Journal of Operations Management 18 (2000) 719–737
JOURNAL OF OPERATIONS MANAGEMENT
www.elsevier.com/locate/dsw

A typology of project-level technology transfer processes

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Abstract

This paper develops a conceptual typology of inward technology transfer (ITT), which explicitly considers technology transfer at the project, rather than the firm, level of analysis. Building on extant technology management literature and the organizational theories of information processing and interdependence, we carefully characterize the three dimensions of the typology: the technology uncertainty of the technology that is transferred, the organizational interaction between the technology source and recipient, and transfer effectiveness. Appropriate matches of technology uncertainty and organizational interaction result in four archetypal cases called "transfer process types", which represent the most effective approaches to technology transfer. Real-life examples of effective and ineffective matches are presented, and implications of the typology for future research and practice are discussed. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Technology transfer; Technological innovation; Configurational research; Project management; Information processing theory; Interdependence theory

1. Introduction

Effective acquisition and utilization of new technology from an outside source can contribute greatly to the operational success of a firm. We have observed in the field that acquiring and assimilating new product and process technologies is often quite difficult. For example, at one computer electronics firm, the transfer and utilization of a new core product technology led to substantial delays and cost over-runs in a product development effort. In this case, the firm had limited interaction with the technology vendor, even though it was a risky and critical technology. In contrast, at a medical equipment manufacturer, the acquisition and utilization of a new flexible manufacturing system led to production of high quality parts in sufficient variety and volume within a reasonable timeframe. This occurred even though this was the first usage of an FMS by that firm. In this case, the firm worked closely with the FMS vendor throughout the transfer process and even had, as planned, vendor personnel on the shop floor for several weeks. Clearly, some transfers are more successful than others.

Technology transfer into the firm is a challenging and — we believe — a more often recurring operational problem. Organizations are emphasizing

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PII: S0272-6963(00)00045-0

"focus" on selected core conversion activities that are their key competitive competencies. This results in the need for more interfaces with external organizations to source technologies as fewer product and process technologies are developed or produced internally. Supply chain management philosophies have taken hold, suggesting that some firms need practical skills in upstream technology transfer if they wish to routinely achieve functionally effective, low-cost, time-efficient transfers. And some firms are actively responding to the increasing rate of technology innovation and technological options, meaning they could more often source "risky" technologies (technologies which have greater uncertainty) from external organizations. For all these reasons, in many firms technology transfer is no longer an occasional activity, which can be managed in an ad-hoc fashion; rather, it is a recurring process, which requires purposeful management supported by a well-developed portfolio of organizational skills.

How should companies actually go about conducting the transfer of individual product and process technologies? In addressing this question, the technology transfer literature primarily considers governance forms, such as direct investment, joint venture, direct sale or licensing (Oxley, 1999; Kumar et al., 1999; Davidson and McFetridge, 1985; Teece, 1977). This literature typically takes the perspective of a source nation or firm, which wishes to gain economic value from sharing or selling proprietary technologies, and generally considers the political, corporate or strategic level of analysis rather than an operational, project level (Reddy and Zhao, 1990; Contractor and Sagafi-Nejad, 1981). This literature focuses heavily on legal, contractual, and ownership issues regarding technology transfer (Finan et al., 1999; Reddy and Zhao, 1990), generally following a transaction cost framework. The transaction cost approach, however, has shortcomings in many practical contexts (Contractor and Sagafi-Nejad, 1981) because it does not deeply examine the work-level inter-organizational issues involved in technology transfer. A smaller subset of the technology transfer literature does adopt an inter-organizational focus (Galbraith, 1990; Rebentisch and Ferretti, 1995; Gibson and Smilor, 1991), but this literature typically examines inter-organizational factors, such as communication, only on an individual, unidimensional basis. The technology transfer literature also does not fully consider the nature of the technology to be transferred, as it generally only considers a single technology attribute, if it does so at all (e.g., Howells, 1996; Davidson and McFetridge, 1985).

The existing technology transfer literature contributes important insights. However, to the best of our knowledge, prior work does not systematically synthesize the many potentially relevant variables into a single, unified, theory-based typology of the variety of project-level inter-organizational work processes necessary to transfer different types of technologies. Accordingly, this paper aims to contribute to the operations management and technology management literatures by developing a conceptual framework of effective technology transfer at the project level. The conceptual framework captures the nature of the technology to be transferred, the activities and interactions across organization boundaries, and contingent relationships between technology and organization, all at the project level of analysis. The objective of this framework is to provide theoretical insight and practical guidance into selection of the best management approaches for transferring a technology into an organization. Because the framework addresses the transfer of technology *into* an organization of interest, the framework is called the inward technology transfer (ITT) typology.

A typology is a conceptually derived classification scheme where the classifications are "ideal types, each of which represents a unique combination of organizational attributes" (Bozarth and McDermott, 1998). A typology is an application of the configurational approach to the study of an organizational phenomenon. This approach "allows researchers to express complicated and interrelated relationships among many variables without resorting to artificial oversimplification of the phenomenon of interest" (Dess et al., 1993). The configurational approach has been applied widely in the fields of strategy and operations management (e.g., Miles and Snow, 1978; Porter, 1980; Schmenner, 1986; Hill, 1994; Ward et al., 1996), and is well suited to the study of organizational situations too complex to be modeled adequately by bi-variate relationships (Meyer et al., 1993; Bailey, 1994; Bozarth and McDermott, 1998). Technology transfer is an inherently multidimensional task characterized by complex and interrelated relationships among many variables. This multidimensionality and multivariate complexity is explicitly considered in the development of the ITT typology.

The best known typology in operations management is the product–process matrix (Hayes and Wheelwright, 1979), which identifies the matrix dimensions of volume and variety. This typology identifies along the matrix diagonal the best choice of operations process type by matching the volume and variety of the product under consideration. Like the product–process matrix, the ITT typology (see Fig. 1) identifies along the diagonal the best choice of technology transfer process type by matching the intrinsic technology uncertainty of the technology to be transferred and the organizational interaction between the technology source and recipient. There are four transfer process types (arrayed along the diagonal): arms-length purchase, facilitated purchase, collaborative hand-off, and co-development. Each transfer process type represents the best match, or fit, between technology uncertainty and organizational interaction. Developing theoretically based specifications for the technology uncertainty and organizational interaction dimensions, as well as for each of the transfer process types, are key tasks of this paper.

The paper is organized as follows. Section 2 provides definitions of key concepts regarding technology, transfer and effectiveness. This discussion is necessary because considerable terminological confusion arises due to the diversity of meanings applied to similar words in the extant literature. The typology is grounded in established organization theoretic perspectives: organizational information processing theory (OIPT) and the theory of interdependence between organizations. Section 3 describes these general theories, explains how they underlie the abstract concepts of technology uncertainty and organizational interaction, and then applies these theories to the specific context of ITT. Section 4 synthesizes technology management literature and organizational theory to identify key subdimensions underlying technology uncertainty and organizational interaction. Section 5 describes the four transfer process types, which are ideal matches of technology uncertainty and organizational interaction arrayed along the diagonal of Fig. 1. Section 6 presents real-life application examples of the ITT typology from an in-depth case study of a high-tech product development effort. Implications for theory, future research, and managerial application of the typology are addressed in Section 7.

