Impact of Information Technology on Knowledge Work

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Dedication

This thesis is dedicated to my family members and friends. Without their support, I would not have made it this far.

Abstract

As intangible assets emerge as a key determinant of performance and competitive advantage of firms, the organizational processes involved in creating and sharing knowledge within the firm are being recognized as important. Research in information systems research has traditionally focused on examining the role of systems such as knowledge management systems that support these activities. This dissertation focuses on collaborative problem solving processes among non-collocated parties, an activity central to the creation of knowledge that inherently involves significant knowledge sharing.

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Dissertation Introduction

As intangible assets emerge as a key determinant of performance and competitive advantage of firms, the organizational processes involved in creating and sharing knowledge within the firm are being recognized as important. Research in information systems research has traditionally focused on examining the role of systems such as knowledge management systems that support these activities. This dissertation focuses on collaborative problem solving processes among non-collocated parties, an activity central to the creation of knowledge that inherently involves significant knowledge sharing. It uses a proprietary dataset shared under strict confidentiality requirements by an engineering manufacturing and services firm. The dataset contains a longitudinal archival record of calls over a three-year period to technical support by field technicians of the firm maintaining HVAC systems. It also includes comprehensive records of all repository searches for information made by field technicians since the installation of the repository system.

I study knowledge work in the context of the North American service division of the firm that is engaged in the maintenance of commercial HVAC systems from locations all over the US. Field technicians in the organization are dispatched to customer locations to attend to service problems reported by customers. In most instances during service calls, field technicians use their accumulated knowledge and experience to fix the problems they encounter. To supplement their personal knowledge, they can access an online knowledge repository and search for documents from company issued laptops that has an Internet connection. However, when field technicians fail to solve a problem based on their knowledge and expertise and information obtainable from the repository, they can call the central technical support center for assistance in problem solving. The technical support center is staffed by technical support engineers who work with field technicians over the phone to troubleshoot, diagnose and help fix malfunctioning equipment. My dissertation comprises three essays that examine phenomena related to knowledge sharing from three different perspectives in this context.

In essay one, I study knowledge sourcing from three sources in the technical support center. When a technical support engineer receives a call from a field technician, the technical support engineer has three sources of knowledge for solving the problem at hand: (i) their own expertise, (ii) the documents stored in the knowledge repository, and (iii) help from other collocated technical support engineers in the technical support center. Organizational efforts to enhance the productivity of knowledge work by deploying information technologies have usually focused on codification and enabling knowledge sharing among individuals. While prior research has examined the productivity consequences of specific organizational initiatives, we adopt an integrative perspective on how the productivity of knowledge work is affected by complementarities between three important factors: (i) the degree of codification of relevant knowledge within a repository, (ii) the expertise of the knowledge workers, and (iii) the extent of availability of peers to provide help through personalization. In this essay I study the interaction between these three sources of knowledge. I find that the expertise of the technical support engineer and the help available from colleagues in the technical support center improve problem solving efficiency, whereas the number of knowledge documents on their own reduce the efficiency of problem solving. However, more interestingly, I find that with respect to the documents in the repository, novices derive benefits whereas experts are worse-off. Similarly, with respect to interpersonal help seeking, novices benefit more than experts whereas experts are worse off. Our finer grained analysis of the effects of each of the factors in the presence and absence of the others provides interesting insights about their roles in influencing performance. Individual expertise is both a complement as well as a substitute for codified knowledge and personalized knowledge. Overall, the evidence points towards performance benefits accruing primarily from the synergistic combination of expertise, codified knowledge and access to personalized knowledge rather than from any of these resources individually. The results have implications for the design of systems to support knowledge intensive tasks and provide a deeper understanding of the nature of knowledge work and resources enabling task performance.

In Essay 2, I study joint problem solving processes between non-collocated individuals interacting over lean electronic media who never meet in person. Prior studies in the area of joint and collaborative problem solving suggest that mutual knowledge, often developed through casual interpersonal interactions or interactions over rich media, facilitates the sharing of context specific information to solve unstructured/complex problems. This body of research suggests that colocation and face-to-face interpersonal communication are required to develop both a shared understanding of what the other party knows and a shared vocabulary to express nuances involved in problem solving. However, parties increasingly communicate over electronic media and often never meet in person. In our specific context for example, the field technician and the technical support engineer collaborate to find solution to complex maintenance problems in the field with no opportunity to meet in person. This raises the question: can the field technician and a technical support engineer who communicate exclusively over a lean medium develop the mutual knowledge to solve a complex problem. I posit that repeated interaction between a field technician and a technical support engineer over lean media enables the development of the mutual knowledge as repeated interaction expands the richness of a lean channel. The analysis suggests that field technician – technical support engineer dyads improve in task efficiency as the frequency of the interaction between them increases. We also find that the depth of the expertise of the technical support engineer, measured as the number of knowledge documents authored by the technical support engineer; and the absorptive capacity of the field technician, measured as the number of knowledge documents accessed by the field technician, positively moderate the impact of mutual knowledge in improving the efficiency of joint problem solving. This suggests that a technical support engineer documenting a solution not only benefits other technical support engineer and other field technicians, but also benefits the given technical support engineer in joint problem solving. Similarly, by reading a knowledge document a field technician becomes prepared for a more productive exchange with a technical support engineer.

