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TRANSFORMATIONAL TECHNOLOGIES AND THE CREATION OF NEW WORK PRACTICES: MAKING IMPLICIT KNOWLEDGE EXPLICIT IN TASK-BASED OFFSHORING[1]

By: **Paul M. Leonardi**
Department of Communication Studies and Department of Industrial Engineering and Management Sciences
Northwestern University
2240 Campus Drive
Evanston, IL 60208
U.S.A.
Leonardi@northwestern.edu

Diane E. Bailey
Center for Work, Technology and Organization
Department of Management Science and Engineering
428 Terman Building
Stanford University
Stanford, CA 94305
U.S.A.
diane.bailey@stanford.edu

Abstract

Studies have shown the knowledge transfer problems that arise when communication and storage technologies are employed to accomplish work across time and space. Much less is known about knowledge transfer problems associated with ***transformational technologies****, which afford the creation, modification, and manipulation of digital artifacts. Yet, these technologies play a critical role in offshoring by allowing the distribution of work at the task level, what we call* ***task-based offshoring****. For example, computer-aided engineering applications transform input like physical dimensions, location coordinates, and material properties into computational models that can be shared electronically among engineers around the world as they work together on analysis tasks. Digital artifacts created via transformational technologies often embody implicit knowledge that must be correctly interpreted to successfully act upon the artifacts. To explore what problems might arise in interpreting this implicit knowledge across time and space, and how individuals might remedy these problems, we studied a firm that sent engineering tasks from home sites in Mexico and the United States to an offshore site in India. Despite having proper formal education and ample tool skills, the Indian engineers had difficulty interpreting the implicit knowledge embodied in artifacts sent to them from Mexico and the United States. To resolve and prevent the problems that subsequently arose, individuals from the home sites developed five new work practices to transfer occupational knowledge to the offshore site. The five practices were* ***defining requirements, monitoring progress, fixing returns, routing tasks strategically****, and* ***filtering quality.*** *The extent to which sending engineers in our study were free from having to enact these new work practices because on-site coordinators acted on their behalf predicted their perceptions of the effectiveness of the offshoring arrangement, but Indian engineers preferred learning from sending engineers, not on-site coordinators. Our study contributes to theories of knowledge transfer and has practical implications for managing task-based offshoring arrangements.*

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Keywords: Transformational technologies, work practices, offshoring, knowledge transfer, distributed work

Introduction

Given the important role that information technology plays in offshored and distributed work, it is no surprise that organizations and information systems scholars have paid close attention to how IT enables and constrains the flow of knowledge and information across time and space. Two types of IT in particular have dominated researchers' attention: communication and storage technologies (Alavi and Tiwana 2002; Malhotra and Majchrzak 2005). Phones, e-mail, chat rooms, and other *communication technologies* primarily serve as conduits for messages containing knowledge and information. *Storage technologies* such as knowledge management systems and version control systems permit storage, retrieval, and sharing of knowledge and information that is explicitly codified (Davenport and Prusak 1998).

The attention paid to these two types of IT has revealed problems of knowledge transfer that plague individuals working across time and space. Researchers have found that communication technologies inadequately convey contextual cues and consequently impede separated individuals from establishing mutual knowledge (Cramton 2001), sharing unique knowledge (Griffith et al. 2003; Hollingshead 1996), and deciphering new knowledge (Alavi and Tiwana 2002). Storage technologies similarly foster problems: Because these technologies store decontextualized knowledge (Dibbern et al. 2004; Majchrzak et al. 2005) that is communicated asynchronously (Montoya-Weiss et al. 2001), individuals who later retrieve the knowledge struggle to appropriately apply it (Sole and Edmondson 2002) and to integrate it into their streams of action (Kirkman and Law 2005). Researchers seek to address these problems by developing new IT that can convey context (Boland et al. 1994) and by incorporating contextualization into team communication strategies (Te'eni 2001).

In addition to communication and storage technologies, a third type of IT facilitates the offshoring or distribution of much knowledge-intensive work, but its role in knowledge and information transfer has received scant research attention to date. This third type of IT, which we call *transformational technologies*, affords the creation, modification, and manipulation of digital artifacts in the process of converting input into output. Whereas communication and storage technologies are meant to transmit and store artifacts with little alteration of their content, form, or purpose, transformational technologies are designed to output artifacts that are distinctly different in content, form, or purpose from the original input. Examples of transformational technologies include spreadsheet applications and word processing technologies that individuals use to convert input like handwritten notes into budgets and reports. Transformational technologies also encompass sophisticated mathematics-based information technologies such as computer-aided engineering (CAE) technologies, which are used to transform input from computer-aided design (CAD) drawings, including physical dimensions, location coordinates, and material properties, into computational models for analysis. Transformational technologies are becoming increasingly important in offshored and distributed work because, in the course of transforming input into output, they allow collaborative authoring (Malhotra et al. 2001), transmission and storage of knowledge (Thurk and Fine 2003), and shared access to common information (Thomke 2006).

When used to accomplish work across time and space, transformational technologies are often employed in conjunction with communication and storage technologies, as illustrated in Figure 1. Individuals may send task requests and inquiries via communication technologies; they may even send task artifacts, as in the case of e-mail attachments or file transfer protocols. Alternatively, messages sent by communication technologies may simply provide pointers to artifacts in storage technologies. But whereas communication technologies may serve as the transport mechanism for task products and storage technologies may serve as their repositories, transformational technologies provide the mechanisms for creating, viewing, modifying, and analyzing a large range of knowledge artifacts. In short, offshored or distributed work does not end when a message is sent or a file is stored or retrieved. Rather, work is often begun and continues through the use of transformational technologies, whose output embodies task-critical knowledge and information for further communication and data storage in a cycle of ongoing work.

Despite the important role played by transformational technologies in facilitating offshored and distributed work, they are often overlooked by researchers. Malone and Crowston's (1994) early attempt to construct a taxonomy of collaborative-work technologies included only communication technologies and a variety of groupware, such as meeting scheduling technologies and electronic meeting rooms. More recently, in a study of 54 distributed teams covering a range of industries and projects, Majchrzak et al. (2005) detailed the technologies that teams employed to support their virtual collaboration; the resulting list covered a range of communication and storage technologies, but almost no transformational technologies (application sharing programs came the closest). In a study of

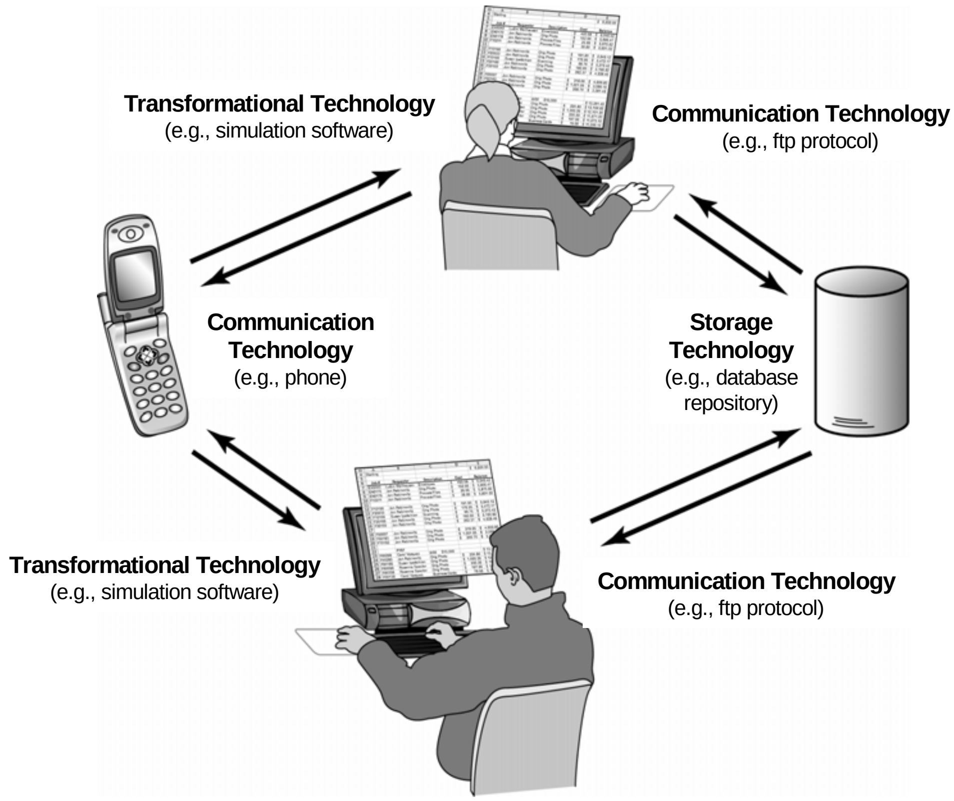

Figure 1. Flow of Knowledge and Information in Offshored or Distributed Work

globally distributed software development teams, Cramton and Webber (2005) reported that teams employed e-mail, Lotus Notes, telephone, databases, and video and telephone conferencing in their work across national boundaries; transformational technologies were absent from this list. In general, studies of offshored and distributed work tend to focus on team processes of communication and coordination and their associated technologies rather than on domain-specific task processes and the technologies employed to carry them out (Hinds and Bailey 2003; Martins et al. 2004; Maruping and Agarwal 2004; Powell et al. 2004).

In this paper, we add to the literature of knowledge transfer problems in offshored and distributed work by investigating how individuals contend with problems that arise from the use of transformational technologies across time and space. To begin, we draw upon the literature on distributed teams and on IT outsourcing and offshoring to argue that the problems associated with transformational technologies are likely to differ from those identified for communication and storage technologies. Thus, to fully understand the potential obstacles associated with offshoring or distributing knowledge-intensive work, researchers needs to include in their purview the entire suite of information technologies that individuals employ.

Theoretical Background

Before transformational technologies became commonplace in many occupations, it was difficult or impossible for individuals in different places to work together on the same task because there were few mechanisms for sharing task artifacts. As a result, large chunks of work were assigned to collocated groups to reduce interdependencies across time and space. Work was typically offshored or distributed if it could be divided at functional boundaries, thus reducing the need for coordination (Kotabe and Swan 1994). For example, the U.S automotive industry for many years has sent the entirety of engineering design work for particular vehicles offshore, thereby reducing the need for collaborative task work and requiring only the delivery of the end product: a completely engineered vehicle (Clark and Fujimoto 1991). In work that is offshored or distributed in this manner, individuals working across time, space, and function often have problems bridging differences in their occupational knowledge and work practices. Problems routinely occur, for example, when individuals fail to convey function-specific contextual knowledge, such as time constraints, requirements, or goals (Alavi and Tiwana 2002; Cramton 2001). To overcome these problems, these groups need to develop a common, highly abstract knowledge base so that each member can understand all of the functional domains well enough for the group to work together.

Transformational technologies are dramatically reshaping the way offshoring occurs by permitting the global distribution of work within, rather than only across, functions. Because these technologies can digitize work artifacts (e.g., financial spreadsheets or scientific reports), work becomes portable in ways that it has not been in the past. By permitting the electronic transmission of artifacts and thereby enabling individuals at geographically disparate sites to work on shared task products, digitization makes offshoring possible at the task level within functions. In automotive engineering, for example, transformational technologies enable the offshoring of tasks that take mere hours, such as building computational models, rather than offshoring the whole of engineering design work. This new form of distributed work—which we term *task-based offshoring*—brings with it new implications for knowledge transfer. These implications arise, in part, from the type of knowledge that transformational technologies embody.

Like communication and storage technologies, transformational technologies may embody explicit knowledge, as studies of scientists and laboratories have made clear (Latour and Woolgar 1986; Pickering 1995). A spreadsheet with embedded formulas that compute values based upon data entry, for example, embodies the explicit knowledge that is represented in the formulas, such as simple trigonometric functions. Unlike these other technologies, transformational technologies have the further potential to embody implicit knowledge. We use the term implicit in the manner proposed by Griffith, Sawyer and Neale (2003), who construe implicit knowledge as lying between explicit and tacit knowledge: Implicit knowledge is not currently declarative like explicit knowledge, but, unlike tacit knowledge, could be made so. Implicit knowledge is often embodied in an artifact's structure or features. For example, a model built in a finite element analysis software program might feature small rectangular shapes in one area and large ones elsewhere, a difference that would suggest that analyses are intended for the area with the smaller shapes (whose size facilitates more precise computations). The implicit knowledge embodied by transformational technologies is helpful because artifacts are often created, viewed, and manipulated within these technologies absent clear documentation of how they were created, what assumptions they reflect, or their intended use. Gleaning this kind of information from an artifact typically requires interpretation of embodied implicit knowledge on the part of a knowledgeable user (Thurk and Fine 2003).