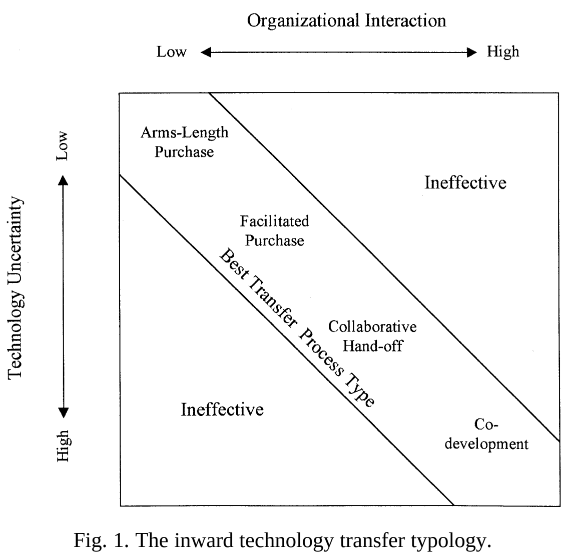

Fig. 1. The inward technology transfer typology.

2. Definitions

Technology is “any tool or technique, any product or process, any physical equipment or method of doing or making, by which human capability is extended” (Schon, 1967). In the operations context, technology is technical knowledge (or “know-how”) applied to improve an organization’s ability to provide products and services (Bohn, 1994). Because technical knowledge varies widely in degree of physical embodiment, a specific technology could be a machine, an electrical or mechanical component or assembly, a chemical process, software code, a manual, blueprints, documentation, operating procedures, a patent, a technique, or even a person. Improvement includes extending, augmenting, refining or replacing some elements of the organization’s operational processes and value-adding capabilities in order to achieve one or more functional objectives such as: technical performance enhancement, capacity increases, flexibility and variety increases, conformance quality improvement, personnel skills development, cost reduction, and task and process time reduction.

The common thread among the many extant definitions of technology transfer is movement of the technology from one organization to another; that is, across the organizational boundary of the source and recipient (Bell and Hill, 1978; Keller and Chinta, 1990; Bozeman and Coker, 1992). However, characterizations of the initiation and conclusion of the technology transfer process vary widely. We define the starting point of the technology transfer process to be the point in time immediately after the recipient's decision to acquire a given technology has been made. Some characterize the conclusion of the technology transfer process as occurring simply once the technology has moved across the organizational boundary (Davidson and McFetridge, 1985); however, we adopt an operational perspective by viewing the actual utilization of the technology by the recipient organization as the concluding step in the technology transfer process (Gruber and Marquis, 1969; Bell and Hill, 1978, Tsang, 1997). Utilization is more than simple physical receipt of the technology — it involves the actual implementation of the technology in a production process or its incorporation into a new product. Therefore, for our purposes, the technology transfer process consists of the inter-organizational activities employed to achieve both movement of technology across the organizational boundary from the source to the recipient and its utilization by the recipient to achieve some specified functional objectives. In turn, the effectiveness of the technology transfer process is the degree to which the utilization of the transferred technology fulfills the recipient firm's intended functional objectives within cost and time targets.

3. Organizational theory foundations

Information processing is the purposeful generation, aggregation, transformation and dissemination of information associated with accomplishing some organizational task (Tushman and Nadler, 1978; Robey, 1986). Here, the task of interest is technology transfer. Although specific sub-tasks, information sources, and information transformation requirements may differ among technology transfer situations, all technology transfers involve some information processing to conduct the transfer. Accordingly, it is useful to view technology transfer through the lens of OIPT. This theory, which has an inherently contingent perspective, underlies our typology of technology transfer. OIPT explains that organizational tasks pose information-processing requirements to the organization. Various means applied by the organization provide information-processing capabilities. The degree to which requirements and capabilities are appropriately matched determines the quality of task outcomes (Galbraith, 1973, 1977). While OIPT has a long history, it has only recently begun to appear in operations management research (Flynn and Flynn, 1999; Tatikonda and Rosenthal, 2000a).

Organizational tasks vary in the degree to which the means to accomplish them are certain. Task uncertainty is "the difference between the amount of information required to perform the task and the amount of information already possessed by the organization" (Galbraith, 1977, p. 36), and represents the quantity of knowledge or information that must be acquired and processed. In addition to the quantity of information that must be processed, the quality (or richness) of the information is also important (Daft and Lengel, 1986). Task-related characteristics cause or contribute to task uncertainty. For example, Perrow (1967) identified, at an abstract level, that task variety and analyzability contribute to task uncertainty. An additional point to be recognized is that task uncertainty is organization-specific: what is certain to one organization may be uncertain to another (Galbraith, 1977; Robey, 1986).

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

A key consideration in our framework is the relationship between organizations engaged in a technology transfer. The two distinct organizational units (source and recipient) are engaged in a work task (the transfer of a technology) where the two units are reliant on each other, to some degree, to accomplish the task at hand. Interdependence theory describes the degree of, and elements of, inter-organizational relationships (Thompson, 1967; McCann and Galbraith, 1981; Adler, 1995). It addresses structural and process aspects of relationships between two distinct organizational units. Four forms of interunit interdependence have been identified (Thompson, 1967; Van de Ven et al., 1976), and range from low to high interdependence: (1) pooled, (2) sequential, (3) reciprocal, and (4) team interdependence. Lower levels of interdependence means that the units can do the work quite independently of each other, and have "little need for interaction, consultation or exchange" (Daft, 1986, p. 153). Greater interdependence means higher relationship intensity. In general, lower interdependence affords greater reliance on planning, while greater interdependence requires more emphasis on problem solving and communication during the task activity (Daft, 1986). Higher forms of interdependence represent a greater capacity for information processing, both in quantity and quality.

The four forms represent different degrees of an inter-organizational relationship. At a more detailed level, three essential "components of the relationship" (Walton, 1966) have been identified: (a) exchange of information in the joint decision process, (b) structure of interunit interactions and decision making, and (c) attitudes towards the other unit. We refer to the three components as "communication", "coordination" and "cooperation".

The value of considering the organizational information processing and interdependence theories together is straightforward. Task uncertainty causes

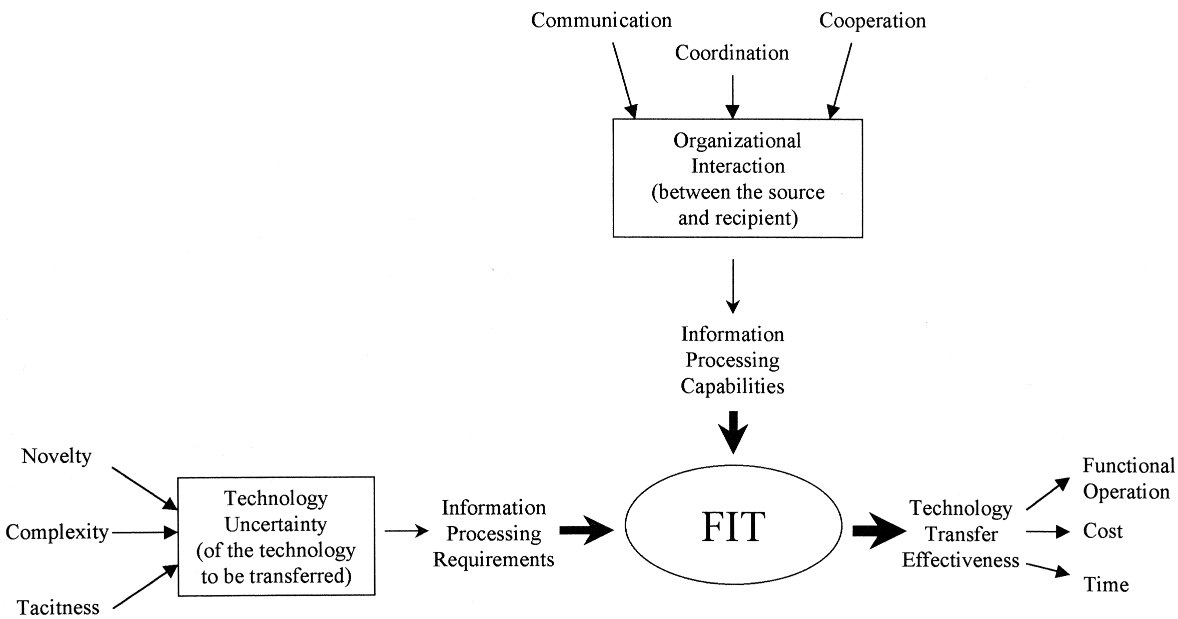

Fig. 2. Organizational information processing theory applied to technology transfer.