In essay 3, I examine the question: how does the ongoing use of information technology (IT) help individuals develop individual skill and expertise. On one hand, IT systems can routinize and structure knowledge intensive tasks, thus reducing the level of human judgement and ingenuity involved in task performance. On the other hand, IT systems can increase the importance of specialized domain knowledge in task performance by professionals such as doctors, lawyers, and (even) academicians by requiring human interventions only in complex, non-routine cases which are not addressable by systems. This raises the question: Can IT help in the development of skill and expertise of individual knowledge workers? In our specific context, the question is: can field technicians develop their skill and expertise through internalization i.e., by accessing the documents stored in the knowledge repository and through socialization i.e., by interacting electronically with the technical support engineers. Our analysis indicates that field technicians acquire general and specific knowledge through internalization and tacit knowledge through socialization. Internalization and socialization helps field technicians in a way that influences their calling behavior i.e., as field technicians acquire knowledge and expertise through internalization and socialization, they are able to solve more of the problems in the field and need to call the technical support center less frequently. Also, field technicians that acquire knowledge and expertise through internalization and socialization are more likely to be promoted, suggesting that internalization and socialization leads to the development of human capital that is rewarded by the organization. This study provides evidence that IT in general, and knowledge repositories in particular, help knowledge workers develop human capital.

Essay 1: The Influence of Individual Expertise, Codification and Personalization on the Performance of Knowledge Work: An Integrative Analysis

1.1 Introduction

Increasing the productivity of knowledge work is one of the central challenges facing modern firms. The strategies of firms to systematize and make organizational knowledge available for access to employees reflect a combination of two approaches – *codification* and *personalization* (Bush and Tiwana 2005, Alavi and Leidner 2001). Codification refers to the strategy of capturing knowledge that is potentially important for task performance in documents. Codified knowledge is typically stored in central document repositories that individuals can look up and represents a *people to documents* approach to obtaining inputs for knowledge work. In contrast, personalization is the strategy of creating mechanisms to help individuals contact others when they need help or assistance. Personalization represents a *people to people* approach for obtaining help which includes a variety of mechanisms through which individuals can contact others for assistance and inputs such as by physically walking over to request help, calling for help and emailing for help.

Despite decades of research into knowledge management systems, the effective support of knowledge intensive tasks remains elusive (Ko and Dennis 2011). The performance of knowledge intensive tasks, viewed through the lens of socially constructed practices is seen as idiosyncratic and non-routine (Pentland and Feldman 2009, Durcikova et. al. 2011). Supporting knowledge work is complex because it involves the resolution of both uncertainty and equivocality and also because the specific sequence of activities involved in task performance and their relationship to outcomes varies considerably. As a result of the interplay of problems, tools and approaches to problem solving, the resources to support knowledge work can only be partially anticipated in advance (Malone et. al 1994, Pentland 2003). Ethnographic studies of knowledge work highlight that knowledge workers draw on their own knowledge, use codified knowledge when available and also draw on the resources of others in making sense of tasks and evolving appropriate responses (Pentland 2003, Faraj and Xiao 2006).

The productivity and outcomes of tasks in contexts of knowledge work are thus linked to a combination of three key resources: individual knowledge and expertise, codified knowledge from sources such as document repositories and inputs obtained through interactions with others (Borgatti and Cross 2003).

Prior research has largely examined the direct effects of one or some combination of two of these determinants i.e., codified knowledge use, personalized knowledge obtained from others and individual expertise (Kankanhalli, Tan and Wei 2005, Wasko and Faraj 2005, Dong-Gil and Dennis 2011). We extend the prevailing research by examining the effects of two-way and three-way complementarities among these inputs in knowledge work. We adopt a task performance perspective to explore how individual experience, codified knowledge and personalized knowledge are combined in the execution of organizational routines and how they influence knowledge worker performance. Our results suggest that individual expertise and personalized knowledge are both associated with enhanced task performance. We also find that the availability of codified knowledge and personalized knowledge enhances task performance of novices more than those with higher levels of expertise. The results also suggest a three-way complementarity among individual expertise, personalized knowledge and codified knowledge, indicating that the joint presence of all three of these factors significantly enhances task performance. Interestingly, greater codified knowledge is not directly related to enhanced task performance. These results thus contribute to a deeper understanding of the individual and joint effects of codified knowledge, individual expertise and personalized knowledge on the performance on knowledge intensive tasks.

The next section of the paper presents an overview of the research setting before we present our conceptual arguments and research hypothesis. Next, we describe data gathering strategy. Finally, we present the results of our analysis and their implications for future research and practice.

1.2 Research Setting

The setting for our research is the technical support unit of *Aircom*, a large North American engineering firm that manufactures, sells and services heating, ventilation and air conditioning (HVAC) systems for commercial clients. Around 1500 field technicians spread across 617 office locations provide the warranty and ongoing maintenance services to US customers. When these field technicians encounter problems in on-site maintenance or repair, they rely upon a Technical Support Center. In our study, we gathered archival data on the activities of the technical support group of the controls division that is located in the manufacturing facility of a large Midwest metropolitan area. The group operates as a call center, and it is staffed by experienced technical support engineers (TSEs) who work from cubicles in a large bay. Each TSE has cordless phones with headsets so that they can move around while still being on engaged with the field technicians on calls. The technical support center has analog and digital simulators in several locations around the room where engineers can step up to simulate specific situations being described by field technicians to aid problem diagnosis.