In the context of transformational technologies, problems of transferring knowledge and information across time and space thus appear likely to arise from sending artifacts created with these technologies and trusting in the recipient's correct interpretation of the knowledge embodied in the artifacts. These problems are distinct from issues of mutual knowledge creation that involve conveying context-dependent knowledge and translating one's unique occupational knowledge into terms that others can understand. The knowledge transfer problems associated with transformational technologies concern a skill (the ability to interpret the implicit knowledge associated with artifacts routinely created and modified within an occupation) that is a reflection of one's occupational knowledge. Whereas problems in mutual knowledge creation and the sharing of contextual information, because they often arise across occupational and functional domains, are generally viewed as problems in communication and coordination (Cramton 2001; Hinds and Bailey 2003; Majchrzak et al. 2005; Weisband 2002), an inability to interpret implicit knowledge in artifacts could be construed as lacking adequate technical knowledge to perform the work. Because the supplier's technical knowledge is critical to the success of an offshoring relationship (Beath and Walker 1998), such a conclusion could have severe ramifications. Consequently, problems in interpreting implicit knowledge may resonate more broadly in task-based offshoring than in cross-functional offshoring, in which only a general understanding of the domain knowledge possessed by members of other functions is needed and hence the interpretation of knowledge encoded in the artifacts produced with transformational technologies may not be expected or important (Star and Griesemer 1989).

The IT outsourcing and offshoring literature most often views a dearth of knowledge on the supplier's side as an inadequate understanding of firm-specific work practices, business needs, and specifications, not insufficient occupational knowledge that is more universal in nature (Dibbern et al. 2004). Because time spent bringing the offshore employees "up to speed" on the home site's practices and processes is costly (Barthélemy and Geyer 2001; Pfannenstein and Tsai 2002) authors have recommended a number of methods for quicker knowledge transfer. Rottman and Lacity (2004) suggested that the home site send representatives to the offshore site to provide intense training in work methodologies and technologies. Having offshore workers spend several months at the home site is also recommended (Morstead and Blount 2003).

Several researchers have suggested that offshore sites send an on-site coordinator to the client site to shepherd the flow of knowledge offshore (Carmel 2006; Rottman and Lacity 2004). Other approaches seek to reduce the problem through job selection or job design when planning offshored work, for example by only offshoring work for which necessary knowledge can be made fully explicit (Aron and Singh 2004) or by reengineering jobs to be offshored by decreasing their context-dependent content (Apte and Mason 1995).

A study by Apte and Mason (1995) stands out in its recognition that the supplier's employees may have difficulty interpreting implicit knowledge in artifacts. In arguing that offshored jobs should be designed to have strong symbol manipulation content and little need for customer interaction or physical presence, Apte and Mason noted that it was necessary for the relevant symbols to be "packaged" in a movable medium and that the individual at the offshore site could "open the package, interpret the symbols and supply meaning and understanding to them" (p. 1256). A more frequent worry than the supplier's employees being able to interpret artifacts from the client is the possibility that, over time, the client may lose the technical knowledge necessary for completing the work (Clark et al. 1995; Duncan 1998; Takeishi 2001). Consequently, determining how much the client learns during the relationship appears a more common interest to date than how much the supplier learns (Abraham et al. 1998; Goo et al. 2007).

Yet, the offshoring literature consistently shows that many task-based offshoring arrangements involve technical experts at the home site and far less experienced individuals at the offshore site (Carmel and Agarwal 2002; Lacity and Willcocks 2001). This disparity in expertise raises the strong possibility that individuals who receive work offshore may not be able to interpret the knowledge embedded in artifacts by their expert and distant colleagues. More broadly, this disparity suggests that individuals at the offshore site may lack the necessary occupational knowledge and judgment, beyond simply the ability to interpret implicit knowledge embodied in artifacts, to undertake the work. For example, less experienced individuals may struggle simply to create appropriate artifacts on their own and to otherwise carry out tasks.

As a result, offshore employees may need to learn not just firm-specific work practices, needs, and specifications, but general occupational skills and knowledge. Until offshore employees gain such knowledge, individuals at the home site may find it necessary to thoroughly detail what is to be done and how, perhaps by making explicit the knowledge that is implicit in work artifacts sent offshore. In other words, the client may have to "spell out" more knowledge and information for tasks to be completed by the supplier. Depending on the capability of the transformational technology to facilitate documentation of explicit knowledge, the client's employees may have to develop new work practices, similar to what studies of technology use have shown when individuals cannot fully accomplish a task solely through the use of a particular IT (Mackay et al. 2000; Oudshoorn et al. 2004; Pollock 2005).

In sum, overlooking transformational technologies in offshored and distributed work is problematic because doing so may obscure problems in transferring knowledge and information across time and space. To investigate these problems and how individuals contend with them, we compare two models of task-based offshoring. Both models feature experts at the home site and less experienced workers at the offshore site. One model has on-site coordinators who mediate between the home and offshore sites; the other model does not. Having an on-site coordinator to essentially broker knowledge transfer is the recommendation perhaps most commonly followed by firms (Farrell 2006). Studies of knowledge brokering suggest that individuals who mediate between contexts separated by differences in expertise can translate knowledge in ways that make it palpable to less experienced individuals (Barley 1996; Bechky 2003; Hargadon and Sutton 1997); however, these studies were not conducted in an offshoring context in which working across time and space may make brokering difficult. We thus investigate the extent to which having a coordinator is helpful in providing occupational knowledge to offshore individuals and in aiding their interpretation of implicit knowledge embodied in artifacts created in transformational technologies. We also consider what new work practices individuals may develop to help in this endeavor.

We thus address three research questions: (1) What work practices are developed to help transfer occupational knowledge and to aid in the interpretation of implicit knowledge embodied in artifacts? (2) What role do coordinators play in these practices? (3) In the context of knowledge transfer problems and learning needs, how effective do individuals in the client and supplier sites perceive the offshoring arrangement to be?

Research Methods

Research Setting

We chose International Automobile Corporation (IAC) as the setting for our study. IAC is a large automobile manufacturer headquartered in the United States whose distribution of engineering work across several continents is increasingly typical of the industry. Although the majority of IAC's engineering workforce resides at its technical center in Michigan, IAC has long maintained engineering operations abroad and today has engineering centers in more than eight countries. Each center develops vehicle architectures upon which different models (called programs) can be based. In 2003, IAC opened a new center in India to provide digital engineering services to IAC's global engineering centers. The center in India was unique in that it had no vehicle program of its own; its sole purpose was to complete off-shored engineering tasks for other IAC centers. We focused on two of IAC's program-based centers (the home sites, in Mexico and the United States) and their interactions with the India center (the offshore site).

Each of the three sites employed the same IT suite consisting of one shared database and three other technology suites. The database, a storage technology, was housed in the United States and served as the digital repository of all CAD files related to vehicle development, with access to engineers around the world. The CAD files served as input to a suite of CAE technologies that supported model building and analysis. The CAE suite, which consisted of the main transformational technologies in our study, was identical across the Mexico, U.S., and India sites, but each site held its own licenses and ran the technologies independently on its own computers. The U.S. and Mexico sites had purchased licenses for the CAE suite approximately 6 years before the start of this study and the India site purchased their licenses approximately 3 years prior. A second suite of technologies, consisting of communication and storage technologies, aided the storage of models and analyses completed by the Indian engineers and the sending of these engineering artifacts to Mexican or U.S. engineers, who would examine, analyze, and interpret them. This suite consisted of task-specific file directories on the servers of the Mexico and U.S. sites to which Indian engineers posted their work via ftp and from which Mexican and U.S. engineers downloaded files to their desktop computers. Beyond these technologies for creating, storing, and sharing engineering artifacts, all three sites also made use of a suite of standard communication technologies, including e-mail, phone, voicemail, and PowerPoint.

At the Mexico and U.S. centers, engineers were organized by specialty. Two of the specialties most directly involved with product development were design engineers (DEs) and performance engineers (PEs). DEs were responsible for particular vehicle parts from conception to design through manufacturing. DEs drafted their parts in CAD, ensured manufacturability, and confirmed satisfaction of performance requirements.[2] To accomplish this final step, DEs worked closely with PEs, who were responsible for validating and testing vehicle performance.

For years, IAC had operated proving grounds at which PEs conducted physical performance tests (e.g., crash tests), but increasingly such tests were carried out virtually in CAE technologies. Drawing upon the DEs' CAD models, PEs created CAE models representing all of the parts in a vehicle. PEs utilized sophisticated computational techniques within the CAE technologies, such as finite element analysis, to test vehicle performance by calculating a vehicle's structural, mechanical, thermal, and other states under a variety of conditions. PEs relayed the test results back to DEs, who, in the event of test failure, had to modify their designs.

Although both DEs and PEs employed IT in their everyday work, the activities of the latter were the primary focus of task-based offshoring at IAC. Unlike DEs, whose design tasks required hands-on familiarity with and constant assessment of physical parts, PEs worked almost exclusively with digital representations of parts and vehicles. In the eyes of IAC managers, and in accordance with IT offshoring recommendations (Apte and Mason 1995; Farrell and Rosenfeld 2005), the digitized, computational nature of model building and analysis meant that PEs could easily share work across time and space, as reflected in these comments from two managers.

> *When you look at our portfolio of engineering expertise, it makes the most sense to offshore performance engineering work because, unlike DEs, PEs will, at least someday, we hope, work in a completely virtual world to do their model building and analysis. So it just makes sense that we get them the technologies they need, the information systems to coordinate their work, and then they'll be able to divide up their work and send it around the world. That's the beauty of using these technologies.*

> *It wasn't like you were going to take a bumper and send it to a different country and say, "Here, run some tests on this." That just wasn't feasible. Bumpers are expensive to ship and the facilities that you'd have to build to test them are even more expensive. But now that we work in math, you can do that. It's like sending a bumper, but the postage is free.*

IAC mandated no universal arrangement across its engineering centers for offshoring PE work to the India service center. Consequently, differing historical conditions at the Mexico and U.S. centers prompted different arrangements across the two sites. We call the Mexican center's arrange-

[2] Carlile (2004) and Obstfeld (2005) provide similar examples of the work of design engineers.

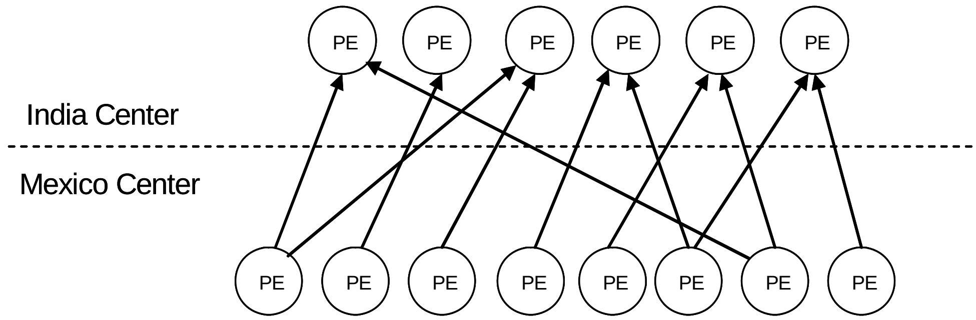

Figure 2. Direct-Interfacing Model (Mexico)

ment a *direct-interfacing* model. Under this model, as shown in Figure 2, when a Mexican PE wished to offshore a task to India, she had to first identify and contact the appropriate Indian PE. She arranged with this PE how the CAD and CAE models would be transferred, what tasks needed to be done, and by what date. Over the course of the assignment, the two engineers interacted until the Mexican PE was satisfied with the completed work. In effect, a Mexican PE worked with an Indian PE just as she would have an engineer who sat two desks away from her in Mexico. She may have simultaneously interacted with more than one Indian PE, perhaps because she had offshored two separate tasks.

By contrast, PEs under the U.S. center's arrangement, which we refer to as a *gate-keeping* model, were rarely in direct contact with Indian PEs. Instead, as illustrated in Figure 3, U.S. and Indian PEs interacted through third party on-site coordinators. Upon receiving an offshoring request from a U.S. PE, the coordinator collected the relevant CAD and CAE models, wrote up a statement of requirements (SOR) to specify the tasks, and then sent the models and SOR to the Indian PE, whom he ensured understood the specifics of the request. Coordinators reviewed completed work as it was returned and summarized results for the U.S. PEs.