information-processing requirements. The form of inter-organizational interdependence provides information-processing capacity. Appropriate match of requirements and capabilities leads to effective performance of the task. In the specific context of our typology, technology uncertainty corresponds to the general theory construct of task uncertainty; organizational interaction corresponds to the general theory construct of organizational approach; and technology transfer effectiveness corresponds to task effectiveness. By adapting the general OIPT principles to the specific context of technology transfer, we can state that the type of technology uncertainty posed by the technology that is transferred should be appropriately matched with the type of organizational interaction (provided through the form of inter-organizational interdependence) between source and recipient (and vice versa). An appropriate match between technology uncertainty and organizational interaction will result in an effective technology transfer. Fig. 1 identifies the best matches, called transfer process types, along the diagonal of the ITT framework. This application of the general theory of OIPT to the technology transfer context is illustrated in Fig. 2.

4. Typology dimensions and subdimensions

Many variables influence the ITT process. This section reduces the multivariate complexity of this phenomenon by synthesizing the many factors into a few overall subdimensions of technology uncertainty and organizational interaction. These subdimensions are contributors to technology uncertainty and organizational interaction, and in turn are contributors to information processing requirements and capacity. In addition, we explicitly identify subdimensions of transfer effectiveness.

4.1. Technology uncertainty

The general OIPT concept of task uncertainty corresponds to “technology uncertainty” when considered in the specific context of technology transfer. OIPT describes task uncertainty as lack of knowledge about how to accomplish the task. In technology transfer, technology uncertainty is the lack of knowledge regarding how to move and implement the technology of interest. Hence, technology uncertainty is the difference between the level of knowledge required by the recipient organization to acquire and implement the technology, and the level of knowledge the recipient actually possesses.

Many factors contribute to technology uncertainty (and in turn increase the information processing requirements). In the spirit of the configurational research approach, we synthesize these elements into a few macro-factors, which comprise three essential subdimensions of technology uncertainty: technology novelty, technology complexity and technology tacitness. Technology novelty refers to the degree of prior experience with the technology and the degree of change in the technology relative to prior technologies. Technology complexity includes the level of interdependence between components in the technology, level of interdependence between the technology and elements external to it, and the scope of the technology. The tacitness of the technology refers to the tacitness of the knowledge embodied by the technology, and includes the degree to which the technology is physically embodied, codified, and complete. The three subdimensions represent largely different concepts; nonetheless, they overlap to some degree because some technological elements influence more than one subdimension. Higher levels of each subdimension increase the level of technology uncertainty. In general, a technology that is more novel, complex, and/or tacit will be more uncertain than a technology that is familiar, simple, or well defined. Moreover, higher levels of technology uncertainty will lead to greater information processing requirements. Table 1a lists the set of the factors underlying each of the technology uncertainty subdimensions. Note also, that like the general OIPT concept of task uncertainty, technology uncertainty is organization-specific. Different levels of experience or absorptive capacity (Kedia and Bhagat, 1988; Cohen and Levinthal, 1990; Glass and Saggi, 1998) may mean that what is highly uncertain to one organization may not be for another.

4.2. Organizational interaction

The second dimension in the ITT typology, corresponding to the general OIPT concept of organizational approach, is organizational interaction, which

Table 1
Inward technology transfer typology subdimensions

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

characterizes the nature of the inter-organizational relationship between the source and recipient. As with technology uncertainty, organizational interaction has many contributing factors. We synthesize these factors into three macro-factors, which constitute essential subdimensions of organizational interaction: communication, coordination, and cooperation between the two organizations. Communication includes the methods of communication, magnitude and frequency of communication, and nature of information exchanged. Coordination refers to the nature of the planned structure and process of interactions and decision-making between source and recipient (Parkhe, 1991). Cooperation is the "willingness of a partner to pursue mutually compatible interests rather than to act opportunistically" (Das and Teng, 1998, p. 492). The subdimensions are conceptually different; nonetheless, they overlap somewhat. Higher levels of organizational interaction provide higher levels of information processing capability. Note also that these three subdimensions correspond to the three components of an inter-organizational relationship described above in the discussion of interdependence theory. Table 1b provides a detailed set of the underlying factors for each of the organizational interaction subdimensions.

4.3. Transfer effectiveness

The final concept of the ITT typology is technology transfer effectiveness. The inter-organizational activities in technology transfer may be seen as constituting a "project". Key elements of project operational effectiveness are time, cost and technical performance (Meredith and Mantel, 1995). These elements apply readily to the technology transfer context, making up three subdimensions of transfer effectiveness: the functional operation of the technology (analogous to technical performance), transfer-related costs, and the time taken to complete the transfer project.

5. Technology transfer process types

This section specifies in more detail the ITT typology, shown graphically in Fig. 1. Each of the two axes (technology uncertainty and organizational interaction) and the diagonal (transfer process) of the ITT typology is a spectrum or dimension from low to high. We define four categories, which we call transfer process types, along the diagonal to aid in practical application of the typology. These four categories represent ideal matches of technology uncertainty and organizational interaction, arrayed from low to high: arms-length purchase, facilitated purchase, collaborative hand-off, and co-development. Note that these four transfer process types correspond roughly to the four types of organizational interdependence types identified in the interdependence theory literature. Although each category name provides accessible terminology for real-world application, what is by far most important is the *relative location on the given axis or diagonal*. We describe each transfer process type below in terms of the primary dimensions of the typology and in terms of each subdimension. In addition, in Table 2, we provide a stylized example of each transfer process type to illustrate the underlying concepts in a more concrete manner.

The first transfer process type is the arms-length purchase. For the recipient, the technology to be transferred has low levels of complexity, novelty, and tacitness. The technology can therefore be used by the recipient as soon as it is received with little or no difficulty. The recipient has all or virtually all the information needed to successfully move and implement this technology. Therefore, the level of technology uncertainty is low. The relationship between the source and recipient is a simple market transaction where the recipient utilizes the technology with little or no assistance from the source. There is little communication between the source and recipient; and little cooperation or coordination is required. The overall level of organizational interaction is therefore low. The information processing requirements posed by the technology and the information processing capabilities provided by the organizational approach are both low, and therefore are appropriately matched.

The second transfer process type is the facilitated purchase. Complexity, novelty, and tacitness are relatively higher for the technology in this category than in an arms-length purchase transfer. For example, the technology may be functional in its present form (exhibiting a relatively low degree of tacitness). However, because of a lack of expertise or experience, the recipient does not know how to immediately utilize the technology (a medium level of novelty), or the technology has a non-trivial number of components or interactions (a medium level of complexity). In this transfer process type, as well as in an arms-length purchase, the actual movement of the technology in the transfer is likely to be trivial. Organizational interaction is characterized by low to medium levels of communication, coordination, and cooperation. The recipient purchases the technology from the source in a traditional market transaction. However, the source provides guidance and information to the recipient in utilizing the technology. There is more communication between the recipient and source than in the arms-length purchase transfer mode, and this communication includes non-trivial technical information related to the functioning and implementation of the technology. The recipient may disclose information about the target use of the technology, so there would be two-way communication and cooperation. Still, most of the technical information comes from the source firm. There are low to medium levels of information processing requirements and information processing capabilities.