The TSEs have access to a central document repository that provides access to expertise in the form of documents related to equipment maintenance and trouble shooting. This repository contains engineering documents needed for problem solving as well as the documentation of commonly occurring problems and their solutions. The repository also contains troubleshooting and repair manuals as well as support documents authored by technical support engineers. Calls from field technicians often involve novel issues that are not covered in equipment troubleshooting and repair manuals. Therefore, the technical support group is also expected to codify and document new solutions so that others can reuse them in the future. Submissions to the document repository are voluntary and not compensated but the number of repository contributions is one of the metrics used by managers during performance appraisals. The knowledge repository is continuously growing with new documents being regularly added to the repository.

The TSEs are required to work from the physical office of the support center in order to foster interpersonal interactions in solving field problems. For instance, it is common for a TSE taking a call to walk over to a colleague to request help in resolving a current call. TSEs have only 30 seconds of personal time between the end of one call before the phone rings with the next caller in the queue and most engineers are usually busy taking calls. The group's norm is for the help seeker to wait at the colleague's desk to ask their question. However, since the average call lasts about 10 minutes, the individual being asked for help often puts their current caller on hold when they see someone waiting to ask a question, particularly when the wait time may be excessive because they are in the middle of a call. In such instances, the helper often puts their current call on hold, provides the help needed and then gets back on the call to complete the conversation.

However, TSEs have other duties as well; for example, they are responsible for interfacing with R&D and Quality Control groups to discuss field issues that may need design changes or changes to manufacturing and quality processes. Senior TSEs are also responsible for finding solutions to field problems that are not resolved over the phone and may need more detailed investigation. When TSEs want to handle these other tasks and don't want to take calls, they log out of the computerized call management system and move out of the call handling area. Call center statistics such as the names of TSEs logged in, statistics regarding the number of calls handled by each of them, the length of their current call and the number of callers on hold and the average wait time are provided on a large display so that the group has an overview of the individuals taking calls as well as the current workload of calls.

The problem solving tasks of the TSEs in commercial HVAC systems represent a particularly appropriate context for our study because the knowledge involved in problem solving is dynamic and highly contextual and the efficiency or the quality of problem solving outcomes can continue to improve over time. TSEs are the source of last resort for field technicians confronting repair or maintenance problems in the field. In our study, problems encountered by field technicians arise from complex assemblies comprising heating and cooling equipment modules that interface with other systems and are controlled by digital and analog controllers. As a result, even the relatively routine problems exhibited by such systems are often too complicated to diagnose and troubleshoot easily (Das 2003). There are often multiple approaches to solving the complex problems; taking more variables into account or framing the problem from different perspectives based on prior experience can continually lead to superior solutions to recurrent problems. As mechanical installations age with use and the tolerances change with wear and as individual modules are replaced over time, individual HVAC systems begin to exhibit idiosyncratic behaviors and symptoms that are not covered in the standard repair manuals and training sessions. Ethnographic studies of similar contexts (e.g. Pentland and Reuter 1994, Orr 2006) suggest that the task in diagnosis is to create a representation of the problematic situation that is sufficiently complete to indicate a course of repair. But the resources available to build this representation are generally sparse such as the confusing and often contradictory problem reports by customers, abnormal sounds and readings from voltage and pressure probes at different points that are not anticipated in standard maintenance manuals or covered in training and HVAC certification. When field technicians call technical support, the problems are usually ambiguous. The steps followed in technical diagnosis and problem solving may require processes that go beyond the formally recommended procedures and often involve improvisation and bricolage (Das 2003). These problem-solving processes tax the expertise of individuals, and they can benefit from the availability of codified knowledge and the ability to interact with other technical support engineers.

1.3 Theory and Hypotheses

The information processing perspective on organizations suggest that the performance of knowledge intensive tasks such as problem solving in technical environments involves the resolution of both uncertainty and ambiguity (Haas and Hansen 2007)). Individuals face uncertainty when they have questions related to a problem, but do not have the information to address the questions (e.g. *Are there any service bulletins to cover wires loosening up and burning? Or, What is the freeze* *avoidance setpoint for this system?*). Individuals can resolve uncertainty by acquiring additional information from document repositories. For example, to answer the question regarding the freeze avoidance setpoint, a TSE can search the document repository and get the list of results that provide design specifications such as the set points for equipment. In contrast, individuals experience ambiguity when they know they have a problem to solve, but they are not clear about the questions to ask or the appropriate way to frame the issue so that it can be addressed. Descriptions of problems, such as "*Cannot connect to BMTW BCU after changing out standard capacity card, what is the problem?, What could be causing low superheat diagnostic readings?, or Why do I get a CSC alarm in Tracer Summit?"* reflect situations of ambiguity. Ambiguity is resolved by sensemaking and forming different interpretations that fit observed symptoms and using judgments to decide the root causes. Seeking help and discussing the questions with a colleague is important to resolve ambiguity (Cross and Sproull 2004).