The coordinator role arose at the U.S. center because that center offshored tasks to India prior to the opening of the IAC India center. Before the center existed, U.S. PEs sent tasks to engineering consulting firms in India, each of which sent a representative to the U.S. center to serve as the conduit for work sent and received. When the center in India was established, these representatives from the Indian consulting firms, whose efforts the U.S. PEs deemed valuable, became coordinators in the U.S. model. Lacking this history of task-based offshoring, the Mexico center developed its own, more direct model for offshoring work to the India center.

U.S. managers considered the coordinator role superfluous and were working to dismantle it now that the Indian PEs worked within the IAC organization. In the minds of the managers, the two primary kinds of knowledge required to complete the PE tasks sent to India were, first, knowledge of how to operate the CAD and CAE technologies and, second, knowledge of how to interpret and act upon the implicit knowledge embodied in the artifacts created with those technologies. Managers believed that the second form of knowledge derived in part from knowing how to use the technologies and in part from fundamental engineering principles taught in university programs. Because Indian PEs held engineering degrees and were fully adept with the technologies, the U.S. managers believed that Indian PEs could complete the offshored tasks with little more information conveyed to them than the particularities of each assignment, which could be captured in a brief request form. From the U.S. managers' perspective, coordinators had been useful as intermediaries between IAC and external consulting firms, but were not needed with an internal, IAC-owned Indian center.

Knowledge differences in realms other than tool use, however, suggested that the offshoring of engineering tasks might require considerable knowledge transfer between sending and receiving PEs, thus providing coordinators with a possible role as knowledge brokers. The tenure of Indian PEs with IAC was shorter than most of their counterparts in the United States and Mexico, which meant they lacked certain firm-specific knowledge of work practices. Moreover, Indian PEs grew up in an era when automobiles were uncommon in India: Most Indian PEs were raised in families without a car, did not currently own a car; in many cases, they had never driven a car. Consequently, the product knowledge of the Indian PEs was far inferior to that of their colleagues abroad. These differences spoke to levels and types of expertise at the two sending centers in Mexico and the United States that was

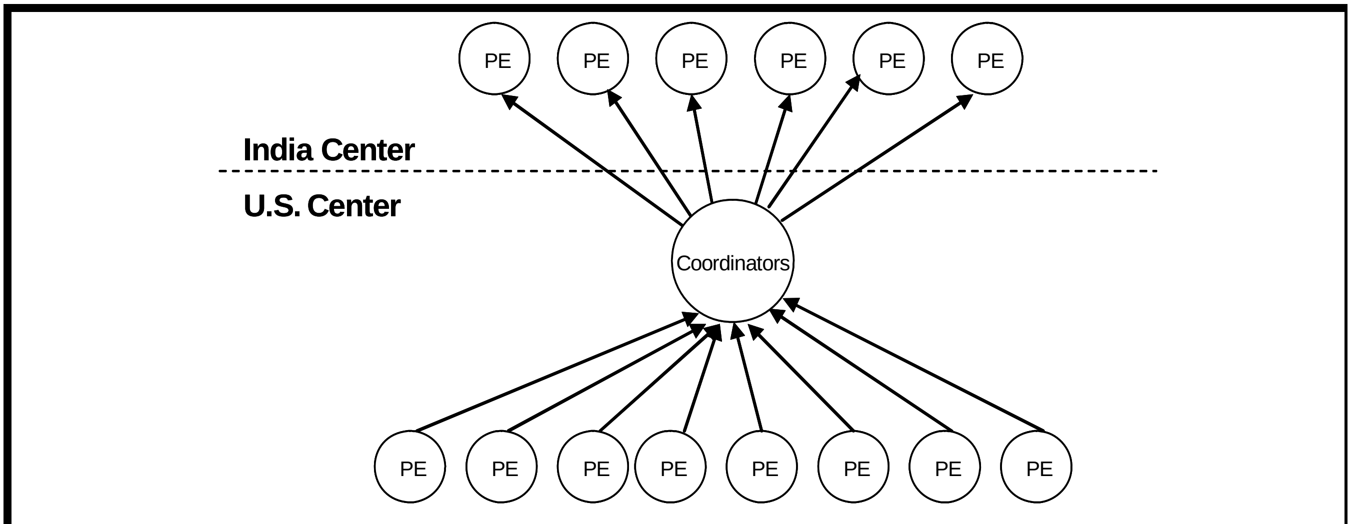

Figure 3. Gate-Keeping Model (United States)

unmatched at the India center, a situation that gave rise to the possibility that organizational and product knowledge would need to be transferred across sites in the offshoring process. In addition, because the PEs at the India center had the same type and degree of university engineering education as their Mexican and U.S. counterparts (and thus possessed the formal knowledge deemed necessary to do this work), but as a group were younger and had less practical work experience, the likelihood of occupational knowledge transfer was also strong.

Data Collection and Analysis

Given the exploratory nature of this study, we followed the work of other researchers who have adopted an iterative approach to data collection and analysis (Ancona and Caldwell 1992; Majchrzak et al. 2000; Sutton and Hargadon 1996). Our strategy was to collect initial data from observations and interviews of informants, analyze those data to determine what questions remained unanswered, and then employ other data collection methods to fill in the holes in our analysis. Table 1 summarizes, for each phase of our data collection details about the method, the informants or source, the topics explored, and the purpose of the data collection and analysis.

Phase 1: Collection and Analysis of Observation and Interview Data

Research has repeatedly shown that people have a difficult time articulating what work they do and how they do it (Collins 1974; Dreyfus and Dreyfus 1986; Orr 1996). Therefore, we spent a total of 10.5 months conducting ethnographic observations for the purposes of understanding the activities that individuals routinely carried out to transfer knowledge and information between the sending and receiving sites. The first author spent 4 months (August through November 2005) observing PEs and coordinators at the U.S. center. He next spent 2.5 months (January through mid-March, 2006) observing the work of PEs at the Mexico center. Finally, both authors and a research assistant spent a total of 4 person-months (mid-April through mid-July 2006) observing the work of PEs at the India service center. In total, we observed 6 PEs at the Mexico center, 12 PEs and 3 coordinators at the U.S. center, and 11 PEs at the India center.

During our observations, we wrote careful, detailed field notes in which we recorded the informant's every action, including his typed commands, conversations, tool usage, and use of documents and other work artifacts. We asked for screenshots when PEs worked on the computer, made photocopies of physical documents they employed (e.g., manuals, faxes), and described or sketched other artifacts (e.g., vehicle parts). We audio-recorded most conversations. After each session, we immediately expanded our running field notes, incorporating into them transcriptions of recorded conversations and full descriptions of the artifacts we had collected. The final record of action—dialogue interwoven with descriptions and images of artifacts keyed to the exact moment of their use—provided us with thorough documentation of work practices. To ensure we understood the work practices undertaken by each PE, we typically spent at least three sessions with each informant.

Table 1. Summary of Data Collection and Analysis by Phase

	Stage	Method	Informants/Source	Topics	Purpose
Phase I	Data collection	Observations (total 10.5 months)	3 U.S. coordinators 12 U.S. PEs 11 India PEs 6 Mexican PEs	Everyday activities undertaken to transfer knowledge for offshored work	To understand what sending PEs and coordinators did to transfer knowledge and facilitate offshoring
		Semi-structured interviews (30 to 60 minutes)	3 Coordinators 53 PEs 9 managers	Observed activities	To confirm observed activities and gain deeper understanding for why PEs carried them out
	Analysis	Inductive, iterative coding	Expanded field notes from observations plus interview transcripts	Work practices	To group sets of lower-level activities into coherent work practices
Phase 2	Data collection	Survey (96% response rate)	73 U.S. PEs 49 Mexican PEs (all PEs in Mexico and U.S. who had offshored tasks)	Frequency of work practices, plus effectiveness measures	To confirm that work practices identified in Phase 1 were commonly employed across the total sending PE population and to gauge PEs' assessment of off-shoring effectiveness
	Analysis	ANOVA and regression	118 survey responses (all but 4 of the surveyed PEs)	Offshoring model com-parison and testing of relationships among survey variables	To measure differences in the frequency of work practices across Mexican and U.S. PEs and to determine if frequency was related to effectiveness assessments
Phase 3	Data collection	Project-tracking logs	59 Mexican tasks 104 U.S. tasks (all tasks offshored during a 2-year period)	Task completion data, including time spent by sending PEs and their rating of performance	To confirm survey results from Phase 2 (reflecting overall assessments at time of study) with data from tracked tasks (reflecting particular assess-ments at time of task completion)
	Analysis	ANOVA and regression	163 log entries (sum of tasks from Mexico and U.S.)	Offshoring model com-parison and relationship among project log variables	To measure differences in time spent managing offshored work across Mexican and U.S. PEs and to determine if time spent was related to ratings of performance

We also conducted semi-structured interviews at each location to clarify activities documented in our observations and to gain a deeper understanding of why the activities were undertaken. We developed protocols for informants based on location (Mexico, United States, India) and job type (PE, coordinator, manager). Interviews ranged in length from 30 minutes to 1 hour and were audio-recorded and later transcribed. In total, we conducted an interview with each of the three U.S. coordinators as well as 53 PEs and 9 managers across the three sites.

We analyzed the observation and interview data collected at each site immediately after ending our stay there. We chose this strategy of site-specific coding to help focus our data collection efforts at the next site (Perlow et al. 2004). To perform these analyses, we employed an inductive qualitative coding scheme. Starting with the U.S. observation and interview data, which were collected first, we began by examining the work of the coordinators, whose jobs wholly concerned the practice of offshoring. From multiple reads of our data, we developed a list of the types of activities the coordinators conducted. Examples of activities included "collect relevant information from DE," "place phone call to Indian PE to check on task status," and "inspect completed work received from India." We coded each instance of these activities in the observation and interview records. Next, we sorted coded activities into clusters based on similarity until we could identify a coherent set of work practices that coordinators employed in the offshoring of work (Strauss and Corbin 1998). For example, we grouped activities such as "collect

Table 2. Identified Work Practices and Their Constituent Activities

Work Practice	Constituent Activity
Defining Requirements	• Collect task information • Collect relevant information from DE • Define project • Prepare SOR (including type of analysis, type of model, and issues to attend to) • Prepare PowerPoint file to complement SOR
Monitoring Progress	• Place phone call to Indian PE to check on task status • Send e-mail to Indian PE to check on task status • Remind PE of deadline
Fixing Returns	• Inspect completed work received from India • Fix problems in received models and analyses
Routing Tasks Strategically	• Hold weekly status calls with Indian managers • Monitor number of jobs currently at India • Gauge number and timing of expected tasks to be sent • Reserve/confirm available resources • Send new jobs when resources clearly available
Filtering Quality	• Compare returned work against defined requirements • Determine what aspects of returned work meet criteria • Ask Indian PE to redo aspects of returned work that fail to meet criteria or expectations

task information," "define project," and "prepare SOR" into the work practice "defining requirements." The other work practices were "monitoring progress," "fixing returns," "routing tasks strategically," and "filtering quality." Table 2 lists the specific activities associated with each work practice. We describe the work practices in detail in the next section.

We used these practices derived from the coordinator data as codes with which to analyze the data collected on the work of PEs at the U.S center. We chose to use this iterative process because it is effective when one is attempting to uncover whether processes are similar or different across groups (Eisenhardt 1989; Lofland and Lofland 1995; Taylor and Trujillo 2001). When we completed overlaying this coding scheme on the data for U.S. PEs, we went back through the data to determine if the PEs conducted additional offshoring practices that coordinators did not, but found none. We again employed this same coding scheme after completing observations and interviews with PEs in Mexico. To verify that we had not missed additional practices in the data we went back through the Mexico center data with an open-coding scheme (Strauss and Corbin 1998). We uncovered no additional practices conducted by Mexican PEs.

Phase 2: Collection and Analysis of Survey Data

To confirm that the work practices identified in Phase 1 were commonly employed by all PEs at the Mexico and U.S. sites beyond the PEs that we observed and interviewed, we devised a survey instrument (Appendix A) to query PEs about their offshoring practices. Survey questions 1 and 2 asked for information on the number of years the PE had offshored tasks and the number of tasks that she had offshored, which we employed as control variables. Survey questions 3 through 7 asked PEs to rate on a 5-point scale the frequency with which they conducted a specific observed work practice when offshoring work to India. To prompt the respondents' recognition of the practice while keeping the survey length short enough to ensure completion, each question included a set of specific constituent activities that strongly reflected and accurately represented the practice as indicated by our Phase 1 analysis.[3] For example, question 3, "I spend a significant portion of time collecting information, defining projects, and preparing SORs to send to the India center," includes three specific activities that together make clear the work practice of "defining requirements." Questions 4 through 7 similarly listed specific activities for the remaining work practices. Survey questions 8, 9, and 10 asked respondents to assess the effectiveness of the offshoring arrangement via three key

[3]By not asking about each activity separately, we could not verify statistically that the activities listed in Table 2 loaded onto their respective work practices as determined in our Phase 1 analysis. Although this choice is a limitation of our study, our primary intent was to gauge whether or not the practices were common among PEs, which necessitated a short survey to ensure completion by engineers facing tight deadlines.

metrics that our observation and interview data indicated were reflective of PEs' expectations: (1) the quality of the task completed; (2) the speed with which the task was completed; and (3) the amount of time a PE saved by offshoring the task.