The third transfer process type is the collaborative hand-off. In this category, the technology is generally medium or high on two of the subdimensions of technology uncertainty, but possibly low or medium on the third subdimension. The overall level of technology uncertainty is therefore higher than in the facilitated purchase. Uncertainty arises both in the

Table 2
Stylized examples of transfer process types

Transfer process type	Example
Arms-length purchase	A small bakery must replace a general-purpose oven that has worn out. The technology is familiar, simple, and explicit. The oven is acquired through a market transaction, so there is little communication, coordination, or cooperation.
Facilitated purchase	The bakery wants to expand in both scale and in the variety of its product line. It decides to buy larger, more sophisticated programmable ovens, again through a market transaction. However, the bakery employees do not have experience with programmable cooking equipment, so there is a good deal of interaction with customer service representatives needed to get the ovens working properly. The technology is more complex and less familiar, although still low on tacitness. There are greater levels of communication, cooperation, and coordination in this instance than in the arms-length purchase above.
Collaborative hand-off	The bakery has become very successful, so it would now like to expand into producing a larger volume of products for retail sale in the local area. Therefore, the baker must install more sophisticated, automated baking equipment capable of producing larger volumes of goods. A food processing equipment vendor manufactures the needed equipment, but compared to what the bakery has previously used, this equipment is unfamiliar (novel), much more complex, and because it must be customized to some extent it is not in its completed form when it arrives at the bakery's facility (somewhat tacit). The bakery has extensive discussions with the vendor about the bakery's requirements, constraints and capabilities. The equipment supplier delivers the equipment, but it sends an engineer to work with the bakery over the course of several weeks to get the production line running properly. There is a good deal of communication, coordination, and cooperation in this case.
Co-development	The bakery has now decided to move into a different category of baked products — "thaw and cook" cookies. These cookies are delivered to supermarkets partially baked and frozen, and are then "baked" fresh for customers in their in-store bakeries. This is a very different type of product and so it requires a different type of production technology. This technology has been used in bread, cakes, and muffins, but not cookies. Great-tasting cookies are what the bakery has traditionally been known for, and the goal is to replicate the use of this technology for cookies. To accomplish this goal, the bakery enters into an alliance with a company that has produced thaw and cook bread products. The technology is novel to the bakery and very complex. It is also highly tacit because although the technology exists for the bread products, the technology is essentially simply a prototype that serves as a conceptual starting point for cookie products. The technology vendor has its production engineers work with the bakery production engineers to develop new technology for the production of thaw and cook cookies. There is a great deal of communication, coordination, and cooperation.

In these examples, a bakery makes a number of changes to its product line and production process, and must therefore acquire and utilize different technologies of increasing uncertainty.

movement of the technology (because it may not be clear that all knowledge embodied by the technology is actually moved to the recipient, or there may be uncertainty about how to move the technology), as well as in the utilization of the technology by the recipient. The organizational interaction between the source and recipient is higher than in the facilitated purchase. The levels of communication and cooperation are greater, and more attention is devoted to coordination activities between the source and recipient. Therefore, the collaborative hand-off exhibits medium to high levels of technology uncertainty and organizational interaction, and thus results in relatively higher levels of information processing requirements and capabilities.

The fourth transfer process type is co-development, which represents a match between very high levels of technology uncertainty and organizational interaction. The technology is high on the novelty, complexity, and tacitness subdimensions. Such a technology is likely to be poorly documented, incompletely specified, or perhaps not even available in its final form. The recipient may have some idea of what the technology should accomplish functionally but without a detailed design or set of specifications. Such technology can reside in the source organization primarily as knowledge or procedures about a product or process. Technology in this category might even be a collection of functional elements that are to be combined together in a new way to form a system. In addition, for this technology, there is likely to be uncertainty regarding whether it is possible to move all needed information from the source to the recipient. The relationship between the source and recipient in a co-development transfer will be characterized by a very high degree of communication, cooperation, and coordination. The organizational boundaries between the source and recipient are effectively blurred or possibly even eliminated. The source and recipient work together, largely as one integrated (albeit often ad-hoc) organization, to move the technology to and utilize it successfully in the recipient organization. There is often, although not always, extensive and lengthy physical co-location of personnel from the source and recipient organizations. Co-development transfers could include deep supplier involvement in product or process development. Some (but not all) strategic alliances, joint ventures and joint R&D agreements are examples of the level of organizational interaction found in a co-development transfer. The organizational interaction in this transfer process type provides the highest level of organizational interaction and the highest level of information processing capability.

Note that these categories represent ideal types of the technology transfer process. There is an inherent contingency perspective here. If the information processing capabilities (provided by the organizational interaction) are appropriately matched to the information processing requirements (determined by the technology uncertainty), the technology transfer should be effective. As we discussed above, an effective transfer is one that is accomplished on time, within budget, and fulfills the functional objectives of the technology within the recipient. If there is no appropriate match, then the transfer is likely to be ineffective. A transfer in which the information processing capability is inadequate for the level of information processing requirements, which would be represented by a location below and to the left of the diagonal in the ITT typology diagram, would result in a transfer that is likely to either take longer than planned and/or fall short of functional objectives. An alternative example of an ineffective transfer would be the case where the information processing capabilities are greater than necessary for the information processing requirements, which would be represented by a location above and to the right of the diagonal in the ITT typology diagram. Here, the transfer may achieve its functional and time objectives but will likely exceed its cost targets.

6. Real-life illustration: laser printer product development project

6.1. Case context

To illustrate the typology in a real-life context, we now present examples drawn from a product development effort we observed in the field. The product was an “imagesetter”, essentially a very high-end laser printer, which sold for US$30,000 and was intended for exacting publishing applications that specialized publishers and printers require. This product did not “print” on paper; rather it “wrote” via the laser onto special-purpose film for subsequent generation of four-color printing plates. The development effort took more than 2 years, and a total of 50 engineers participated in the development project at some point in time. The product was developed and marketed by a United States-based division of Agfa.

This product makes an interesting case study because it is a substantial and reasonably complex product containing a variety of major elements. One key element was the laser diode, which did the writing. The product contained complex optical elements and assemblies to guide and modify the laser beam. Motorized cylinders moved the film through the device. The product also contained the equivalent of a personal computer to accept electrical signals to the device (in the form of images and text to be written) and to control the operation of the laser. Hence, the product had an Intel CPU, associated hardware, sophisticated proprietary software, and the Unix operating system. The product contained miscellaneous electrical and mechanical components, and the “skin” (the box that encapsulated the internal elements of the device).

This development project was documented as an extensive, descriptive research case study (Tatikonda and Rosenthal, 1998) based on 50 hours of interviews with personnel from multiple functions and many additional hours of archival documentation review. Semi-structured interview protocols, data triangulation techniques, and other descriptive research case study methodological procedures were employed (per Yin, 1984).

This case study was documented *before* development of the ITT typology. This case study had impressed upon us the importance of effective ITT, and motivated us to study the issue further. Accordingly, the examples drawn from the case study *are not* intended as an empirical test of the typology (which is a step for future research), but rather to simply illustrate the applicability of the ITT typology.