Searchable document repositories containing codified knowledge, also referred to as non-relational resources since they do not involve interpersonal interaction (Zimmer et. al 2008), are central components of knowledge management systems. The ready availability of codified knowledge helps task performance in several ways. First, documents describing the steps that led to the resolution of identical or reasonably similar problems faced by others in the past allows individuals to reuse or adapt the prior solution to address the current problem rather than have to craft a solution afresh (Kankanhalli, Tan and Weil 2005). Documented solutions can also serve as *scaffolding* to allow individuals to gain experiential knowledge to address problems that might otherwise be beyond the scope of their current knowledge base (Gray and Durcikova 2006). Research suggests that individuals' task performance is enhanced when they can draw on codified knowledge from searchable document repositories. However, there is evidence that drawing on codified knowledge can also adversely affect performance. For instance, Haas and Hansen (2005) found that experienced teams in a consulting firm were more likely to lose their bids when they utilized documented knowledge in preparing their proposals.

While the benefits from reusing or adapting codified knowledge are likely to drive the demand for documents in repositories, such repositories are useful only if knowledgeable individuals contribute to repositories by codifying knowledge useful for problem solving. Organizations offer a variety of incentives to encourage the ongoing documentation of knowledge that individuals gain in the course of task performance (Alavi and Leidner 2001). Prior research suggests that knowledgeable individuals can anticipate the needs of coworkers and that they are motivated to document solutions to recurrent problems to minimize interruptions from interpersonal requests for help by others (Liu, Ray, Whinston 2010). Documenting relevant knowledge related to recurrent problems allows knowledgeable individuals to reduce task-interrupting information requests and be more efficient in helping others (Tiwana and Bush 2005).

Organizations represent social environments where individuals seeking clarifications often turn to collocated coworkers for inputs (Zimmer et. al 2007, Borgatti and Cross 2003). Asking others for help is an important step in the enactment of sensemaking processes on complex organizational problems. In obtaining personalized knowledge, individuals provide a narrative account of their problem to colleagues. Such narratives are important in helping individuals become knowledgeable as well as in the social construction of knowledge in communities of practice (Brown and Duguid 2001). These interpersonal interactions enable the resolution of ambiguity and equivocality, particularly in instances where prescribed procedures have already been tried and found to be ineffective. In fast paced environments, dialogic coordination among individuals talking through problem situations helps individuals explore multiple perspectives (Faraj and Xiao 2006). These workplace interactions also enable socialization and knowledge externalization that contribute to new knowledge creation. Obtaining personalized knowledge also involves joint sense making, and it enables individuals to pool knowledge, draw from collective knowledge, and reframe prior experiences to generate novel and creative insights to current problems (Cross and Sproull 2004).

By seeking help and obtaining personalized knowledge from coworkers, individuals can execute tasks that they may be unable to perform on their own. While help seekers gain benefits from being helped, knowledgeable individual who are helpful to others gain reputation, prestige and standing in the workplace (Tiwana and Bush 2005). Since rendering personalized knowledge requires knowledgeable individuals to voluntarily interrupt their own work to help others, such behaviors are not mandated and are considered to be extra-role citizenship behaviors. Recent research has begun to recognize this as paradox of citizenship behaviors because they can be detrimental to the helpers in their own task performance (Bergeron 2007). Though helpers derive non-instrumental benefits by building social capital and enhancing their reputations (Tiwana and Bush 2005, Wasko and Faraj 2005), research suggests that the outcomes from helping may be asymmetric with helpseekers benefiting more than helpers.

1.3.1 Direct Effects of Personal Expertise, Codified Knowledge and HelpSeeking

Individual expertise is an important source of influence on the performance of knowledge workers. Individuals develop expertise in the course of their work and this enables them to make superior judgments; expertise is a complex combination of domain knowledge and understanding of contingencies that could affect the problems facing them (Ericcson 2005). Experts' mental models of problems and solutions and cognitive processes for problem solving are different from those of novices (Bereiter and Scardamalia 1993). Experts can process more information, and they are more efficient in problem diagnosis and troubleshooting. Their knowledge influences what they notice and how they organize, represent, and interpret information in the task environment; they have the ability to remember, reason, and solve problems. In particular, experts can intuitively identify and focus on aspects of problems that are important for creating solutions (Ericsson and Charness 1994) because they notice features and meaningful patterns of information that are often overlooked by novices. Moreover, experts possess content and contextual knowledge that reflects a deeper domain understanding. Experts can also flexibly retrieve important aspects of their knowledge and create solutions to novel problems based on knowledge of solutions to other problems that have worked in the past (Christensen and Schunn 2007). They can perform complex tasks intuitively without deliberate information processing and with little attentional effort. Developing expertise is believed to be linked to exposure to a broader set of problems of the domain and the ability to recognize complex linkages of problems and symptoms with solutions.