To determine the respondent pool for our survey, we asked U.S. coordinators for a complete list of PEs at the U.S. center who had offshored work to India since its 2003 inception. In total, they gave us the names of 73 U.S. PEs. In Mexico, we received a similar list with the names of 49 PEs. We then printed hard copies of the survey and physically went to the desks of all 122 PEs to ask them to fill out the survey. We received responses from all but three PEs in the U.S. and one PE in Mexico, resulting in 118 completed surveys (96 percent response rate).

We analyzed these survey responses in two ways. First, we submitted all 10 questions to an analysis of variance test to determine differences in PEs' responses across the two offshoring models. We averaged the three effectiveness scores from questions 8, 9, and 10 into a composite variable representing the PEs' overall assessment of effectiveness. Second, we regressed the four effectiveness variables (quality, speed, and time savings plus the overall assessment) against the frequencies with which PEs conducted the observed work practices to test if differences across the two models could account for differences in PEs' assessment of effectiveness.

Phase 3: Collection and Analysis of Project-Tracking Data

The final phase of data collection and analysis occurred fortuitously and gave us the opportunity to confirm the PEs' assessments and estimates on the surveys with similar effectiveness assessments that they had previously provided to their managers. A PE manager in the U.S. center gave us a project-tracking log of all the work that his PEs offshored to the India center over a two-year period. For each offshored task entered in the log, the manager had recorded four project-tracking variables with numeric values: (1) the number of hours the U.S. PE expected the task would take to complete; (2) the actual hours the task took to complete; (3) the number of hours the U.S. PE spent redoing the Indian PE's work due to poor quality; and (4) the approximate number of hours the U.S. PE spent communicating with the coordinator to offshore the task. A fifth entry for each task reflected the U.S. PE's overall rating (on a five-point scale) of the India center's performance on that task. In total, this log tracked 104 offshored tasks. After some probing, we discovered that a manager in the Mexico center had kept a similar log over the same two-year period tracking 59 jobs.

From the data in the logs we created a sixth variable, the delayed completion time, to capture the amount of time a task required for completion in excess of the sending PE's original estimate. To calculate this value, we subtracted the expected number of hours to complete the task from the actual number of hours it took to complete the task. Positive values represented how long the sending PE had to wait for his results beyond his expectation for task completion. Negative values indicated how much sooner than expected a sending PE received the completed work. We employed analysis of variance tests on the log data to determine differences across sites and regression analyses to correlate the four project-tracking variables with the overall performance rating. We then compared these results with the results obtained by the survey.

Findings

Our qualitative analysis of the activities performed by PEs and coordinators in the U.S. and PEs in Mexico identified five offshoring work practices related to knowledge transfer between the home and offshore sites among individuals who shared artifacts that they created and modified with transformational technologies. Three work practices (defining requirements, monitoring progress, and fixing returns) were common to both Mexico's direct-interfacing model and the gate-keeping model of the U.S. center and were aimed, respectively, at helping the Indian PEs act on and interpret artifacts created with CAD and CAE technologies, spotting interpretation and other knowledge-related problems early, and managing the consequences when mistakes in interpretation or knowledge application were made. At the U.S. center, coordinators, not PEs, enacted these three work practices. At the Mexico center, which lacked coordinators, PEs enacted them.

Coordinators in the United States also enacted two other work practices (routing work strategically and filtering quality) that no PEs, either in Mexico or the United States, carried out. These work practices reflected the coordinators' ability to leverage their unique position to gain knowledge of the offshore site and to prevent awareness among U.S. PEs of Indian PEs' struggles in gaining and applying occupational knowledge. Strikingly, U.S. PEs enacted no substantive work practices associated with offshoring beyond providing brief task descriptions (as U.S. managers envisioned, unaware of the work undertaken by coordinators), a finding that is testament to how coordinators shielded U.S. PEs from all offshoring activities.

Three Work Practices Common to Both Offshoring Models

Defining Requirements

PEs in Mexico and the United States knew from experience, from standard practices developed in their centers, and from progress to date on their project the types of analyses they needed to conduct to test vehicle performance in any particular case. The type of analysis largely dictated the type and form of model to build. CAE technologies did not automatically develop the appropriate model upon specification of the required analysis because more than one kind of model could be generated from the same set of CAD files. PEs therefore had to judge for themselves which model should be built to meet analysis needs. For example, to run a frontal impact analysis a PE might have opted to build a model that was precise in its representation of the front of the vehicle but not the rear to reduce computation time while providing sufficiently detailed analytical results. A model, once built, might be modified to improve its replication of physical test results or to provide more detailed results for a specific area of the vehicle. Modification required that a PE could examine an existing model, determine what its creator intended, and decide how to improve it to meet a given objective. To do their work, PEs thus required both technical knowledge of how to set up a model for a given analysis and interpretive skills in how to decipher existing models.

Mexican PEs and U.S. coordinators quickly discovered that Indian PEs, lacking the same work experience, the same organizational knowledge, and the same awareness of the status of the project, needed to be explicitly told not only the type of analysis that was to be performed, but also the type of model to be built for it. Additionally, Indian PEs had to be told what types of changes ought to be made to the model should certain results obtain or errors occur. When the task was to alter an existing model, Indian PEs needed to be told what the model was intended for and how it should be modified.

The first work practice that Mexican PEs and U.S. coordinators therefore conducted to offshore tasks was to define task requirements by specifying in great detail what was to be done.[4] One PE in Mexico described how he started out by giving limited instructions via a standard text-based statement of requirements (SOR) form, but soon found that it was necessary to spend extra effort defining requirements via PowerPoint files to ensure that work requests would be completed successfully.

> *I have to be very clear about how I outline the jobs I send. I started by filling out this common SOR form we had but that didn't seem to have enough detail on it since the jobs always came back with problems. Then I started to do e-mails followed up by calls. That was better but something was still missing. Then I started to put actual images of things I did before, things I wanted them to emulate in the current job, into a PowerPoint and putting arrows all over it indicating things to pay attention to. That works the best, it's visual so they can see what to do, but it also takes a hell of a lot of time.*

This PE was typical of Mexican PEs, who put together PowerPoint files with images and text to indicate precisely the types of issues to which the Indian PEs should pay attention. By showing examples of past models and using text explanations to draw attention to specific model features, the Mexican PEs made explicit knowledge that was implicit in these artifacts and, in doing so, helped Indian PEs learn how to interpret such knowledge. The engineers used PowerPoint because the CAD and CAE technologies lacked text or memo creation capabilities for making explicit the implicit knowledge in existing models.

Typically, a work request in the United States was initiated when a PE called the coordinator on the phone, stopped by his desk, or sent an e-mail outlining very briefly the kind of task she wished to offshore. Thereafter, it was the coordinator's job to define the task requirements and send the resulting PowerPoint file to India. Coordinators followed up with phone calls to India nearly every day. In one instance, a coordinator (C) realized that the Indian PE was still not exactly clear on how to build the requested model even after receipt of the PowerPoint file and decided that what was needed were more examples in which implicit knowledge was made explicit for the Indian PE.

> *C: Is that OK?…I see.…OK, well, I will define it more for you.…I will put some more images in a PowerPoint so you can look at it and then I will also find a sample and put the sample on the ftp site.… OK. Thank you.*

[4] Defining requirements often necessitated interacting with DEs to confirm the CAD files, material properties, and number of welds. Mistakes in this information, if made locally when handing off the work to a collocated colleague, were easy enough to address because the DEs were close by; mistakes sent to India, however, delayed work while messages cycled back and forth for clarification. Problems of distance thus added to, but were not solely responsible for, the need for higher specificity and accuracy in defining requirements when offshoring work.

> C: *[He hangs up the phone and turns to the observer.] This is going to take me a lot of time. I'm happy to help, but this will be intensive.*

Spelling out exactly what needed to be done and how, including what to look out for and what to do in the event of various types of problems, proved challenging for the Mexican PEs and U.S. coordinators because particularities of the vehicle design (including emerging problems with the design itself) rendered each task unique and its requirements idiosyncratic. The same level of detail would not have been required if the sending PE had done the work himself because not only did he already know what to do, he also did not need to think through every possible contingency, just the ones that actually arose.

Monitoring Progress

One indication that Indian PEs might be having problems creating, interpreting, and acting on artifacts was if they missed deadlines for returning work to the home sites. Because the Indian PEs were not just down the hall, the Mexican PEs and U.S. coordinators had no casual encounters with them that might have conveyed progress information nor could they observe them at work. Moreover, because the Indian PEs employed their own set of CAE technologies and kept their intermediate files on their own servers halfway around the globe, individuals at the home sites had no electronic means of inspecting work in progress. Thus, a second practice conducted by Mexican PEs and U.S. coordinators was to actively monitor the progress of tasks by sending e-mails and by making phone calls to India. The following type of exchange between a U.S. coordinator (C) and an Indian PE (I) was common:

> C: *So how is the progress going on the model? I haven't heard from you guys for a while.*
> I: *Oh, very well, thank you, we are updating the brake booster module now.*
> C: *Will it be ready on schedule?*
> I: *We should be only two or three days behind based on the issues we discussed earlier.*
> C: *I can expect it by Friday?*
> I: *Yes, Friday, that's very good. Thank you for clarifying.*

Monitoring progress served the additional purpose of conveying to the Indian PEs organizational knowledge about the importance of meeting deadlines in vehicle development, which if missed could cause programs to run over budget by millions of dollars and risk program cancellation. Thus, Mexican PEs and U.S. coordinators would often call and leave a voicemail message not so much hoping for an immediate response, but to signal to Indian PEs that the deadline was approaching and they were awaiting results.

Fixing Returns

CAE technologies featured error-checking algorithms that helped engineers find potential problems in models. However, the algorithms could not address all errors in a model; in particular, they could not detect errors in models that were technically sound, but that failed to reflect the assumptions or meet the requirements of a particular analysis. Mistakes of this nature often arose in models and analyses prepared by the Indian PEs, either because they did not fully understand the task requirements or because the requirements were poorly defined and communicated. Fixing returned work therefore constituted the third shared work practice between Mexican PEs and U.S. coordinators. This comment from a U.S. coordinator as he inspected a model sent from India was emblematic of the kinds of issues that arose when the Indian PE was unclear about model requirements; in this example, the Indian PE either did not understand what the requirements of a certain kind of analysis were or he did not know that type of analysis was required:

> C: *[To observer] Do you see here? [He points on the computer screen to a section of the finite element model on the rear driver door.] They meshed this part at five millimeters.*[5] *Do you know how long it will take this job to run if all these parts rear of the B-pillar are at 5 mills? It'll take forever. This is for frontal ODB [offset deformable barrier, frontal ODB is a type of analysis] so we don't need that detail past the B-pillar. Only front structure needs to be meshed that fine. I'll have to go though this and change the element size. I thought I was clear about this to them before. This will probably take three or four hours to fix. This would not be acceptable for the sending engineer.*

Occasionally, rework was needed as the result of mistakes made by Indian PEs whose dearth of product knowledge, rather than more universal occupational knowledge, left them

[5]A mesh is the name for a finite element model in which surfaces are divided into elements shaped as small triangles or rectangles upon whose nodes subsequent computations will be made. To mesh is to create such a model.

unfamiliar with the normal configuration of a vehicle. One coordinator recalled how he received from India a model of a fuel system on a truck with a fuel-fill pipe and door on both sides of the vehicle. The Indian PE had taken advantage of the CAE tool's mirror function to reflect the first half of his model to create the second half, thereby reducing his modeling effort. In so doing, however, the Indian PE had failed to recognize that vehicles sport the fuel system outlet on only one side.