6.2. Case examples

As part of the development effort, the firm sourced, and in some cases modified, technologies from external vendors. We describe the transfer process situations for six technologies. Each of the six examples may be called a technology transfer project. These technologies varied in their uncertainty levels, and the firm employed different organizational interaction levels for different technologies. The firm did not employ formal terminology such as "organizational interaction" or "technology uncertainty" (although they did refer to some technologies as having greater "risk"). Nonetheless, they made decisions regarding transfer process types, sometimes quite consciously and other times by default (that is, without concerted analysis and decision-making about transfer process type). The data collected were not sufficient to allow rigorous assessment and weighting of each of the three-technology uncertainty and organizational interaction subdimensions. However, the data were sufficient to allow reasonable judgements of the relative levels of the overall technology uncertainty and organizational interaction dimensions for each transfer project example below. Each example first notes the recipient's intended functional objectives for the technology, the technology uncertainty level, and the organizational interaction level employed by the firm. Each example then contains observations regarding the effectiveness of the transfer process.

6.2.1. Hard disk controller

The functional purpose of this electronic device was to control the hard-disk memory. Substantial memory is required in this product. The actual technology uncertainty was low. Industry standards for this device were very well established, the device was already available on market, and the firm had substantial experience with such devices. A low level of organizational interaction was employed. In this case, the firm put in place the best match of technology uncertainty and organizational interaction, resulting in an "arms-length purchase" transfer process.

The transfer effectiveness was high. Although the device did require some adaptation to the firm's product system, it worked as intended in the expected implementation time frame. The match of technology uncertainty and organizational interaction was effective, consistent with the prescriptions of the ITT typology.

6.2.2. CPU chip

The functional purpose of this device was to serve as processor for the entire product system. This chip was to provide greater functionality than prior CPU chips because it would double the number of bits that could be processed. The actual technology uncertainty was moderately low. This product was the first application of this specific CPU chip by this firm. This CPU chip had just been introduced to the market, but technical standards had been disseminated earlier, and the firm had previous experience with prior generations of this chip. A low organizational interaction level was employed.

Transfer effectiveness was high. The CPU worked as intended, with no notable problems in movement or implementation. The match of technology uncertainty and organizational interaction resulted in a transfer process type similar to an "arms-length purchase". The match was effective, consistent with the prescriptions of the ITT typology.

6.2.3. Film

Although not a part of the product system sold by the firm, the imagesetter product was to write on this film media. Therefore, Agfa had to learn about this film and optimize its product to write on the film successfully. The new film was required because of the new laser diode. The film had not yet been introduced to the market and had not been used before in prior versions of Agfa's product systems. It was anticipated that this film would soon be a standard product in the marketplace. The actual technology uncertainty was of a medium level. The organizational interaction level employed was moderately high. Agfa worked closely with the vendor (Kodak) to characterize the film and understand the film's operation in the product system. The transfer process employed was a "collaborative hand-off".

Transfer effectiveness was moderately high. The firm encountered unexpected interactions between the film and other elements of the product system. It took longer than expected to optimize the whole product. The vendor was able to provide information about technical characteristics of the film and learn along with Agfa. All in all, the match was effective, consistent with the prescriptions of the ITT typology. The firm knew this technology was new to them and had the vendor's assistance and collaboration when needed. This included hand-in-hand experimentation with the vendor at the recipient firm's development site.

6.2.4. Computer operating system

The functional role of this element was to serve as the operating system for computer elements of the product. It was required to process the incoming electrical "write" signals, control the laser beam, and control the movement of film media. The actual technology uncertainty was relatively high. It was a new version of the UNIX operating system. The organizational interaction level employed was low because the firm essentially conducted a market purchase.

Transfer effectiveness was low. Contrary to the firm's expectations, the operating system did not have sufficient capability to support real-time processing and control, which is essential for this type of product. The technical capabilities of the operating system had been greatly overestimated. Achieving the desired functionality required a software "work-around", which lengthened development project time and required significant additional technical resources. All in all, the match of technology uncertainty level and organizational interaction level was ineffective. For this level of technology uncertainty, the ITT prescribes a "collaborative hand-off" transfer process type. Greater organizational interaction would likely have helped the firm better assess the technology, better prepare for implementation of the technology, and save time and cost in implementation by relying in part on the vendor's experience.

6.2.5. Optical prism

The functional role of this element was to modify and direct the laser beam, and correct for "wobble" in the mechanical system. The actual technology uncertainty was relatively high. The firm had no experience with optical prisms (Agfa's prior experience was with optical polygons, which are quite different). The firm chose to use the optical prism because a competitor used a similar component, and so Agfa assumed that the technology had been sufficiently "proven". The organizational interaction level employed was moderately low.

Transfer effectiveness was low. Implementation was greatly delayed because desired functionality could not be readily achieved. Substantial experimentation was required to determine how to successfully incorporate the optical prism element into its mechanical assembly so to achieve the intended functional properties. All in all the match was ineffective, as would be predicted by the ITT typology. The level of organizational interaction was too low given the level of technology uncertainty. Substantial interaction with the vendor would have most likely quickened the transfer, particularly by arriving more quickly at a functioning optical prism assembly. Per the typology, a "collaborative hand-off" transfer process would likely have been much more effective.

6.2.6. Laser diode

This element was to provide very high technical performance (three times the dots-per-inch capabilities of prior laser elements) and high reliability. The actual technology uncertainty was very high. The firm had employed other laser devices before, but had no experience with this new type of laser diode. The laser diode required considerable efforts to characterize its electro-optical parameters and function. At first, the laser diode would not write equally well on all locations of the film media. Further, the laser diode had a very high degree of interaction with other product system elements, requiring much mutual optimization. A moderate level of organizational interaction level was employed. The firm worked with the vendor (Sharp) to understand the laser device in very early laboratory tests.

Overall transfer effectiveness was low. The physical transfer of the laser diode was not problematic; however, its implementation in the product was very challenging and incurred lengthy delays. In addition, the realized unit cost of the laser diode was higher than expected. The match of technology uncertainty and organizational interaction was ineffective, as would be predicted by the ITT typology. The laser diode was a critical technology that posed significant technology uncertainty. Greater organizational interaction with the vendor throughout the transfer would likely have helped the firm anticipate problems and more quickly resolve technical implementation challenges as they arose.

6.3. Cross-transfer observations

These examples illustrate that some matches of technology uncertainty and organizational interaction were quite effective, while others were not. In general, when the matches were ineffective, the firm had employed a lower level of organizational interaction than in fact was required, and/or underestimated the uncertainty level of the technology to be transferred. Although technology transfers of some individual elements were problematic, by the end of the development project the overall functional objectives for the product had not only been met but exceeded. Still, the product introduction was delayed considerably, and the product cost was higher than targeted. The imagesetter product was a tremendous sales success and also served as a platform for successful subsequent new products. Although this case study had bottom-line success, we posit that the firm would have been more successful in transferring the specific technologies, and hence would have been more successful in accomplishing the product development project as a whole, if they had consistently employed transfer process type matches of technology uncertainty and organizational interaction prescribed by the typology. This in turn would most likely have led to even greater sales revenues and profits due to earlier entry into the market, and would have freed up development capacity that Agfa could apply to other new product development efforts. Fig. 3 shows graphically the actual technology uncertainty and organizational interaction matches of the six examples.