Though expertise is no longer considered to be an innate ability, the precise set of factors that combine to create expertise continues to be elusive. However, studies confirm that learning developed through the duration of experience with tasks in a domain is a key contributor toward task performance (Ericcson 1996) and progressive problem solving (Bereiter and Scardamalia 1993). The performance of knowledge work over prolonged periods of time leads to an accumulation of both explicit knowledge and tacit knowledge of the nuances and exceptions in handling of tasks. In addition to greater amounts of specialized knowledge, individuals with extended experience in a task domain develop the capacity for abstraction and more complex representations of classes of problems and their solutions (Moxley, Ericsson, Charness, Krampe 2012). The acquisition of individual expertise developed through learning by doing helps individuals to be more efficient at problem solving. Therefore, we hypothesize that:

H1a: The level of individual expertise in the task domain will have a significant influence on task performance.

Codified knowledge is available in searchable document repositories that are the central components of knowledge management initiatives (Ko and Dennis 2011). The ongoing documentation of helpful information such as incidents of problems and solutions allows firms to develop a codified base of knowledge. Employees are provided incentives to record their learnings so that they may be useful to others (He and Wei 2009) and experts who do so also gain social capital and reputational benefits (Tiwana and Bush 2005). Since providing personalized knowledge interrupts their task performance, knowledgeable individuals are also motivated to document their knowledge to minimize disruption of their tasks by help seekers (Liu, Ray, Whinston 2010). Access to codified knowledge such as documented solutions to problems that have worked in the past can significantly reduce the time taken for future problem solving (Haas and Hansen 2002). In domains such as medicine characterized by high rates of new knowledge creation, the ability to access updated codified knowledge reduces errors and enhances diagnostic performance (Davenport and Glaser 2002). Therefore, we hypothesize that:

H1b: The level of codified knowledge in the repository will have a significant influence on task performance.

Obtaining personalized knowledge is an important aid to problem solving, not only for individuals who have limited domain knowledge but also for others who may be experienced but yet not have encountered some of the unusual problems in the domain. Beginning with the classical analysis of R&D projects by Allen (1984) to more recent discussions of problems in product development organizations (Sosa, Eppinger and Rowles 2004), academic research has emphasized the importance of interpersonal interactions in obtaining useful knowledge. Ethnographic studies of copier repairmen engaged in the maintenance of complex equipment (Orr 2006) and of technicians providing technical support for callers (Das 2004; Pentland and Reuter 2004) suggest that interpersonal knowledge sharing among peers is widespread and contributes to learning and task performance. Research on the role of social networks in workplaces highlights that the information and knowledge obtained by individuals through interactions with others enhances individual performance (Borgatti and Cross 2003). An accurate understanding of *who knows what* to decide, whom to access for help is an important factor enhancing individual and team performance (Faraj and Sproull 2000). Interpersonal interactions can help individuals obtain a variety of social and task related inputs (Cross and Sproull 2004). Overall, there is considerable evidence that personalized knowledge obtained through interpersonal interactions improves task performance. We therefore hypothesize that:

H1c: The level of personalized knowledge accessible through interpersonal interactions will have a significant influence on task performance.

1.3.2 Complementary Effects of Expertise, Codified Knowledge and Personalized Knowledge

Though prior research has examined the direct effects of expertise, codified knowledge and personalized knowledge on task performance, their complementary effects have received limited attention. Our research extends the prevailing insights by examining the two-way and three-way complementary effects of these factors.

The Complementary Effects of Expertise and Codified Knowledge

The availability of codified knowledge improves knowledge workers' performance by allowing individuals to reuse knowledge. For instance, when an engineer in the technical support center receives a call regarding an issue for which a solution already exists in the codified repository, he or she can resolve the current problem by finding the existing solution and directly applying it or adapting it to suit the specific context. However, problem solver's own expertise could influence the extent to which they benefit from the level of knowledge codification in the repository (Haas and Hansen 2007).

Novices are more likely to encounter situations where their existing resources are insufficient for the task at hand. The knowledge base of novices comprises of isolated facts and propositions with little meta-knowledge such as the relative importance of different elements of information for problem solving and how the different elements are related to each other (Ericsson 1996). Novices' knowledge acquisition mainly involves memorization of disconnected elements of knowledge, which they later attempt to recall when solving problems. In addition to being constrained by their limited knowledge base, the ability of novices to recall knowledge for application is also limited by lack of organization and understanding of inter-relationships among knowledge components (Christensen and Schunn 2007). The performance of novices is likely to be significantly enhanced by the ability to access codified knowledge from the repository since this allows them to search for and reuse prior solutions in the document repository. As a result, greater levels of codification expand the variety of problems that novices can solve and also speed up their problem solving (Haas and Hansen 2007). These arguments are consistent with the findings of Arnold et. al (2006) who find that novices, in comparison with experts, use expert systems more for declarative knowledge and for problem solving strategies.

