. and Zander, U. (1993). Knowledge of the Firm and the Evolutionary Theory of the Multinational Corporation. *Journal of International Business Studies* 24(4):625–645.

Krishnan, V. (1996). Managing the Simultaneous Execution of Coupled Phases in Concurrent Product Development. *IEEE Transactions on Engineering Management* 43(2):210–217.

Krishnan, V. and Ulrich, K.T. (2001). Product Development Decisions: A Review of the Literature. *Management Science* 47(1):1–21.

Kuhn, T.S. (1962). *The Structure of Scientific Revolutions*. Chicago, IL: University of Chicago Press.

Lam, A. (1997). Embedded Firms, Embedded Knowledge: Problems of Collaboration and Knowledge Transfer in Global Cooperative Ventures. *Organization Studies* 18(6):973–996.

Lei, D.T. (1997). Competence-Building, Technology Fusion, and Competitive Advantage: The Key Roles of Organizational Learning and Strategic Alliances. *International Journal of Technology Management* 14(2–3–4):208–237.

Lynskey, M.J. (1999). The Transfer of Resources and Competencies for Developing Technological Capabilities—The Case of Fujitsu-ICL. *Technology Analysis & Strategic Management* 11(3): 317–336.

MacDonald, N. (1993). Metrics May Be Hazardous to Your Health. *Newsletter of the Technology Transfer Society* 18(10):1–2.

Madhavan, R. and Grover, R. (1998). From Embedded Knowledge to Embodied Knowledge: New Product Development as Knowledge Management. *Journal of Marketing* 62(4):1–12.

Matson, J.E., Barrett, B.E. and Mellichamp, J.M. (1994). Software Development Estimation Using Function Points. *IEEE Transactions on Software Engineering* 20(4):275–287.

McDaniel, S., Ormsby, J.G. and Gresham, A.B. (1992). The Effect of JIT on Distributors. *Industrial Marketing Management* 21(2): 145–149.

McDonough, E.F. and Barczak, G. (1992). The Effects of Cognitive Problem-Solving Orientation and Technological Familiarity on Faster New Product Development. *Journal of Product Innovation Management* 9(1):44–52.

McKeen, J.D., Guimaraes, T. and Wetherbe, J.C. (1994). The Relationship between User Participation and User Satisfaction. *MIS Quarterly* 18(4):427–451.

Melnyk, S.A. and Swink, M. (2002). *Value-Driven Operations Management: An Integrated Modular Approach*. New York: McGraw-Hill Irwin.

Menor, L.J., Tatikonda, M.V. and Sampson, S.E. (2002). New Service Development: Areas for Exploitation and Exploration. *Journal of Operations Management* 20(2):135–157.

Meredith, J.R. and Mantel, S.J. (1995). *Project Management: A Managerial Approach*. New York: John Wiley & Sons.

Meyer, M.H. and Curley, K.F. (1991). An Applied Framework for Classifying the Complexity of Knowledge-Based Systems. *MIS Quarterly* 15(4):454–472.

Meyer, M.H. and Roberts, E.B. (1986). New Product Strategy in Small Technology-Based Firms: A Pilot Study. *Management Science* 32(7):806–821.

Meyer, M.H. and Utterback, J.M. (1995). Product Development Cycle Time and Commercial Success. *IEEE Transactions on Engineering Management* 42(4):297–304.

Miller, J.A. (1995). Changes Ahead—Prepare Now. *Research Technology Management* 38(5):9–10 (September–October).

Montoya-Weiss, M. and Calantone, R. (1994). Determinants of New Product Performance: A Review and Meta-Analysis. *Journal of Product Innovation Management* 11(5):397–417.

Moore, K.R. (1998). Trust and Relationship Commitment in Logistics Alliances: A Buyer Perspective. *Journal of Supply Chain Management* 34(1):24–37.

Nagarajan, A. and Mitchell, W. (1998). Evolutionary Diffusion: Internal and External Methods Used to Acquire Encompassing, Complementary, and Incremental Technological Changes in the Lithotripsy Industry. *Strategic Management Journal* 19(11): 1063–1077.

Naumann, J.D., Davis, G.B. and McKeen, J.D. (1980). Determining Information Requirements: A Contingency Method for Selection of a Requirements Assurance Strategy. *Journal of Systems and Software* 1(4):273–281.