For Mexican PEs, fixing returned work from India undermined their confidence in the occupational knowledge and skills of Indian PEs. One informant noted, *"It just seems that they don't pay attention to detail. Either that or their skills are not very good."* Another Mexican PE commented that rework issues made him think twice about offshoring work: *"The question is, should I send something at all if I know I'll have to fix it?"* Such issues did not concern U.S coordinators, who viewed it as their job to review and fix work that came back from India if they had the time to do so. Additionally, the coordinators' backgrounds as contractors from Indian consulting firms provided them with knowledge of engineering organizations in their home country that prompted structural rather than individual attributions. One coordinator said, *"I know these guys [Indian PEs] are crunched for time, so I try to help them out by fixing little things."*

Two Work Practices Unique to the U.S. Gate-Keeping Model

In addition to carrying out the three practices common to both the Mexico direct-interfacing model and the U.S. gate-keeping model, U.S. coordinators enacted two other work practices that Mexican and U.S. PEs did not: routing tasks strategically and filtering quality. Unlike the three work practices common to both models, which revolved around knowledge transfer from the home site to the offshore site, the practice of routing tasks strategically was enabled by the transfer of knowledge of project status, staffing levels, and workload from the offshore site to the home site. The second practice uniquely performed by coordinators, filtering quality, reflected how coordinators stopped knowledge of the Indian PEs' success or failure in acquiring occupational knowledge from spreading within the home site to the U.S. PEs.

Routing Tasks Strategically

Neither the Mexican PEs nor the U.S. coordinators employed any kind of project management tool to make knowledge of workloads transparent across sites. As a result, Mexican PEs, who only handled the offshoring of their individual tasks and thus never developed a broader perspective of how much work was being offshored across their center, had no way of knowing if the task they were offshoring was entering a partially or fully loaded system in India. Beyond providing additional information with which to judge whether delays were due to problems in interpreting and applying knowledge or if they were due to stretched resources, such knowledge would have helped the Mexican PEs to determine what tasks to offshore and when to do so. U.S. coordinators, by contrast, handled offshoring requests from multiple PEs and therefore developed a broader sense of how many different tasks were in queue. Moreover, the three coordinators at the U.S. center held a weekly conference call with Indian managers and PEs during which they learned the current workload level and workforce capacity in India. This knowledge of work status at both the Indian and U.S. centers enabled coordinators to route tasks strategically by "reserving" resources at the India center, as illustrated in this exchange between a coordinator (C) and an Indian manager (I):

> *C: Between Aero/Thermal and HVAC [two functional groups at the U.S. center] I have about six jobs coming in the next week. How busy are you guys?*
>
> *I: We have about four jobs currently in progress. Gupta mentioned there would be two or three more for structures [another functional group in the United States] this week.*
>
> *C: So if I send you the three smaller jobs this week and the three bigger ones next week will you have the resources to work on them?*
>
> *I: I think if you can send them all next week then we can finish what we have here and finish Gupta's jobs and devote all attention to these jobs next week. Will that be acceptable for you?*

Filtering Quality

Coordinators in the United States took it as their mandate to return work from India to sending PEs that was nearly completely free from error. To achieve their goal, coordinators filtered the quality of returned work. Filtering entailed making a direct comparison between the requirements that the sending PE laid out and the model or analysis returned from India. Should a discrepancy appear between the two, coordinators regularly sent the work back to India for further revision. Consequently, U.S. PEs rarely saw a model that was returned directly from India and therefore saw few errors in the work of the Indian PEs.

By filtering quality, coordinators prevented U.S. PEs from gaining knowledge of the quality of Indian work (beyond noting the time taken to do the task) and thus curtailed any questioning of the knowledge or skills of the India PEs. The coordinators' practice of filtering quality was thus in part a strategic maneuver left over from the early days of offshoring work from the U.S. center, when coordinators had to "sell" the capabilities of their respective consulting firms to the PEs. But after IAC built the India center in 2003 and hired as regular employees most of the engineers who staffed it, the need to sell consulting services became less important. Yet, coordinators found it difficult to dispense with their objective because they had come to believe that the essence of their job was to make offshoring between the United States and India seamless for U.S. PEs. In the coordinators' eyes, any time a U.S. PE was unhappy with work returned from India, the coordinator had not done his job effectively.

Confirmation of Qualitative Findings Across All U.S. and Mexican PEs

To confirm the results of our qualitative analysis regarding work practices, we triangulated our observation and interview data with the survey and project-tracking data. Recall that we surveyed *all* PEs at the U.S. and Mexico centers that had offshored work, at least once, to India, but we conducted observations of and interviews with only a subset of these engineers. We reasoned that if our findings generalized to all PEs, then we should see a significant difference across the entire population in the frequency with which U.S. and Mexican PEs conducted the first three work practices (defining requirements, monitoring progress, and fixing returns). If coordinators enacted these practices and made the process seamless for U.S. PEs, then U.S. PEs would not have to engage in these practices. Mexican PEs, on the other hand, had no coordinators to help them and thus would have to conduct these three practices themselves. Further, we expected that there would be no difference in the frequency with which either U.S. PEs or Mexican PEs conducted the final two work practices (routing tasks strategically and filtering quality) because coordinators were the primary individuals to conduct these two work practices, as opposed to PEs.

The descriptive statistics and survey data ANOVAs summarized in Table 3, Panel A, show precisely these results. According to these self-reports, Mexican PEs enacted defining, monitoring, and fixing practices much more frequently than did U.S. PEs. There were no significant differences, however, in the frequencies with which these groups conducted routing or filtering practices. The survey findings indicate that coordinators conducted practices that freed up time for U.S. PEs, whereas Mexican PEs had to conduct these practices themselves, which took time away from their other work. Further, U.S. PEs benefited from routing and filtering practices, but Mexican PEs did not.

The data provided by the project-tracking logs suggest similar differences in the conduct of the five work practices. The logs contained estimates from PEs in both the United States and Mexico of the amount of time they spent "communicating" with Indian PEs for a particular task and how long they spent "reworking" that task once they received it from India. Our interviews with the managers in the United States and Mexico who maintained these logs indicated that they defined communication to include the amount of time PEs spent "preparing" a task to be sent, "confirming" that the Indian PEs understood the requirements, and "checking up on the status" of a task that was underway. Thus, the communication estimate in the project-tracking logs seems to capture both the "defining requirements" and "monitoring progress" practices uncovered in our qualitative data. Similarly, managers defined reworking as the amount of time a PE spent "fixing" the quality of the returned task. This rework variable thus captured the essence of the "fixing returns" practice we identified above.

Table 3, Panel B, displays the results of the ANOVAs for these two variables.[6] The results are in line with the survey results in that they indicate significant differences in the amount of time U.S. and Mexican PEs spent communicating about (similar to defining requirements and monitoring progress in the survey data) and reworking tasks (similar to fixing returns in the survey data) that that they had offshored.

U.S. and Mexican PEs' Perceptions of Effectiveness of the Offshoring Model

If the U.S. and Mexican PEs involved in offshoring were spending considerably different amounts of time defining task requirements in ways that meticulously spelled out knowledge, monitoring progress to ensure understanding on the part of Indian PEs, and fixing mistakes in returned work that reflected gaps in knowledge or understanding, it stood to reason that they might also have differing perceptions of the effectiveness of the offshoring arrangement. We therefore first used ANOVAs to test for differences in the U.S. and Mexican PEs' survey ratings of effectiveness in terms of qual-

[6] The project-tracking logs did not capture the routing or filtering practices conducted by coordinators. The logs were created and maintained by PE managers, who were largely unaware that the coordinators were conducting these less visible practices.

Table 3. Differences Between the United States and Mexico in the Conduct of Work Practices

A. Analysis of Variance of Survey Data

Variable	Mean	Std. Dev.	d.f.	Sum of Squares	Mean Square	ή²†	*F*
Defining	1.92	.97	1	12.34	12.34	.14	18.69**
Monitoring	1.69	.70	1	11.89	11.80	.08	10.11**
Fixing	2.79	1.11	1	17.49	17.49	.12	16.21**
Routing	1.56	.68	1	.81	.81	.02	1.65
Filtering	1.60	1.12	1	1.22	.122	.03	3.28

B. Analysis of Variance of Project-Tracking Data

Variable	Mean	Std. Dev.	d.f.	Sum of Squares	Mean Square	ή²†	*F*
Communication Time (Defining & Monitoring	4.50	4.63	1	269.25	269.25	.08	13.49***
Rework Time (Fixing)	5.46	5.93	1	272.20	272.20	.05	8.06**

*p < .05 **p < .01 ***p < .001

†$ή^2 = SS_{effect} + SS_{error}$

ity of tasks returned, speed with which tasks were returned, and time savings of offshoring work. The results are displayed in Table 4, Panel A. On the whole, U.S. PEs rated effectiveness significantly higher than Mexican PEs did across all three metrics, even controlling for the number of years a PE had spent offshoring work and the number of tasks she had offshored. Although the project-tracking logs assessed effectiveness with only one variable (the 5-point rating of performance for each task), the results for these data replicate these findings, as shown in Table 4, Panel B. Irrespective of the amount of time a task was late from its expected completion date (delayed completion time), U.S. PEs rated performance significantly higher than did Mexican PEs.

Next, to determine whether the conduct of the three work practices of defining requirements, monitoring progress, and fixing returns was related to PEs' effectiveness assessment, we regressed each of the three survey effectiveness variables and the composite variable (which we created by averaging values for the three surveyed criteria) against the frequency with which PEs reported participating in these work practices.[7] Table 5, Panel A displays the results of the regression analyses on the survey data, which clearly show that the less time PEs engaged in defining, monitoring, or fixing practices, the higher they rated effectiveness, as indicated by the negative coefficients. In fact, the extent to which PEs enacted the three work practices explains nearly 30 percent of the variance in predicting effectiveness on the composite variable.[8] Thus, it seems that when PEs' work was organized under the U.S. gate-keeping model they were considerably more satisfied with the effectiveness of the offshoring arrangement than when their work was organized under the Mexican direct-interfacing model.

[7]We did not include routing or filtering practices in the regression equation because our qualitative and survey data indicated that PEs—whether in United States or Mexico—did not conduct these two practices, which were the sole province of coordinators. However, running a separate analysis for the U.S. site only indicates that the practice of filtering was significantly correlated with perceived performance while the practice of strategic routing was not. This finding suggests that coordinators' practice of routing jobs to specific PEs at the India site may have only played a minor role in the success of the gate-keeping model.

[8]One of the limitations of ethnographic research is that it is difficult to collect large samples. While we recognize that running separate regressions for the two offshoring models (e.g., direct-interfacing, gate-keeping) would have aided in interpretation, our small sample size precluded us from such analyses. However, the findings presented herein show the general trend of the results, which we hope future research will corroborate with a larger sample. We direct the reader to Tables 3a and 4a to determine the effects of differences on offshoring models with regard to frequency of work practices conducted and ratings of perceived effectiveness.

Table 4. Differences Between the United States and Mexico in Perceived Effectiveness of Offshoring

A. Analysis of Variance of Survey Data

Variable	Mean	Std. Dev.	d.f.	Sum of Squares	Mean Square	ή²†	*F*
Years Sending	1.77	.61	1	1.52	1.52	.00	.41
Number Sent	3.12	1.58	1	1.86	1.86	.00	.74
Quality	3.32	1.49	1	159.43	159.43	.62	187.33***
Speed	3.27	1.36	1	107.36	107.36	.49	110.34***
Time Savings	3.36	1.50	1	169.31	169.31	.65	212.55***

B. Analysis of Variance of Project-Tracking Data

Variable	Mean	Std. Dev.	d.f.	Sum of Squares	Mean Square	ή²†	*F*
Delayed Completion Time	7.36	21.55	1	282.13	282.13	.00	.61
Performance	3.58	1.30	1	41.03	41.03	.15	28.25***

***$p < .001$

†$ή^2 = SS_{effect} + SS_{error}$

Table 5. Relationship Between Work Practices and Perceived Effectiveness

A. Regression Results for Survey Data†

Variable	Quality	Speed	Savings	Overall
Defining	–.29**	–.17*	–.22*	–.24**
Monitoring	–.18*	–.31***	–.19**	–.24**
Fixing	–.33***	–.30***	–.29***	–.33***
R^2	.28	.26	.23	.29
F	11.04***	10.31***	8.09***	11.64***

B. Regression Results for Project-Tracking Data†

Variable	Model 1	Model 2	Model 3
Delayed Completion Time	.05	.08	.09
Rework Time (Fixing)		–.48***	–.19*
Communication Time (Defining & Monitoring)			–.48***
R^2	.07	.26	.39
$R^2Δ$		.19***	.13***

*$p < .05$ **$p < .01$ ***$p < .001$

†Entries are standardized coefficients

To corroborate these findings, we ran a separate regression analysis for the data obtained from the project-tracking logs. To determine whether the sending PEs' performance rating for given tasks could be linked to whether or not the tasks were completed before or behind schedule, we included "delayed completion time" as a control variable. We thus created three models, stepping each variable in at a time to observe the change in variance. We stepped the "communication time" variable in last because we believed that it really measured two different constructs (defining and monitoring) and thus would account for the largest portion of variance. The results, shown in Table 5, Panel B, are highly consonant with those for the survey data: Regardless of whether or not a task was completed on time, a PE's performance rating was highly (negatively) correlated with the number of hours spent defining requirements, monitoring progress, and fixing returns.