In contrast to novices, experts are more likely to already know and be able to recall the knowledge needed to solve the recurring problems that are documented in the repository. Experts have their knowledge organized efficiently and their memories hold meaningful information about related elements clustered into related units (Ericsson 1996). The inter-relationships among these clusters correspond to the principles and laws in the domain and represent problems at a deeper, more principled level than novices who tend to represent problems using superficial details. This superior organization allows experts to efficiently recall and navigate a rich array of knowledge and also evolve efficient problem solution strategies using prior knowledge to address novel problems they have not encountered earlier (Christensen and Schunn 2007). Therefore, experts are likely to focus on understanding the problems and solve them through their personal knowledge. Prior work also highlights that experts evolve novel solutions to problems without going through all the steps necessary because their problem solving is automatic (Ericsson and Lehmann 1996, Ericsson and Charness 1994). They often start with a more accurate hypothesis than novices and choose the path to the solution based on their current knowledge. In contrast with novices who are more likely to use the document repository to search for solutions, experts are thus more likely to use the repository to conform their approach to prior documented solutions *after they have an intuitive understanding of how to solve the current problem*. These arguments, on the lines of Dhaliwal and Benbasat (1996), suggest differences in patterns of repository use; whereas novices are more likely than experts to use the repository to identify solutions and experts are more likely than novices to use the repository to cross-check or confirm their own solutions. These arguments are consistent with experimental evidence in the work of Arnold et. al (2006) that experts show a preference for information on justifications and strategy in feedback mode when using expert systems to compare system recommendations against their own judgments.

Prior research also suggests that the performance of experts is impaired when they are provided prior solutions due to *distraction risk* (Haas and Hansen, 2005, Haas and Hansen 2007). Distraction risks arise from the discrepancy between the quality of the solution individuals devise to problems on their own and that they create after examining prior solutions. Since novices are often less likely to be able to create a solution using their own resources than more experienced individuals (Ericsson and Smith 1991), this is a greater risk for experts than for novices. The exposure to solution elements in prior solutions can trap individuals into 'mental ruts and inhibit generative creative processes and result in solutions that are *fixated* and draw unduly on prior solutions (Jansson and Smith 1991). Knowledgeable individuals are susceptible to this tendency, which is also viewed as unconscious plagiarism' or 'cryptomnesia' (Marsh and Landau 1995). In general, these arguments suggest that the performance of experienced individuals could be impaired more than that of novices by distraction risks and anchoring effects arising from codified knowledge in repositories. This leads us to suggest the following hypothesis:

H2a: The availability of codified knowledge accessible through the repository is more likely to improve the performance of individuals with less expertise than those with more expertise.

The Complementary Effects of Expertise and Personalized Knowledge

In situations when an individual encounters situations of ambiguity, access to personalized knowledge: being able to request and receive help from knowledgeable others, is particularly useful (Cross and Sproull 2004). In general, there is a broad consensus that personalized knowledge significantly enhances the performance of individuals being helped. For instance, Orr (2006) observed interpersonal information exchanges helping photocopier repairmen gain complex undocumented knowledge about the idiosyncratic behaviors of machines and how they could be fixed. Similarly, Pentland and Reuter (1994) articulate how individuals enact socially acceptable moves to seek help when they are unable to perform their tasks with their own resources. However, research has not explored whether the accessibility of personalized knowledge in a context differentially affects the performance of experts and novices.

Novices usually seek help more than experts; experts are more likely to be involved in providing help rather than seeking help (Constant, Kiesler and Sproull1996, Borgatti and Cross 2003, Cross and Sproull 2004). While the performance of individuals obtaining help typically increases, helping can be detrimental to the task performance of helpers (Bergeron 2007). The willingness to bear the costs of helping is part of the calculus that accords helpful individuals with intangible benefits such as greater social capital and prestige within communities (Wasko and Faraj 2005, Hansen 1999). Prior research has recognized that seeking help imposes costs on the helper and that help-seeking can be a strategic move by individuals to shift their own work to others (Pentland and Reuter 1994). Prior work suggests that helping is effortful (Hansen 1999), that helping is an imposition the time and effort of helpers (Pentland and Reuter 1994, Cross and Sproull 2004), that helping involves interruptions that can reduce productivity (Froehle and White 2014) and that individuals help others in spite of the negative effects on their own task performance (Bergeron 2007).

For an individual with a high level of expertise, the greater use of personalized knowledge by others is likely to result in more interruptions to their own work (Liu, Ray, Whinston 2010). Therefore, where there is greater personalized knowledge accessed through interpersonal interactions, while individuals benefit from seeking help, experienced individuals with more expertise who are usually those providing help are likely to see a reduction in task performance. We therefore hypothesize that:

H2b: The level of personalized knowledge accessible through interpersonal interactions is likely to enhance the performance of novices more than that of experts.

The Complementary Effects of Personalization and Codification

Prior research provides two contrasting perspectives about the effects of codification and personalization. The first perspective, embodied in the early research on knowledge management, suggests that document repositories and relational sources are mutually exclusive alternatives. This perspective suggests that codification and personalization each steer individuals along different trajectories of learning. Codified knowledge was viewed as likely to be more relevant for contexts of routinized repeated problem solving, whereas interpersonal interactions were viewed as more helpful in contexts with non-routine and diverse problems where rich interpersonal interactions facilitate sense-making and help solve unstructured problems (Haas and Hansen 2002).