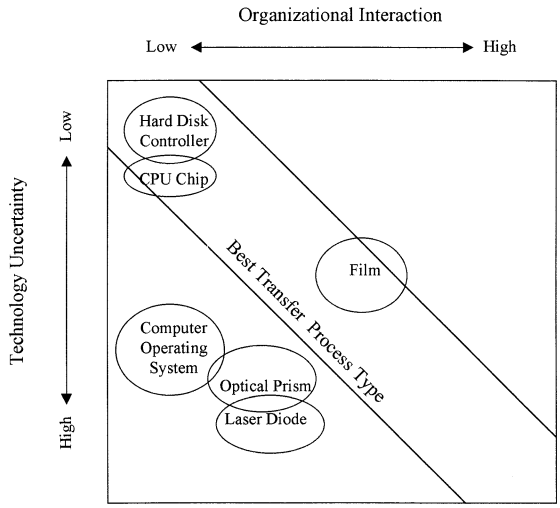

Fig. 3. Agfa case study: actual matches of technology uncertainty and organizational interaction.

The Agfa case illustrates several situations where underestimation of technology uncertainty occurred. We have observed that technology uncertainty can also be overestimated. Overestimation can occur through inaccurate assessment of technology uncertainty. In other cases purposeful overestimation occurs, allowing project managers to obtain greater personnel and other resources to accomplish the transfer. This increases total transfer project costs while assuring greater achievement of functionality and time objectives. And in other instances, the technology uncertainty was adequately assessed, but the correspondingly appropriate organizational interaction level was not employed due to lack of organizational resources. We have also observed that there is an important unit of analysis issue in assessing technology uncertainty. For example, in a single product development project, there can be many individual technology transfer projects (we illustrated six transfer projects for the single Agfa imagesetter product). The uncertainty associated with the macro product development project can be overestimated, while the technology uncertainty associated with certain individual technology transfers is underestimated, and vice versa. And finally, as we discuss in Section 7, selected variables in addition to technology uncertainty and organizational interaction may contribute to transfer effectiveness and so require consideration.

7. Discussion and directions for future research

7.1. Competencies

The ITT typology indicates that successful transfer of different technologies may require qualitatively different transfer processes. There are at least two significant organizational competencies required by the recipient organization in order to conduct a given transfer process type. The first competency is assessment of the technological uncertainty associated with the technology to be transferred. An inaccurate assessment of the uncertainty associated with the technology to be transferred will result in an improper choice of transfer process type. The penalty for the wrong choice is excessive cost (if uncertainty is judged to be higher than it actually is) or unsuccessful functional implementation (if the uncertainty is judged to be lower than it actually is). Assessing technology uncertainty is challenging (and as the Agfa case study illustrated, assessments are often inaccurate). Firms need to develop skills in assessment. To aid firms in practical assessment of the technology uncertainty, future research should develop feasible and reliable techniques for estimation of a technology's uncertainty level. Such research might also contribute to improved conceptual and practical definition of detailed technology uncertainty characteristics in various application contexts.

The second competency is the organizational ability to provide the required level of organizational interaction. Each organizational interaction level represents different abilities of the recipient organization. Presumably any firm can adequately perform the organizational interaction required for an "arms-length purchase" since it is trivial. But the successively higher levels of organizational interaction require successively greater and more complex skills. If the recipient organization anticipates the need to employ a variety of transfer process types, then the firm needs to develop some skills at each organizational interaction level. And many firms do require talent in routinely conducting complex interfirm interactions (Fine, 1999). While some recipient organizations have considerable skills in all levels of organizational interaction, in other organizations these skills require further development. Future research should investigate efficient means to develop and implement these organizational interaction skills.

Competencies in organizational interaction suggest the need for firms to make appropriate strategic choices. There are potential benefits from choosing to transfer the types of technologies that are most compatible with the organizational interaction skills present (or easily attained) in the recipient organization. From the perspective of the product–process matrix, this is analogous to choosing to produce products that are best manufactured via a given operations process type (e.g., the job-shop process) because the organization is particularly skilled in that operations process type (relative to other operations process types), and can obtain competitive distinction by leveraging that skill. The organization can focus on what it does well, and aim to avoid that which it does not do quite as well. While a firm might wish to rely most heavily on one transfer process type, some firms (particularly those in dynamic industries) will require competency in all transfer process types. This is analogous to a traditional assembly line firm, which must maintain some skills in the other operations process types (e.g., job shop manufacturing) because some parts of the overall product still require isolated usage of those other skills.

7.2. Effectiveness

The unit of analysis for the ITT typology is the individual technology transfer project, and the typology employs tactical, internal outcomes measures in determining the effectiveness of the technology transfer. These are the traditional elements of project operational success: functional (or technical) performance, cost achievement, and timeliness (Meredith and Mantel, 1995). Each transfer project has a unique set of objectives because the specific functional, cost and time objectives vary across transfer projects. In addition, the relative importance of achieving the functional objective, cost or timeliness will also vary across transfers. For example, a firm in one transfer instance may prioritize speediness of the transfer, and so de-emphasize the importance of cost containment.

There are other dimensions to transfer effectiveness as well. These include sociotechnical (e.g., transfer personnel satisfaction), external (e.g., market success), and strategic (e.g., development of a long-term organizational competencies) outcomes. Organizations should balance emphasis on project operational outcomes with other objectives as necessary given the specific transfer context. Exclusive focus on operational outcomes is not always appropriate.

There is an important temporal issue regarding when effectiveness can be assessed. In some cases, transfer effectiveness can be assessed at the point of completion of the transfer. This could be true in the case of a new process technology, where the utilization of the technology in process ramp-up would indicate the functional outcomes of the technology. In other cases, transfer effectiveness may not be known until quite later. For example, a technology transfer might be considered highly effective if the transfer led to a successful new product in the marketplace two years after the transfer instance, or if recipient organizational personnel gained lasting new skills regarding the new technology or new abilities in interacting with the given technology vendor.

7.3. Testable propositions

The ITT typology posits testable propositions. The general proposition is that "the greater the technology uncertainty associated with a given technology, the greater the organizational interaction between technology source and recipient that is required for technology transfer success". A first step for future research is empirical confirmation — in a specific operational context — of this general proposition and specific hypotheses based on particular levels of technology uncertainty and organizational interaction. Such research requires careful development of context-specific scale operationalizations of technology uncertainty, organizational interaction, and transfer effectiveness, followed by large-sample confirmatory studies.

7.4. Organizational theory extensions

Our development of the ITT typology employed information processing theory and interdependence theory as organization theoretic foundations. The project-level technology transfer problem lends itself to study by other organizational and strategic theories as well: the resource-based view of the firm, organizational learning, and transaction cost economics. The ability to conduct technology transfer — both in assessment of technology uncertainty and in implementing various organizational interaction levels — is a valuable skill, competency or "resource", and so can be viewed through the lens of the resource-based view of the firm (Wernerfelt, 1984; Leonard-Barton, 1995; Teece et al., 1997). Organizational competence in technology transfer is for some firms a tremendously valuable skill. The explicit recognition that transfer process knowledge is a valued competence provides a motivation for the firm to institutionalize existing skills and develop greater skills in technology uncertainty assessment and organizational interaction. This suggests purposeful "knowledge management" and continuous learning. Theories of organizational learning can be applied to this end (Cohen and Levinthal, 1990; Nonaka, 1994). Organizations can learn from transfer events through planned efforts such as use of appropriate project leadership, documentation of process activities, and post-project reviews. Finally, each transfer process type has unique organizational costs. The theory of transaction cost economics (Williamson, 1975; Zajac and Olsen, 1993) considers the quantity and variety of organizational and market transactions to determine, which corporate structural form provides the lowest economic cost to the firm. The transaction cost perspective, along with the notions of organizational competencies, can lead to identification of competitive strategies of the firm in terms of which transfer process types to focus on. These theoretical perspectives would enhance and enlarge the conceptual basis provided by the ITT typology.