Together the results of the surveys and project-tracking logs indicate that PEs were much more satisfied with the effectiveness of the offshoring arrangement when their work was organized under the gate-keeping model than when it was organized under the direct-interfacing model precisely because they were less involved with the day-to-day mechanics of offshoring. A U.S. PE confirmed this conclusion: *"I mean so far this offshoring thing has been pretty easy."* A Mexican PE explained his own dissatisfaction:

> *At the height of it, I was spending almost four hours a day working on just making sure things with India were going OK. If I didn't have to do that, I would have been much happier. I just want to send work, and I want it to come back, and I want to be able to immediately use the results in my work.*

Perceptions of Indian PEs at the Offshore Site

Whereas, from the perspective of the home site, the U.S. PEs were pleased with the offshoring arrangement thanks to the efforts on their behalf by the coordinators and the Mexican PEs were dismayed with the time that transferring knowledge to India took away from their other activities, from the perspective of the offshore site, the Indian PEs had exactly opposite perceptions and preferences. For the Indian PEs, the coordinators formed a barrier that separated them from the individuals with whom they most wanted to converse and from whom they wanted to learn. By contrast, the Mexican PEs were helpful instructors whose efforts the Indian PEs greatly appreciated. In short, as compared to the U.S. gate-keeping model, the Mexican direct-interfacing model yielded more opportunities for learning on the part of Indian PEs via direct knowledge transfer from the Mexican PEs. Over time, this learning paid dividends to the Indian PEs in the form of more complex and interesting tasks sent under the Mexican model.

Indian PEs often commented that although CAD and CAE technologies afforded the sending of files, the technologies did not provide capabilities for articulating the assumptions necessary for building and analyzing models. When these assumptions were incompletely stated in the PowerPoint file sent by a coordinator, which was often the case, Indian PEs had to contact the coordinator, who in turn contacted the sending PE, who then sent the necessary specifications and requirements to the coordinator, who forwarded them to the Indian PE. Beyond the obvious time delays inherent in these transactions, the gate-keeping model, in the eyes of the Indian PEs, placed an obstacle between them and the sending PE. This obstacle was problematic for at least two reasons. First, the Indian PEs feared inaccuracies in mediated exchanges because the coordinator with whom they had direct contact was not always an "expert" in the particular tasks he sent to India. These comments from two Indian PEs reflect that suspicion.

> *The intermediate person [coordinator] between North America and [the India center] may not have the full knowledge of crash [a functional domain]. Maybe he is from a structural background [a different functional domain]. Maybe he is a structural engineer. So, he may not know what is really quite professional. So, in that case if we have direct interaction with the crash engineer, that will help us in understanding more from the crash point-of-view.*
>
> *I think someone who is not directly involved in the work [a coordinator] will not understand the approximations that will be valid.*

Second, the Indian PEs believed that having to deal with coordinators prevented them developing working relationships with the sending PEs that would ultimately engender quicker knowledge transfer and more challenging tasks. An Indian PE explained,

> *Working [without coordinators] is better because we can just send [PEs] what we've done and they can look it over and tell us if there is a problem. Sometimes it's even better because they fix it right there and then they ask us to do a more complex thing so we didn't even have to do the more boring work. [He laughs.] I think we can also get their assumptions directly from them after some amount of communication.*

Direct communication with the sending PEs afforded opportunities for Indian PEs to learn from the expertise of their colleagues abroad. Indian PEs remarked that they were often able to ask Mexican PEs questions about why they had made certain assumptions in modeling or analysis, or how to run a particular set of performance tests. Vehicle models from prior projects—the artifacts created by sending PEs on CAD and CAE technologies and often sent to the Indian PEs with the PowerPoint file—were incomplete transmitters of knowledge, but they did serve as learning devices that structured interactions between Mexican and Indian PEs. When an Indian PE received a model from a Mexican PE, he was able to study that model, examine how the Mexican PE had set it up, and then query that sending PE as to why she made the choices she did. As one Indian PE noted,

> *It's not always learning from an engineer. It's learning from their models that they give to us and going into their detail models and starting their models. How do they present these things, and why do they present? So, questioning them and getting back why they define things like this, that makes it possible for us to learn more and there is more to think about and more questions to ask.*

Thus, by examining the artifacts of CAD and CAE technologies, Indian PEs could see *what* a sending PE had done to build or analyze a model, but they were left to guess at *why* the sending PE had taken such steps. Consequently, having access to the sending PE to probe her about various characteristics of a model proved to be a valuable learning experience for Indian PEs.

An advantage of learning from overseas colleagues was, ultimately, the assignment of more challenging and interesting tasks. During our observations, Indian PEs frequently announced that they wished to receive larger and more complex tasks from PEs in the program-based centers. Larger, more complex tasks entailed a greater degree of analytical, as opposed to model-building, work. The former was considered more challenging, the latter more routine. By pushing Indian PEs to expand their skills, complex work afforded an opportunity for the Indian center to prove its worth as a regional engineering center and to ensure the status of Indian PEs as fully capable and knowledgeable IAC engineers.

The project-tracking logs we collected from the Mexican and U.S. centers provided a means to verify the Indian PEs' perceptions that they were more likely to gain larger and more complex tasks under the Mexican direct-interfacing model. One variable in the project-tracking log recorded the number of hours the sending PE estimated that the particular offshored task should take, which we used as an indicator of the size and complexity of the task. An ANOVA test indicated that this time estimate differed significantly across the two offshoring models ($F = 43.07$; d.f. $= 1, 163$; $p < .001$). Specifically, the average expected completion time for a task offshored by Mexican PEs was 125.6 hours as compared to 49.7 hours for tasks offshored by U.S. PEs. The tasks offshored to India through the direct-interfacing model were thus arguably much larger and more complex than the tasks offshored through the gate-keeping model, confirming the beliefs of the Indian PEs.

Discussion

We set out to show that transformational tools, which are enabling offshoring at the task rather than solely the functional level, but which have been largely overlooked in the literature on offshored and distributed work, may be prompting new kinds of knowledge transfer problems beyond those that have been identified in the context of communication and storage technologies. Our findings supported this contention by highlighting how individuals engaged in task-based offshoring found themselves having to transfer occupational knowledge across time and space. We reported how U.S. coordinators and Mexican PEs at the home sites created three work practices (defining requirements, monitoring progress, and fixing returns) that revolved around transferring primarily occupational knowledge, and to a lesser extent product and organizational knowledge, to the offshore site. For the Mexican PEs, having to carry out these practices required time that they thought they were saving by offshoring tasks and ultimately detracted from their perceptions of the effectiveness of the offshoring arrangement. U.S. coordinators created two other practices (routing tasks strategically and filtering quality) that reflected, respectively, transferring knowledge from the offshore site to the home site and preventing knowledge of Indian PEs' success or failure in acquiring knowledge from spreading within the home site. All five practices arose solely because transformational technologies were employed to facilitate the offshoring of engineering tasks that would otherwise have been completed by the sending engineers at the home sites. By broadening the research lens to include the full suite of IT employed in work, and in so doing examining the new forms of offshored and distributed work arrangements that transformational technologies make possible, our study contributes to theory on knowledge transfer among individuals working across time and space. Our findings also have practical implications for managing task-based offshoring arrangements.

Contributions to Theory

Our study begins its contribution to theory by expanding the set of possible knowledge transfer problems that can arise in offshored and distributed work. Over the last decade, numerous studies have highlighted problems, such as creating mutual knowledge and conveying contextual knowledge, that arise when individuals working across time and space employ communication and storage technologies (e.g., Cramton 2001; Griffith et al. 2003; Majchrzak et al. 2005). Our study adds to this literature by demonstrating that, in the context of transformational technologies, problems may also arise in the transfer of technical knowledge within an occupation. The transfer of occupational knowledge was necessary in the face of an expertise differential between the home sites and the offshore site that is common in offshoring arrangements, even though most studies of IT outsourcing and offshoring overlook this knowledge disparity in favor of the need to transfer firm-specific work practices, needs, and specifications (Apte et al. 1997; Dibbern et al. 2004; Quinn 2000; Quinn and Hilmer 1994). Our study makes clear that the structural configuration that is arguably the simplest of distributed work arrangements (one without cross-functional boundaries, within the same occupation, with individuals employing identical technologies, and therefore with a bedrock of mutual knowledge) is in fact rife with problems in transferring knowledge across time and space. To remedy these problems, individuals in our study enacted new work practices, a finding that underscores Orlikowski and Iacano's (2001) call to bear in mind that IT and work practices work in conjunction with one another to make alternative work arrangements succeed.

This contribution of our work is best understood in the context of work by Carlile (2004), who in writing about knowledge transfer specified three types of knowledge boundaries between actors or groups: syntactic boundaries (which require only the transfer of knowledge, the meaning of that knowledge is clear to both parties), semantic boundaries (which require that knowledge be translated as well as transferred because its meaning is not universally understood), and pragmatic boundaries (which further require that knowledge be transformed in light of different interests and goals among actors). This typology of boundaries is helpful in thinking about the problems IAC engineers faced in transferring implicit knowledge in the models and analyses that they shared.

At IAC, managers chose to offshore work to the engineering center in India because the region boasted a highly skilled labor force trained in disciplines traditionally associated with automotive engineering (i.e., structural and mechanical engineering). IAC managers believed that this university training, complemented with the Indian engineers' ample skills in using the CAD and CAE technologies, guaranteed that the Indian engineers would be able to interpret the implicit knowledge embodied in work artifacts. As a result, knowledge would only have to be transferred, not translated or transformed, when sent offshore. In terms of Carlile's framework, IAC managers believed that the structural decision to offshore work would create a syntactic boundary that could be easily overcome: Artifacts would be produced at the home sites via transformational technologies and then transferred via communication or storage technologies to the offshore site, where the knowledge they embodied would then be easily and reliably interpreted.

The problem that IAC managers did not foresee was that although the Indian engineers possessed what Black, Carlile and Repenning (2004) deemed *operational knowledge*, namely knowledge of how to use transformational technologies (e.g., how to build a mesh or run an analysis), they lacked what these authors termed *diagnostic knowledge*, or the ability to interpret the output of the tool (e.g., how to look at a mesh and understand why it was built the way it was or how to look at an analysis and understand why it was set up the way it was). In other words, although Indian engineers were equally as proficient as Mexican and U.S. engineers in terms of general engineering knowledge and had equal skills in the use of CAD and CAE technologies, their relative dearth of occupational knowledge in automotive engineering, of organizational knowledge about engineering work practices in IAC, and of product knowledge of vehicles hampered their ability to interpret the implicit knowledge embodied in artifacts. This knowledge imbalance created a semantic boundary across which diagnostic knowledge not only had to be transferred, but also had to be translated into a "common lexicon" (Carlile 2004, p. 558) that could be interpreted by the Indian engineers.

Semantic boundaries are not new in studies of offshored and distributed work: What makes our study unusual is the type of knowledge that was needed to cross this boundary. Most distributed teams researchers who have documented knowledge transfer across semantic boundaries describe individuals who attempt to communicate knowledge that is sticky (Belanger 1999; Janssens 1995), contextual (Alavi and Tiwana 2002; Cramton 2001), or situated (Griffith et al. 2003; Sole and Edmondson 2002). The stickiness, contextuality, or situatedness of the knowledge in these studies is what makes transfer difficult and what prompts the need for translation. By contrast, the knowledge that the home site engineers in our study needed to transfer was specific occupational, organizational, and product knowledge that originally was implicitly embodied in artifacts, but ultimately had to be made explicit.

The knowledge was not sticky, contextual, or situated: The sending engineers did not, for example, have difficulty extracting this knowledge from its environment, replacing local jargon enmeshed in it, or expressing it in terms suitable for a foreign culture. As evidence, a detailed set of task instructions sent from Mexico was indistinguishable from such a set sent from the United States; in short, the knowledge that had to be made explicit was universal in application (United States, Mexico, India) if not in possession (United States, Mexico).