The contemporary perspective, rooted in the view of firms as knowledge creating entities suggests that knowledge codification and personalization are complementary and are a part of the dynamic process of problem solving in firms (Durcikova et. al 2011). This literature highlights codification as important for the diffusion of knowledge among individuals and groups. Interpersonal interactions enable greater knowledge elaboration and help individuals and groups to accumulate and share tacit knowledge that complements explicit knowledge codified in documents. The combined use of codified knowledge in document repositories and personalized knowledge in interpersonal interactions contributes to individuals achieving outcomes superior to those that would be obtained through either one alone. In this regard, document repositories also serve to inform who knows what and helps individuals identify people to seek help from. Personal interactions can also help individuals gain the contextual knowledge needed to make sense of codified knowledge. Overall, we propose the following:

H2c: The level of personalized knowledge accessible through interpersonal interactions is likely to enhance the effects of codification on task performance.

The Complementary Effects of Expertise, Codification, and Personalization

To study the impact of the three-way complementarity of expertise, codification, and personalization, we consider the impact of one in the presence of the other two.

The level of codification and personalized knowledge are together likely to enhance the influence of expertise on task performance. Individuals with a higher level of expertise can build their knowledge base by going through the documents contained in the document repository. Experts can also benefit from personalization to enrich their prevailing expertise. Combining codified knowledge with personalized knowledge is beneficial to experts because they can efficiently gather the information and insights needed for task performance and reach out to knowledgeable others for clarifications and help in finding, interpreting and applying codified knowledge. Because experts have a rich and well-organized knowledge base, they are likely to evolve solutions to problems and take advantage of document repositories to look up and confirm their diagnoses. Further, they can take advantage of the ability to interact with others to seek clarifications, discuss and validate any solutions, and solve the problem at hand. Further, when others approach experts in interpersonal interactions for help, the availability of codified knowledge helps them be more efficient as they can direct help-seekers to look up pertinent documentation in the repository. Thus, the overall effect of expertise on outcomes is enhanced by codification and personalization.

The level of codification and an individual's expertise are together likely to enhance the effects of personalization on task performance. Interpersonal interactions for help involve the sharing of views and perspectives and create new knowledge. Individuals with greater expertise are more likely to be able to engage in productive conversations with coworkers. The availability of documents can further facilitate interactions since disagreements or differences in views can be resolved by referring to knowledge codified in the repository. Thus, the overall effect of personalization is enhanced by the level of codification and individual expertise.

The combination of individual expertise and personalization is likely to enhance the influence of codification on task performance. Codification increases the reuse of prior knowledge in solving recurrent problems. The ability to reach out for help through personalization enables individuals to adapt the codified knowledge to solve the problem at hand. Further, since documents represent abstractions of solutions to prior problems, they are more likely to be useful for problem solving in the presence of expertise and the ability to obtain clarifications from coworkers. Thus, the impact of documents is enhanced in the presence of expertise and personalization. In view of these arguments, we hypothesize that:

H3: The effects of the levels of expertise, codification and access to personalized knowledge complement each other to positively influence task performance.

1.4 Empirical Analysis

The empirical analysis uses archival data made available by Aircom about the ongoing operations of the Technical support group. We obtained data on all incoming calls to the technical support center and the document repository used by the technical support group from September 2008 to August 2011. For each incoming call, the TSE taking the call creates a *ticket* with information on the name and location of the caller, details of the field equipment, a description of the reason for the call, and the solution that the technical support engineer suggested. Our data includes only the closed calls i.e., calls where the caller's problem was solved by the end of the call. The data used in the analysis covered 70,909 closed calls with matching ticket data for each call. On a typical day, there were 59 tech support engineers available to receive calls at the technical support center. On the average, tech support engineers handled about 12 calls each day and the average call duration was 10 minutes. The complexity of the caller's problem indicated in each ticket was coded on a 1-5 scale. During the period of the research, the number of documents in the repository increased from 23,000 to about 41,000.

1.4.1 Constructs and Measurement

Dependent Variable: The dependent variable is the *call length*. This is an important metric available for all calls to the technical support center in the call center log. Though the field technician is ultimately responsible for getting the HVAC system functioning again, the TSE's responsiveness to the call is a key determinant in the field technician getting the system running again. In this regard, the time taken to provide an acceptable solution to the field technician is a key performance metric for the TSE.

Independent Variables: The key independent variables in our research include: (i) the individual expertise of the TSE, (ii) the level of codification, and (iii) the level of personalization. We measured the TSE's expertise at the time of taking the call as *the number of prior calls handled by the technical support engineer* at that time. The level of access to codified knowledge was measured as the *number of documents available in the repository on the given day*. The level of access to personalized knowledge was measured as the *total number of man-hours that TSEs are logged in to the call management system on the given day*. This measure of personalization is influenced by both the number as well as the duration for which TSEs worked on a given day. This is a conservative measure of personalization since most TSEs have other duties (such as writing technical reports, meetings with design engineers, etc.) and take calls for only a part of each day. Since knowledgeable colleagues are present in their cubicles and available for help even when they are not logged in to the system, this is a conservative proxy for the level of knowledge available through interactions with peers.

Control variables: We include the *tenure* of each TSE in days as a control to account for the influence of unobserved characteristics of the TSE such as their familiarity with the organization and understanding of field problems. We also included call complexity as a control since the length of the call is likely to be influenced by the complexity of the call. Call complexity was coded by Aircom managers on a 5-point scale using the *call reason* field in each ticket. The call length is also likely to be influenced by caller attributes. We therefore include two caller characteristics as controls -*the propensity to call to seek help* and *tenure in the organization*. The propensity of the caller to seek help is measured as the number of prior calls made by the caller before the current call. The tenure of the caller is measured as the number of days the caller has been part of the field support staff.