7.5. Additional predictor variables

The ITT typology reduces the multivariate complexity of project-level inter-organizational technology transfer into a few meaningful summary constructs, treating technology uncertainty and organizational interaction as key macro-factors, which influence transfer effectiveness. Still, for purposes of maintaining the scope of the typology, additional variables, which may be relevant predictors of transfer success were not included: (1) ex ante characteristics of the source/recipient relationship (such as the level of experience the source and recipient had in working together on prior transfers), and (2) internal contextual/organizational factors of the recipient (such as the priority of the given transfer project relative to other projects in the firm, the resources provided for movement and utilization of the technology, and personnel performance measurement and reward systems). Future research should incorporate such variables into a broader conceptual framework of project-level technology transfer effectiveness, and future empirical tests of the ITT typology should control for such factors.

8. Conclusions

Effective technology transfer processes are essential in today's operations organizations given supply chain management philosophies, emphasis on operational focus, and overall technological progress. Technology transfer activities now occur relatively often rather than simply on rare occasion as in the past. Still, moving technology from another organization, and utilizing it in the organization of interest, is all too often a difficult and unsuccessful organizational task. The purposeful management of the technology transfer process deserves greater attention. Accordingly, this paper aimed to provide insight into this critical operations issue by identifying effective managerial approaches for the transfer of technologies. The paper adopted the perspective of the technology recipient (hence, "inward transfer") rather than the technology source. A typology of ITT was developed based on extant literature and prior field research, and characterizes four ideal technology transfer process types.

The ITT typology aids firms in categorizing the different transfer situations that arise, in assessing the nature of the technology to be transferred, and in determining the necessary organizational skills required for different transfer situations, all with the objective of increasing operational effectiveness and competitiveness. Firms need to assess and develop their capabilities in accomplishing ITT. The prescriptions of the ITT typology regarding organizational capabilities and focus are quite analogous to the prescriptions of the well-known product–process matrix. In addition, the ITT typology provides a conceptual avenue for future study of boundary-spanning relationships — such as the structure and dynamics of temporary (ad-hoc) inter-organizational project groups — in diverse operational and technological contexts.

Acknowledgements

We thank editor Cecil Bozarth, the associate editor, and the reviewers for their constructive comments on prior versions of this manuscript.

References

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., Callahan, J.R., 1993. The coordination structure of international collaborative technology arrangements. R&D Management 23 (2), 129–146.
Bailey, K.D., 1994. Typologies and Taxonomies: An Introduction To Classification Techniques. Sage Publications, Thousand Oaks, CA.
Barnett, B.D., Clark, K.B., 1996. Technological newness: an empirical study in the process industries. Journal of Engineering and Technology Management 13 (3,4), 263–282.
Bell, R.M., Hill, S.C., 1978. Research on technology transfer and innovation. In: Bradbury, F., Jervis, P., Johnston, R., Pearson, A. (Eds.), Transfer Processes in Technical Change. Sijthoff and Noordhoff, Alphen aan den Rijn, the Netherlands.
Bohn, R.E., 1994. Measuring and managing technological knowledge. Sloan Management Review 36 (1), 61–73.
Bozarth, C., McDermott, C., 1998. Configurations in manufacturing strategy: a review and directions for future research. Journal of Operations Management 16, 427–439.
Bozeman, B., Coker, K., 1992. Assessing the effectiveness of technology transfer from US government R&D laboratories: the impact of market orientation. Technovation 12 (4), 239–255.
Brooks, F.P. Jr., 1987. No silver bullet: essence and accidents of software engineering. IEEE Computer, 10–19, April.
Burns, T., Stalker, G.M., 1961. The Management of Innovation. Tavistock Publishers, London.
Clark, K.B., Fujimoto, T., 1991. Product Development Performance. Harvard Business School Press, Boston.
Cohen, W.M., Levinthal, D.A., 1990. Absorptive capacity: a new perspective on learning and innovation. Administrative Science Quarterly 35 (1), 128–152.
Contractor, F.J., Sagafi-Nejad, T., 1981. International technology

transfer: major issues and policy responses. Journal of International Business Studies 12 (2), 113–135.
Cooper, R.G., 1983. A process model for industrial new product development. IEEE Transactions on Engineering Management 30 (1), 2–11.
Corsten, H., 1987. Technology transfer from universities to small and medium-sized enterprises — an empirical survey from the standpoint of such enterprises. Technovation 6 (1), 57–68.
Daft, R.L., 1986. Organization Theory and Design. West Publishing, St. Paul.
Daft, R.L., Lengel, R.H., 1986. Organizational information requirements, media richness, and structural design. Management Science 32 (5), 554–571.
Das, T.K., Teng, B., 1998. Between trust and control: developing confidence in partner cooperation in alliances. Academy of Management Review 23 (3), 491–512.
Davidson, W.H., McFetridge, D.G., 1985. Key characteristics in the choice of international technology transfer mode. Journal of International Business Studies 16 (2), 5–21.
De Meyer, A., 1991. Tech talk: how managers are stimulating global R&D communication. Sloan Management Review 32 (3), 49–58.
Dess, G.G., Newport, S., Rasheed, A.M.A., 1993. Configuration research in strategic management: key issues and suggestions. Journal of Management 19 (4), 775–795.
Dutta, S., 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.
Ehrnberg, E., Jacobsson, S., 1997. Indicators of discontinuous technological change: an exploratory study of two discontinuities in the machine tool industry. R&D Management 27 (2), 107–126.
Eisenhardt, K.M., Tabrizi, B.N., 1995. Accelerating adaptive processes: product innovation in the global computer industry. Administrative Science Quarterly 40 (1), 84–110.
Ettlie, J.E., Bridges, W.P., St. O'Keefe, R.D., 1984. Organization strategy and structural differences for radical versus incremental innovation. Management Science 30, 682–695.
Finan, W., Cameron, L., Morgan, W., 1999. Transfers of technology: a basic primer on tax considerations. Journal of Technology Transfer 24 (1), 5–24.
Fine, C.H., 1999. Clockspeed: Winning Industry Control in the Age of Temporary Advantage. Perseus Books, New York.
Flynn, B.B., Flynn, E.J., 1999. Information-processing alternatives for coping with manufacturing environment complexity. Decision Sciences 30 (4).
Galbraith, C.S., 1990. Transferring core manufacturing technologies in high-technology firms. California Management Review 32 (4), 56–70.
Galbraith, J., 1973. Designing Complex Organizations. Addison-Wesley, Reading, MA.
Galbraith, J., 1977. Organization Design. Addison-Wesley, Reading, MA.
Geisler, E., 1997. Intersector technology cooperation: hard myths, soft facts. Technovation 17 (6), 309–320.
Ghoshal, S., 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., 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., 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. Jossey-Bass, San Francisco.
Green, S.G., Gavin, M.B., 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.
Gruber, W.H., Marquis, D.G., 1969. Factors in the Transfer of Technology. The MIT Press, Cambridge, MA.
Hagedoorn, J., 1990. Organizational modes of inter-firm-co-operation and technology transfer. Technovation 10 (1), 17–30.
Hayes, R.C., Wheelwright, S.C., 1979. Link manufacturing process and product life cycles. Harvard Business Review 57 (1), 133–140.
Heide, J.B., 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., 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.
Hill, T., 1994. Manufacturing Strategy: Text and Cases. Irwin, Homewood, IL.
Holm, D.B., Eriksson, K., Johanson, J., 1996. Business networks and cooperation in international business relationships. Journal of International Business Studies 27 (5), 1033–1053, London.
Howells, J., 1996. Tacit knowledge, innovation, and technology transfer. Technology Analysis and Strategic Management 8 (2), 91–106.
Johnson, J.P., 1999. Multiple commitments and conflicting loyalties in international joint venture management teams. International Journal of Organizational Analysis 7 (1), 54–71.
Kedia, B.L., Bhagat, R.S., 1988. Cultural constraints on transfer of technology across nations: implications for research in international and comparative management. Academy of Management Review 13 (4), 559–571.
Keller, R.T., 1994. Technology-information processing fit and the performance of R&D project groups: a test of contingency theory. Academy of Management Journal 37 (1), 167–179.
Keller, R.T., Chinta, R.R., 1990. International technology transfer: strategies for success. Academy of Management Executive 4 (2), 33–43.
Khurana, A., 1999. Managing complex production processes. Sloan Management Review 40 (2), 85–97.