Carlile (2004) argued that in the case of semantic boundaries, transformational technologies such as CAD and CAE technologies may aid in knowledge transfer. Our study demonstrates that rather than helping bridge a semantic boundary, transformational technologies used in the context of expertise differentials across time and space contributed to a semantic boundary, which engineering knowledge had to cross. Faced with the clear evidence that, by leaving as implicit that which needed to be explicit, the CAD and CAE technologies and their artifacts could not fully convey the knowledge required by the Indian engineers, the Mexican engineers and U.S. coordinators turned to another mechanism for translating knowledge: They created new work practices. These individuals learned that extra effort was necessary to define requirements thoroughly and completely. When work was returned, U.S. coordinators filtered quality to identify the misunderstandings that resulted in mistakes and to send task artifacts back for rework. Often, sending individuals simply identified problems and fixed the returns themselves.

It is not uncommon for individuals to create new work practices in response to changing organizational structures. Barley and Kunda (2001) suggested that new work practices arise when the demands of a situation become out-of-step with new organizational forms. Offshoring is clearly an important organizational change in which the structure and content of work distribution is dramatically altered for gains in efficiency, cost, and knowledge acquisition. In the case of IAC, the addition of the India center was a structural organizational change that created a syntactic boundary; the deployment of transformational tools to allow tasks to be offshored created a semantic boundary. Our findings indicated that new work practices emerged to help engineers cross these boundaries.

Many researchers have suggested that work practices often serve as filters with which to interpret the functionality of an information technology (Boudreau and Robey 2005; Orlikowski 2000; Vaast and Walsham 2005). Our findings suggest that while the effectiveness of CAE tools was based on the ways in which those tools helped an engineer to accomplish her routine work, the relationship between work and technology may be more interdependent than previously thought. New work practices arose in response to new boundaries, which were themselves the outcomes of organizational and technological change. New work practices such as defining, monitoring, fixing, strategic routing, and filtering created avenues through which occupational domain knowledge could be transferred and translated from the home site to the less expert offshore site. By enabling a context in which implicit knowledge embedded in transformational technologies could be made explicit, these new work practices augmented the functionality of the technologies used to offshore work.

Using these work practices to make implicit knowledge explicit requires time and effort, as the U.S. coordinators and Mexican engineers well attested. Researchers in the field of artificial intelligence have long referred to this problem as the "common-sense problem," arguing that it is difficult and cumbersome to explain to a person or a machine that has little or no prior knowledge of a practice all of the basic steps it is necessary to take to perform that practice (McCarthy 1990; Minsky 1995). In accordance with the common-sense problem, the sending engineers in our study struggled not with making articulate something they knew innately, tacitly, or holistically, but rather with putting down in writing the vast troves of specific domain knowledge that guided their work and decision making. Due to their direct-interfacing arrangement, Mexican engineers wound up spending a significant portion of their time attempting to make explicit to Indian engineers this knowledge. But Mexican engineers faced the pressure of impending project deadlines and thus grew frustrated that they had to spend time "teaching" the Indian engineers. U.S. engineers were buffered from having to teach by the structure of the gate-keeping arrangement, which put coordinators in their place. However, because Indian engineers recognized that the knowledge they needed to obtain had a strong occupational component, they questioned the coordinators' ability to teach them.

This response to the coordinators is worth considering in light of Carlile's (2004) suggestion that knowledge brokers might act as another aid in addition to transformational technologies for crossing semantic boundaries.[9] To the uninformed observer, the U.S. coordinators in the gate-keeping model

[9]Carlile (2004) also suggested that work practice transparency as described by Lave and Wenger (1991) could facilitate knowledge transfer across semantic boundaries. In the case of task-based offshoring, however, work practice transparency is nearly impossible because the learner is critically separated by time and space from the knowledgeable members of the community of practice from whom he needs to learn, hence we do not discuss it.

would seem uniquely positioned to translate knowledge to the less experienced offshore engineers. However, the U.S. coordinators did not act as knowledge brokers in the sense that their structural position suggested might have been possible primarily because coordinators were not expert in the specific domain knowledge that needed to be translated. Research on knowledge brokering suggests that individuals who can effectively move knowledge from one domain to another must have sufficient expertise in both domains to be able to translate that knowledge (Barley and Bechky 1994; Carlile 2002). Due to their lack of specific occupational knowledge, U.S. coordinators could transfer but not translate knowledge; in other words, they could cross syntactic but not semantic boundaries. Thus, when Indian engineers ran into problems interpreting the implicit knowledge embodied in the artifacts produced with the transformational technologies, coordinators actually acted not as knowledge *brokers*, but as knowledge *blockers* who prevented direct access to knowledgeable U.S. engineers.

What coordinators did do, though, was to facilitate the transfer of situated and contextual knowledge from the home site to the offshore site and then back again. In this sense, coordinators provided the important function suggested by offshoring researchers of communicating information about workload and staffing discrepancies as well as negotiating time zone differences (Carmel 2006; Rottman and Lacity 2004). Because coordinators sat structurally in a position that overarched several engineering domains, they were also able to use the contextual knowledge of workloads to route tasks strategically, a practice that allowed them to share and leverage contextual knowledge related to the status of forthcoming as well as existing tasks.

Implications for Practice

The extent to which sending engineers in our study were free from having to enact new work practices to translate knowledge for the engineers offshore predicted their assessment of the effectiveness of the offshoring arrangement. Hence, engineers working under the gate-keeping model were more satisfied with the arrangement than were engineers working under the direct-interfacing model because work in the former model was organized such that coordinators rather than engineers had to enact the new work practices. Yet, engineers at the offshore site relied on the sending engineers to translate the knowledge necessary to perform tasks and learned the most when the sending engineers were actively involved in defining requirements and fixing returned work. Consequently, the direct-interfacing model, which put Indian engineers in direct contact with the sending Mexican engineers, was highly valued by Indian engineers.

Learning takes time and effort for both learners and teachers. Because sending engineers were the only realistic teachers in our study, learning meant taking a productivity hit as sending engineers diverted attention from their own tasks to teach offshore engineers. These findings point to a potential difficulty in task-based offshoring arrangements: The organization of work most effective at helping offshore workers to learn (and thereby alleviate an expertise imbalance) may be in direct opposition to the organization of work that is most efficient for those sending work offshore. Thus, the question that managers of IT-enabled offshoring arrangements may have to ask is, for the effectiveness of the overall system, how should work be organized to strike a balance between learning versus short-term productivity?

In a situation of expertise imbalance, a model of offshoring that facilitates learning may be best for the overall system initially even if it were to lower the short-term productivity of home site individuals. The need for explicit teaching ought to decrease as workers at the offshore site acquire the specific occupational knowledge necessary to competently perform work. Gradually, the semantic knowledge boundary between the home office and the offshore site would revert to a syntactic boundary: Individuals at the home site would no longer have to translate knowledge; instead, they would simply have to transfer it. At that point, the system ought to be ready for transition to a gate-keeping model in which third-party coordinators would manage the transfer of contextual knowledge offshore and transformational technologies would transfer implicit occupational knowledge that now can be interpreted without assistance by the offshore individuals.

Future Research

Limitations in a study often point to avenues for future research. In this regard, our study is no exception; we mention here four possible ways in which remedying limitations in our study might provide useful insights. First, we gathered no cost data and thus could not compare the two models of offshoring beyond assessing perceptions of effectiveness among the individuals involved. Coordinators lightened the sending engineers' workload, but the staffing cost associated with coordinators was a clear trade-off against the engineers' satisfaction with the gate-keeping model. Future studies might provide more comprehensive assessments of effectiveness. Second, future research might examine the extent to which knowledge transfer problems arise in conjunction with transformational technologies and task-based offshoring when expertise is evenly distributed. We found that an expertise imbalance was a strong contributor to problems of transferring knowledge, which leaves open the possibility that other factors may have been overshadowed by this large effect or, alternatively, that few problems arise in conjunction with transformational technologies employed across time and distance when all parties are knowledgeable and capable users. Third, no pragmatic boundaries as described by Carlile (2004) were apparent in our study, perhaps because we examined offshoring in the context of a single function. Studies of cross-functional teams that share a suite of transformational technologies and their artifacts may uncover pragmatic boundaries and, with them, new knowledge transfer problems. Finally, studies of occupational settings beyond engineering are likely to add to the set of work practices we identified that support knowledge transfer and that help to overcome the problems that arise in the context of using transformational technologies to accomplish joint work across time and space.

References

Abraham, T., Ahlawat, S., and Ahlawat, S. 1998. "The India Option: Perceptions of Indian Software Solutions," *International Journal of Technology Management* (15:6/7), pp. 605-621.

Alavi, M., and Tiwana, A. 2002. "Knowledge Integration in Virtual Teams: The Potential Role of KMS," *Journal of the American Society for Information Science and Technology* (53:12), pp. 1029-1037.

Ancona, D. G., and Caldwell, D. F. 1992. "Bridging the Boundary: External Activity and Performance in Organizational Teams," *Administrative Science Quarterly* (37:4), pp. 634-665.

Apte, U. M., and Mason, R. O. 1995. "Global Disaggregation of Information-Intensive Services," *Management Science* (41:7), pp. 1250-1262.

Apte, U. M., Sobol, M. G., Hanaoka, S., Shimada, T., Saarinen, T., Salmela, T., and Vepsalainen, A. P. J. 1997. "IS Outsourcing Practices in the USA, Japan and Finland: A Comparative Study," *Journal of Information Technology* (12), pp. 289-904.

Aron, R., and Singh, J. V. 2004. "Getting Offshoring Right," *Harvard Business Review* (83:12), pp. 135-143.

Barley, S. R. 1996. "Technicians in the Workplace: Ethnographic Evidence for Bringing Work into Organization Studies," *Administrative Science Quarterly* (41:3), pp. 404-441.

Barley, S. R., and Bechky, B. A. 1994. "In the Backrooms of Science: The Work of Technicians in Science Labs," *Work and Occupations* (21), pp. 85-126.

Barley, S. R., and Kunda, G. 2001. "Bringing Work Back In," *Organization Science* (12:1), pp. 76-95.

Barthélemy, J., and Geyer, D. 2001. "IT Outsourcing: Evidence from France and Germany," *European Management Journal*, (19:2), pp. 195-202.

Beath, C. M., and Walker, G. 1998. "Outsourcing of Application Software: A Knowledge Management Perspective," in *Proceedings of the 31st Annual Hawaii International Conference on System Sciences*, Los Alamitos, CA: IEEE Computer Society Press, pp. 666-674.

Bechky, B. 2003. "Sharing Meaning Across Occupational Communities: The Transformation of Understanding on the Production Floor," *Organization Science* (17), pp. 99-120.

Belanger, F. 1999. "Communication Patterns in Distributed Work Groups: A Network Analysis," *IEEE Transactions on Professional Communication* (42:4), pp. 261-275.

Black, L. J., Carlile, P. R., and Repenning, N. P. 2004. "A Dynamic Theory of Expertise and Occupational Boundaries in New Technology Implementation: Building on Barley's Study of CT Scanning," *Administrative Science Quarterly* (49:4), pp. 572-607.

Boland, R., Tenkasi, R., and Te'eni, D. 1994. "Designing Information Technology to Support Distributed Cognition," *Organization Science* (5:3), pp. 456-475.

Boudreau, M.-C., and Robey, D. 2005. "Enacting Integrated Information Technology: A Human Agency Perspective," *Organization Science* (16:1), pp. 3-18.

Carlile, P. R. 2002. "A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development," *Organization Science* (13:4), pp. 442-455.

Carlile, P. R. 2004. "Transferring, Translating, and Transforming: An Integrative Framework for Managing Knowledge Across Boundaries," *Organization Science* (15:5), pp. 555-568.

Carmel, E. 2006. "Building Your Information Systems from the Other Side of The World: How Infosys Manages Time Zone Differences " *MIS Quarterly Executive* (5:1), pp. 43-53.

Carmel, E., and Agarwal, R. 2002. "The Maturation of Offshore Sourcing of Information Technology Work," *MIS Quarterly Executive* (1:2), pp. 65-77.

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

Clark, Jr., T. D., Zmud, R. W., and McCray, G. E. 1995. "The Outsourcing of Information Services:Transforming the Nature of Business in the Information Industry," *Journal of Information Technology* (10), pp. 221-237.

Collins, H. M. 1974. "The TEA Set: Tacit Knowledge and Scientific Networks," *Science Studies* (4), pp. 165-186.

Cramton, C. D. 2001. "The Mutual Knowledge Problem and its Consequences for Dispersed Collaboration," *Organization Science* (12:3), pp. 346-371.

Cramton, C. D., and Webber, S. S. 2005. "Relationships among Geographic Dispersion, Team Processes, and Effectiveness in Software Development Work Teams," *Journal of Business Research* (58:6), pp. 758-765.

Davenport, T., and Prusak, L. 1998. *Working Knowledge: How Organizaitons Manage What They Know*, Boston: Harvard Business School Press.