Neale, M.R. and Corkindale, D.R. (1998). Codeveloping Products: Involving Customers Earlier and More Deeply. *Long Range Planning* 31(3):418–425.

Noori, H. (1990). *Managing the Dynamics of New Technology*. Englewood Cliffs, NJ: Prenctice-Hall.

Nord, W.R. and Tucker, S. (1987). *Implementation Routine and Radical Innovations*. Lexington, MA: Lexington Books.

Parkhe, A. (1991). Interfirm Diversity, Organizational Learning, and Longevity in Global Strategic Alliances. *Journal of International Business Studies* 22(4):579–601.

Perrow, C. (1994). Accidents in High-Risk Systems. *Technology Studies* 1(1):1–20.

Polyani, M. (1967). *The Tacit Dimension*. Garden City, NY: Doubleday.

Poirier, C.C. and Bauer, M.J. (2000). *E-Supply Chain: Using the Internet to Revolutionize Your Business*. San Francisco, CA: Berrett-Koehler.

Ragatz, G.L., Handfield, R.B. and Scannell, T.V. (1997). Success Factors for Integrating Suppliers into New Product Development. *Journal of Product Innovation Management* 14(3):190–202.

Rebentisch, E.S. and Ferretti, M. (1995). A Knowledge Asset-Based View of Technology Transfer in International Joint Ventures. *Journal of Engineering and Technology Management* 12(1–2):1–25.

Reddy, N.M. and Zhao, L. (1990). International Technology Transfer: A Review. *Research Policy* 19(4):285–307.

Roberts, E.B. and Berry, C.A. (1985). Entering a New Business: Selecting Strategies for Success. *Sloan Management Review* 26(33):3–17 (Spring)..

Rogers, E.M. (1995). *Diffusion of Innovations*. New York: Free Press.

Rosenthal, S.R. (1992). *Effective Product Design and Development*. Homewood, IL: Irwin.

Rosenthal, S.R. and Salzman, H. (1990). Hard Choices about Software: The Pitfalls of Procurement. *Sloan Management Review* 31(3):81–91 (Summer).

Sanchez, R. (1996). Modularity, Flexibility, and Knowledge Management in Product and Organization Design. *Strategic Management Journal* 17:63–76 (Winter).

Schrader, S. (1991). Informal Technology Transfer between Firms: Cooperation through Information Trading. *Research Policy* 20(2):153–170.

Schumpeter, J. (1942). *Capitalism, Socialism, and Democracy*. New York: Harper.

Shenhar, A.J. (1998). From Theory to Practice: Toward a Typology of Project-Management Styles. *IEEE Transactions on Engineering Management* 45(1):33–48.

Sheridan, J.H. (1999). Managing the Chain. *Industry Week* 248(16): 50–54.

Simchi-Levi, D., Kaminsky, P. and Simchi-Levi, E. (2000). *Design and Managing the Supply Chain*. New York: Irwin McGraw-Hill.

Singh, K. (1997). The Impact of Technological Complexity and Interfirm Cooperation on Business Survival. *Academy of Management Journal* 40(2):339–367.

Smith, P.G. and Reinertsen, D.G. (1998). *Developing Products in Half the Time*. New York: Van Nostrand Reinhold.

Sobek, D., Liker, J. and Ward, A. (1998). Another Look at How Toyota Integrates Product Development. *Harvard Business Review* 76(4):36–50.

Souder, W.E. (1987). *Managing New Product Innovations*. Toronto: Lexington Books.

Souder, W.E. and Padmanabhan, V. (1989). Transferring New Technologies from R&D to Manufacturing. *Research-Technology Management* 32(5):38–43.

Spann, M.A., Adams, M. and Souder, W.E. (1995). Measures of Technology Transfer Effectiveness: Key Dimensions and Differences in Their Use by Sponsors, Developers, and Adopters. *IEEE Transactions on Engineering Management* 42(1):19–29.

Spinelli, S. and Birley, S. (1998). An Empirical Evaluation of Conflict in the Franchise System. *British Journal of Management* 9(4): 301–325.

Stock, G.N., Greis, N.P. and Dibner, M.D. (1996). Parent-Subsidiary Communication in International Biotechnology R&D. *IEEE Transactions on Engineering Management* 43(1):56–68.

Stock, G.N. and Tatikonda, M.V. (2000). A Typology of Project-Level Technology Transfer Processes. *Journal of Operations Management* 18(6):719–737.