Kogut, B., Zander, U., 1993. Knowledge of the firm and the evolutionary theory of the multinational corporation. Journal of International Business Studies 24 (4), 625–645.

Kumar, V., Kumar, U., Persaud, A., 1999. Building technological capability through importing technology. Journal of Technology Transfer 24 (1), 81–96.

Lam, A., 1997. Embedded firms, embedded knowledge: problems of collaboration and knowledge transfer in global cooperative ventures. Organization Studies 18 (6), 973–996.

Leonard-Barton, D., 1995. Wellsprings of Knowledge: Building and Sustaining the Sources of Innovation. Harvard Business School Press, Boston.

Madhavan, R., Grover, R., 1998. From embedded knowledge to embodied knowledge: new product development on knowledge management. Journal of Marketing 62 (4), 1–12.

Mascitelli, R., 1999. A framework for sustainable advantage in global high-tech markets. International Journal of Technology Management 17 (3), 240–258.

McCann, J.E., Galbraith, J.R., 1981. Interdepartmental relations. In: Nystrom, Starbuck (Eds.), Handbook of Organizational Design. Oxford Univ. Press, New York, pp. 60–84.

McDonough, E.F., Barczak, G., 1992. The effects of cognitive problem-solving orientation and technological familiarity on faster new product development. The Journal of Product Innovation Management 9 (1), 44–52.

McKeen, J.D., Guimaraes, T., Wetherbe, J.C., 1994. The relationship between user participation and user satisfaction. MIS Quarterly 18 (4), 427–451.

Meredith, J.R., Mantel, S.J., 1995. Project Management: A Managerial Approach. Wiley, New York.

Meyer, A.D., Tsui, A.S., Hinings, C.R., 1993. Configurational approaches to organizational analysis. Academy of Management Journal 36 (6), 1175–1195.

Miles, R., Snow, C., 1978. Organizational Strategy, Structure, and Process. McGraw-Hill, New York.

Naumann, J.D., Davis, G.B., McKeen, J.D., 1980. Determining information requirements: a contingency method for selection of a requirements assurance strategy. Journal of Systems and Software 1, 273–281.

Nonaka, I., 1994. A dynamic theory of organizational knowledge creation. Organization Science 5 (1), 14–37.

Oxley, J.E., 1999. Institutional environment and the mechanisms of governance: the impact of intellectual property protection on the structure of inter-firm alliances. Journal of Economic Behavior and Organization 38 (3), 283–309.

Parkhe, A., 1991. Interfirm diversity, organizational learning, and longevity in global strategic alliances. Journal of International Business Studies, 579–601, 4th quarter.

Perrow, C., 1967. A framework for comparative analysis of organizations. American Sociological Review 32, 194–208.

Polyani, M., 1967. The Tacit Dimension. Doubleday, Garden City, NY.

Porter, M., 1980. Competitive Strategy. Free Press, New York, NY.

Rebentisch, E.S., 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., Zhao, L., 1990. International technology transfer: a review. Research Policy 19, 285–307.

Robey, D., 1986. Designing Organizations. Irwin, Homewood, IL.

Rogers, E.M., 1995. Diffusion of Innovations. Free Press, New York.

Schmenner, R.W., 1986. How can service businesses survive and prosper? Sloan Management Review 27 (3), 21–32.

Schon, D., 1967. Technology and Change. Pergamon, London.

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. Harper, New York.

Shenhar, A.J., 1998. From theory to practice: toward a typology of project-management styles. IEEE Transactions on Engineering Management 45 (1), 33–48.

Singh, K., 1997. The impact of technological complexity and interfirm cooperation on business survival. Academy of Management Journal 40 (2), 339–367.

Stock, G.N., Greis, N.P., Dibner, M.D., 1996. Parent-subsidiary communication in international biotechnology R&D. IEEE Transactions on Engineering Management 43 (1), 56–68.

Tait, P., Vessey, I., 1988. The effect of user involvement on system success: a contingency approach. MIS Quarterly, 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., Rosenthal, S.R., 1998. The Design and Development of Agfa Compugraphic's CG9400 Imagesetter. Center for Enterprise Leadership, Boston.

Tatikonda, M.V., Rosenthal, S.R., 2000a. Successful execution of product development projects: balancing firmness and flexibility in the innovation process. Journal of Operations, 18.

Tatikonda, M.V., Rosenthal, S.R., 2000b. Technology novelty, project complexity and product development project execution succcess. IEEE Transactions on Engineering Management 47 (1), 74–87.

Teece, D., 1977. Technology transfer by multinational firms: the resource cost of transferring technological know-how. Economic Journal 87, 242–261.

Teece, D.J., Pisano, G., Shuen, A., 1997. Dynamic capabilities and strategic management. Strategic Management Journal 18 (17), 509–533, Chichester.

Thompson, J.D., 1967. Organizations in Action: Social Science Bases of Administrative Theory. Mc Graw-Hill, New York.

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., 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., Anderson, P., 1986. Technological discontinuities and organizational environments. Administrative Science Quarterly 31 (3), 439–465.

Tushman, M.L., Nadler, D.A., 1978. Information processing as in integrating concept in organizational design. Academy of Management Review 3 (3), 613–624.

Tushman, M.L., Rosenkopf, L., 1992. Organizational determinants of technological change: toward a sociology of technological evolution. Research in Organizational Behavior 14, 311–347.

Van de Ven, A.H., Delbecq, A.L., Koenig, R. Jr., 1976. Determinants of coordination modes within organizations. American Sociological Review 41, 322–338.

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

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., 1996. A theory of conflict in lateral organizational relationships. In: Lawrence, J.R. (Ed.), Operational Research and the Social Sciences. Tavistock, London, pp. 409–428.

Ward, P., Bickford, D., Leong, G.K., 1996. Configurations of manufacturing strategy, business strategy, environment, and structure. Journal of Management 22 (4), 597–626.

Wernerfelt, B., 1984. A resource-based view of the firm. Strategic Management Journal 5 (2), 171–180.

Wheelwright, S.C., Clark, K.B., 1992. Creating project plans to focus product development. Harvard Business Review, 70–82, March-April.

Williamson, O.E., 1975. Markets and Hierarchies: Analysis and Antitrust Implications. The Free Press, New York.

Wong, A., 1984. Partnering through cooperative goals in supply chain relationships. Total Quality Management 10 (4/5), 786–792.

Yin, R.K., 1984. Case Study Research. Sage Publications, Newbury Park, CA.

Yoon, E., Lilien, G.L., 1985. New industrial product performance: the effects of market characteristics and strategy. The Journal Of Product Innovation Management 2 (3), 134–144.

Zajac, E.J., Olsen, C.P., 1993. From transaction cost to transactional value analysis: implications for the study of interorganizational strategies. The Journal of Management Studies 30 (1), 131–145.