Dibbern, J., Goles, T., Hirschheim, R., and Jayatilaka, B. 2004. "Information Systems Outsourcing: A Survey and Analysis of the Literature," *The DATA BASE for Advances in Information Sciences* (35:4), pp. 6-102.

Dreyfus, H. L., and Dreyfus, S. E. 1986. *Mind over Machine: the Power of Human Expertise and Intuition in the Era of the Computer*, New York: Free Press.

Duncan, N. B. 1998. "Beyond Opportunism: A Resource-Based View of Outsourcing Risk," in *Proceedings of the 31st Annual*

Hawaii International Conference on System Sciences, Los Alamitos, CA: IEEE Computer Society Press, pp. 675-684.

Eisenhardt, K. M. 1989. "Building Theories from Case Study Research," *Academy of management Review* (14:4), pp. 532-550.

Farrell, D. 2006. "Smarter Offshoring," *Harvard Business Review* (84:6), pp. 85-92.

Farrell, D., and Rosenfeld, J. 2005. *U.S. Offshoring: Rethinking the Response*, Washington, DC: McKinsey Global Institute.

Goo, J., Kishore, R., Nam, K., Rao, H. R., and Song, Y. 2007. "An Investigation of Factors that Influence the Duration of IT Outsourcing Relationships," *Decision Support Systems* (42), pp. 2107-2125.

Griffith, T. L., Sawyer, J. E., and Neale, M. A. 2003. "Virtualness and Knowledge in Teams: Managing the Love Triangle of Organizations, Individuals, and Information Technology," *MIS Quarterly* (27:2), pp. 265-287.

Hargadon, A. B., and Sutton, R. I. 1997. "Technology Brokering and Innovation in a Product Development Firm," *Administrative Science Quarterly* (42:4), pp. 716-749.

Hinds, P. J., and Bailey, D. E. 2003. "Out of Sight, Out of Sync: Understanding Conflict in Distributed Teams," *Organization Science* (14:6), pp. 615-632.

Hollingshead, A. B. 1996. "Information Suppression and Status Persistence in Group Decision Making: The Effects of Communication Media," *Human Communication Research* (23:2), pp. 193-219.

Janssens, M. 1995. "Intercultural Interaction: A Burden on International Managers?," *Journal of Organizational Behavior* (16:2), pp. 155-167.

Kirkman, B. L., and Law, K. S. K. 2005. "International Management research in AMJ: Our Past, Present and Future," *Academy of Management Journal* (48:3), pp. 377-386.

Kotabe, M., and Swan, K. S. 1994. "Offshore Sourcing: Reaction, Maturation, and Consolidation of U.S. Multinationals," *Journal of International Business Studies* (25:1), pp. 115-140.

Lacity, M. C., and Willcocks, L. P. 2001. *Global Information Technology Outsourcing*. Chichester, UK: Wiley.

Latour, B., and Woolgar, S. 1986. *Laboratory Life: The Construction of Scientific Facts*, Beverly Hills, CA: Sage Publications.

Lave, J., and Wenger, E. 1991. *Situated Learning: Legitimate Peripheral Participation*, Cambridge, England: Cambridge University Press.

Lofland, J., and Lofland, L. H. 1995. *Analyzing Social Settings: A Guide to Qualitative Observation and Analysis* (3rd ed.), Belmont, CA: Wadsworth.

Mackay, H., Carne, C., Beynon-Davies, P., and Tudhope, D. 2000. "Reconfiguring the User: Using Rapid Application Development," *Social Studies of Science* (30:5), pp. 737-757.

Majchrzak, A., Malhotra, A., and John, R. 2005. "Perceived Individual Collaboration Know-How Development Through Information Technology-Enabled Contextualization: Evidence from Distributed Teams," *Information Systems Research* (16:1), pp. 9-27.

Majchrzak, A., Rice, R. E., Malhotra, A., King, N., and Ba, S. L. 2000. "Technology Adaptation: The Case of a Computer-Supported Inter-organizational Virtual Team," *MIS Quarterly* (24:4), pp. 569-600.

Malhotra, A., and Majchrzak, A. 2005. "Virtual Workspace Technologies," *MIT Sloan Management Review* (46:2), Winter, pp. 11-14.

Malhotra, A., Majchrzak, A., Carman, R., and Lott, V. 2001. "Radical Innovation Without Collocation: A Case Study at Boeing-Rocketdyne," *MIS Quarterly* (25:2), pp. 229-249.

Malone, T. W., and Crowston, K. 1994. "The Interdisciplinary Study of Coordination," *ACM Computing Surveys* (26:1), pp. 87-119.

Martins, L. L., Gilson, L. L., and Maynard, M. T. 2004. "Virtual Teams: What Do We Know and Where Do We Go from Here?," *Journal of Management* (30:6), pp. 805-835.

Maruping, L. A., and Agarwal, R. 2004. "Managing Team Interpersonal Processes Through Technology: A Task-Technology Fit Perspective," *Journal of Applied Psychology* (89:6), pp. 975-990.

McCarthy, J. 1990. *Formalizing Common Sense*, Norwood, NJ: Ablex.

Minsky, M. 1995. "Steps Toward Artificial Intelligence," in *Computers and Thought*, E. Feigenbaum and J. Feldman (eds.), Cambridge, MA: MIT Press, pp. 406-450.

Montoya-Weiss, M. M., Massey, A. P., and Song, M. 2001. "Getting it Together: Temporal Coordination and Conflict Management in Global Virtual Teams," *Academy of Management Journal* (44:6), pp. 1251-1262.

Morstead, S., and Blount, G. 2003. *Offshore Ready: Strategies to Plan & Profit from Offshore IT-Enabled Services*, Dallas, TX: ISANI Group.

Obstfeld, D. 2005. "Social Networks, the Tertius Iungens Orientation, and Involvement in Innovation," *Administrative Science Quarterly* (50), pp. 100-130.

Orlikowski, W. J. 2000. "Using Technology and Constituting Structures: A Practice Lens for Studying Technology in Organizations," *Organization Science* (11:4), pp. 404-428.

Orlikowski, W. J., and Iacono, C. S. 2001. "Research Commentary: Desperately Seeking the 'IT' in IT Research — A Call to Theorizing the IT Artifact," *Information Systems Research* (12:2), pp. 121-134.

Orr, J. E. 1996. *Talking about Machines: an Ethnography of a Modern Job*, Ithaca, NY: ILR Press.

Oudshoorn, N., Rommes, E., and Stienstra, M. 2004. "Configuring the User as Everybody: Gender and Design Cultures in Information and Communication Technologies," *Science Technology & Human Values* (29:1), pp. 30-63.

Perlow, L. A., Gittell, J. H., and Katz, N. 2004. "Contextualizing Patterns of Work Group Interaction: Toward a Nested Theory of Structuration," *Organization Science* (15:5), pp. 520-536.

Pfannenstein, L. L., and Tsai, R. J. 2002. "Offshore Outsourcing: Current and Future Effects on American IT Industry," *Information Systems Management* (21:4), pp. 72-80.

Pickering, A. 1995. *The Mangle of Practice: Time, Agency, and Science*, Chicago: University of Chicago Press.

Pollock, N. 2005. "When Is a Work-Around? Conflict and Negotiation in Computer Systems Development," *Science Technology & Human Values* (30:4), pp. 496-514.

Powell, A., Piccoli, G., and Ives, B. 2004. "Virtual Teams: A Review of Current Literature and Directions for Future Research," *Database for Advances in Information Systems* (35:1), pp. 6-36.

Quinn, J. B. 2000. "Outsourcing Innovation: The New Engine of Growth," *MIT Sloan Management Review* (41:4), pp. 13-28.

Quinn, J. B., and Hilmer, F. G. 1994. "Strategic Outsourcing," *MIT Sloan Management Review* (35:4), pp. 43-55.

Rottman, J. W., and Lacity, M. C. 2004. "Twenty Practices for Offshore Sourcing," *MIS Quarterly Executive* (3:3), pp. 117-130.

Sole, D., and Edmondson, A. 2002. "Situated Knowledge and Learning in Dispersed Teams ," *British Journal of Management,* (13), pp. 17-34.

Star, S. L., and Griesemer, J. R. 1989. "Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39," *Social Studies of Science* (19:3), pp. 387-420.

Strauss, A., and Corbin, J. 1998. *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory* (2nd ed.), Thousand Oaks, CA: Sage Publications.

Sutton, R. I., and Hargadon, A. 1996. "Brainstorming Groups in Context: Effectiveness in a Product Design Firm," *Administrative Science Quarterly* (41:4), pp. 685-718.

Takeishi, A. 2001. "Bridging Inter- and Intra-Firm Boundaries: Management of Supplier Involvement in Automobile Product Development," *Strategic Management Journal* (22:5), pp. 403-433.

Taylor, B. C., and Trujillo, N. 2001. "Qualitative Research Methods," in *The New Handbook of Organizational Communication: Advances in Theory, Research, and Methods,* F. M. Jablin and L. L. Putnam (eds.), Thousand Oaks, CA: Sage Publications, pp. 161-194.

Te'eni, D. 2001. "*Review:* A Cognitive-Affective Model of Organizational Communication for Designing IT," *MIS Quarterly* (25:2), pp. 251-312.

Thomke, S. H. 2006. "Capturing the Real Value of Innovation Tools," *MIT Sloan Management Review* (47:2), 2006, pp. 24-32.

Thurk, J., and Fine, G. A. 2003. "The Problem of Tools: Technology and the Sharing of Knowledge," *Acta Sociologica* (46:2), pp. 107-117.

Vaast, E., and Walsham, G. 2005. "Representations and Actions: The Transformation of Work Practices with IT Use," *Information and Organization* (15), pp. 65-89.

Weisband, S. 2002. "Maintaining Awareness in Distributed Team Collaboration," in *Distributed Work: New Research on Working Across Distance Using Technology,* S. Kiesler and P. J. Hinds (eds.), Cambridge, MA: MIT Press, pp. 311-333.

About the Authors

Paul M. Leonardi is an assistant professor of Communication Studies, Industrial Engineering and Management Sciences, and (by courtesy) Management and Organizations at Northwestern University, where he is the Breed Junior Professor of Design. He earned his Ph.D. in Management Science and Engineering from Stanford University. Dr. Leonardi's research explores how the process of organizing shapes new technological artifacts and how those very technologies that organizations develop either reinforce or change the process of organizing. He has explored these issues in the contexts of high-tech mergers, IT service work, and crashworthiness engineering.

Diane E. Bailey is an assistant professor of Management Science and Engineering at Stanford University, where she is affiliated with the Center for Work, Technology and Organization. Her research investigates the interplay of work and technology in high-technology settings. Currently, she is leading a multi-year field study to investigate the role of technology in engineering design and analysis. Dr. Bailey earned a Ph.D. in Industrial Engineering and Operations Research from the University of California, Berkeley.

Appendix A

Survey Given to U.S. and Mexican Engineers

1. How long have you been sending work to the India center? ___________

2. About how many jobs per month do you send to the India center? ___________

Please indicate your level of agreement with the following (circle most appropriate number)

3. [DEFINING REQUIREMENTS][10] I spend a significant portion of time collecting information, defining projects, and preparing SORs to send to the India center.

   strongly disagree **1** **2** **3** **4** **5** strongly agree

4. [MONITORING PROGRESS] I spend a significant portion of time communicating with engineers at the India center to help them complete the jobs I send.

   strongly disagree **1** **2** **3** **4** **5** strongly agree

5. [FIXING RETURNS] I spend a significant portion of time fixing the work I receive from the India center.

   strongly disagree **1** **2** **3** **4** **5** strongly agree

6. [ROUTING TASKS STRATEGICALLY] I spend a significant portion of time monitoring the number of jobs the India center is working on and send them jobs when I know they have the time/resources to work on them.

   strongly disagree **1** **2** **3** **4** **5** strongly agree

7. [FILTERING QUALITY] I spend a significant portion of time going through the models I receive from the India center, picking out what is done well and asking them to redo parts that do not meet my expectations.

   strongly disagree **1** **2** **3** **4** **5** strongly agree

8. I am satisfied with the quality of the models I receive from the India center.

   strongly disagree **1** **2** **3** **4** **5** strongly agree

9. I am satisfied with the speed with which the India center turns around the jobs I assign them.

   strongly disagree **1** **2** **3** **4** **5** strongly agree

10. The amount of time I save by sending a task to the India center is greater than the amount of time it takes me to explain my expectations of that task.

   strongly disagree **1** **2** **3** **4** **5** strongly agree

[10]Bracketed labels refer to the work practice the question targets and were not included on the survey.