Tait, P. and Vessey, I. (1988). The Effect of User Involvement on System Success: A Contingency Approach. *MIS Quarterly* 12(1):90–107 (March).

Tatikonda, M.V. (1999). An Empirical Study of Platform and Derivative Product Development Projects. *Journal of Product Innovation Management* 16(1):3–26.

Tatikonda, M.V. and Lorence, M. (2002). Toward Effective Software Development: A Conceptual Framework of Software Project Types, Development Processes, and Functional Outcomes. In: *New Directions in Supply-Chain Management: Technology, Strategy, and Implementation*. T. Boone and R. Ganeshan (eds.). New York: American Management Association, 171–199.

Tatikonda, M.V. and Montoya-Weiss, M.M. (2001). Integrating Operations and Marketing Perspectives of Product Innovation: The Influence of Organizational Process Factors and Capabilities on Development Performance. *Management Science* 47(1):151–172.

Tatikonda, M.V. and Rosenthal, S.R. (2000). Technology Novelty, Project Complexity, and Product Development Project Execution Success: A Deeper Look at Task Uncertainty in Product Innovation. *IEEE Transactions on Engineering Management* 47(1):74–87.

Tao, Z. and Wu, C. (1997). On the Organization of Cooperative Research and Development: Theory and Evidence. *International Journal of Industrial Organization* 15(5):573–596.

Thompson, J.D. (1967). *Organizations in Action*. New York: McGraw-Hill.

Tornatzky, L.G. and Fleischer, M. (1990). *The Processes of Technological Innovation*. Lexington, MA: Lexington Books.

Tsang, E.W.K. (1997). Choice of International Technology Transfer Mode: A Resource-Based View. *Management International Review* 37(2):151–168.

Turner, G., LeMay, S.A. and Mitchell, M.A. (1994). Solving the Reverse Logistics Problem: Applying the Symbiotic Logistics Concept. *Journal of Marketing Theory and Practice* 2(2):15–27.

Tushman, M.L. and Anderson, P. (1986). Technological Discontinuities and Organizational Environments. *Administrative Science Quarterly* 31(3):439–465.

Tushman, M.L. and Nadler, D.A. (1978). Information Processing as an Integrating Concept in Organizational Design. *Academy of Management Review* (3):613–624.

Tushman, M.L. and Rosenkopf, L. (1992). Organizational Determinants of Technological Change: Toward a Sociology of Technological Evolution. *Research in Organizational Behavior* 14:311–347.

Ulrich, K. (1995). The Role of Product Architecture in the Manufacturing Firm. *Research Policy* 24(3):419–440.

Ulrich, K.T. and Ellison, D.J. (1998), Beyond Make-Buy: Internalization and Integration of Design and Production. Working Paper, The Wharton School.

Ulrich, K.T. and Eppinger, S.D. (2000). *Product Design and Development*. New York: McGraw-Hill.

Urban, G.L. and Hauser, J.R. (1993). *Design and Marketing of New Products*. New York: Prentice Hall.

Van de Ven, A.H, Delbecq, A.L. and Koenig Jr., R. (1976). Determinants of Coordination Modes within Organizations. *American Sociological Review* 41:322–338 (April).

Van de Ven, A.H. and Ferry, D.L. (1980). *Measuring and Assessing Organizations*. New York: Wiley-Interscience.

von Hippel, E. (1987). Cooperation between Rivals: Informal Know-How Trading. *Research Policy* 16(6):291–302.

von Hippel, E. (1994). Sticky Information and the Locus of Problem Solving: Implications for Innovation. *Management Science* 40(4):429–439.

Walton, R.E. (1966). A Theory of Conflict in Lateral Organizational Relationships. In: *Operational Research and the Social Sciences*. J.R. Lawrence (ed.). London: Tavistock, 409–428.

Wheelwright, S.C. and Clark, K.B. (1992). Creating Project Plans to Focus Product Development. *Harvard Business Review* 70(2):70–82 (March–April).

Wong, A. (1999). Partnering through Cooperative Goals in Supply Chain Relationships. *Total Quality Management* 10(4–5):786–792.

Yoon, E. and Lilien, G.L. (1985). New Industrial Product Performance: The Effects of Market Characteristics and Strategy. *Journal of Product Innovation Management* 2(3):134–144.

Zhao, L. and Reisman, A. (1992). Toward Meta Research on Technology Transfer. *IEEE Transactions on Engineering Management* 39(1):13–21.