To account for external factors that may also influence calls to technical support, we included two variables - *the total number of potential callers in the field* (the field technician headcount) and the *dollar value of service contracts being supported* by the field organization as controls. Since our analysis includes two-way interactions and a three-way interaction of variables, we standardized all variables to make the coefficients of main effects and lower order interactions interpretable as suggested by Afshartous and Preston (2011).

1.4.2 Data Analysis, Results

Table 1.1 presents the summary statistics and correlations among key variables.

Table 1.1: Means, standard deviations and correlations between key variables

No.	Variable	Mean (standard deviation)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	Call Duration (seconds)	584.54 (577.41)									
2	Call Complexity	3.31 (1.44)	0.29								
3	Likelihood of Calling	59.55 (52.72)	-0.07	-0.13							
4	# Documents in Repository	29412.1 (4753.96)	0.05	0.02	0.47						
5	Total # Field Technicians	2842.02 (41.78)	0.08	0.08	-0.09	0.21					
6	Value of Field Service Contracts ($)	47705325 (5488943)	0.01	-0.02	0.2	0.53	0.2				
7	Personalization	5127180 (1683279)	-0.05	-0.06	0.33	0.19	0.04	-0.02			
8	TSE Expertise	1691.688 (1575.45)	-0.07	0.02	0.41	0.27	-0.23	0.18	0.13		
9	TSE Tenure (days)	982.97 (513.63)	0.04	-0.02	0.3	0.51	-0.11	0.22	0.31	0.09	
10	Field Technician Tenure (days)	219.46 (567.36)	-0.05	-0.15	0.33	0.42	-0.08	0.21	0.22	0.15	0.32

On a given day, a TSE may take a number of calls of different complexity. We ran ordinary least squares regression, with robust standard errors to control for heteroscedasticity. These results are reported in Table 1.2.

Table 1.2: Results of Regression (n = 70, 909)

Independent Variables	**Model 1 DV=Call Duration Coefficient, (standard error)**	**Model 2 DV=Call Duration Coefficient, (standard error)**	**Model 3 DV=Call Duration Coefficient, (standard error)**
# Documents in Repository	0.092*** (0.006)	0.122*** (0.006)	0.124*** (0.006)
Call Complexity	0.283*** (0.004)	0.29*** (0.004)	0.291*** (0.003)
Likelihood of Calling	-0.067*** (0.004)	-0.031*** (0.004)	-0.031*** (0.004)
Total # Field Technicians	-0.027*** (0.006)	-0.021*** (0.005)	-0.023*** (0.005)
Service Contract Supported ($)	-0.01* (0.005)	-0.004 (0.005)	-0.004 (0.005)
Access to Personalization	-0.029*** (0.004)	-0.019*** (0.004)	-0.017*** (0.004)
TSE Expertise	-0.067*** (0.004)	-0.104*** (0.004)	-0.103*** (0.004)
TSE Tenure (days)	-0.002*** (0.004)	-0.016*** (0.004)	-0.016*** (0.004)
Field Technician Tenure	-0.02*** (0.004)	-0.02*** (0.004)	-0.02*** (0.004)
#documents * expertise		0.062*** (0.004)	0.061*** (0.004)
#documents * personalization		0.004 (0.005)	0.005 (0.006)
Expertise * personalization		0.05*** (0.004)	0.05*** (0.004)
#documents * personalization* expertise			-0.013*** (0.005)
R Squared	0.098	0.1032	0.1033

Model 1 includes the main effects of the three inputs to the technical support process (i.e., individual expertise, the level of codification and the level of personalization), and the control variables. Model 2 includes variables in model 1 as well as the two-way interactions among expertise, codification, and personalization. Model 3 includes variables in model 2 and the three-way interaction of expertise, codification, and personalization.

The results confirm that calls of greater complexity take significantly longer and that calls from field technicians who call frequently (higher likelihood of calling) take less time to handle. Across the three models, the main effects[1] of the technical support engineer's expertise, the level of codified knowledge and the level of access to personalized knowledge are very consistent. In all three models, the expertise of the TSE is negatively associated with call duration ($p < 0.01$). This supports H1a that greater levels of expertise enhance TSE's performance and they are able so solve callers' problems more expeditiously. However, contrary to the expectations of hypothesis 1b, the coefficient reflecting the influence of the level of codification is positive i.e., the level of codification is associated with longer call durations. Finally, hypothesis 1c is supported; the level of access to personalized knowledge is negatively associated with call duration and reflective of more efficient task performance (shorter problem resolution time) with greater access to help through personalization ($p < 0.01$).

Next, we examined the impact of the two-way interactions among the technical support engineer's expertise, codified knowledge and access to personalized knowledge. In Models 2 and 3, the interaction between the level of codified knowledge and the expertise of the technical support engineer is positive and significant ($p < 0.01$). This suggests that novices benefit more from codification than experts. This finding is consistent with H2a. Similarly, in Model 2 and Model 3, the interactions between access to personalization and the expertise of the technical support engineer is positive and significant ($p < 0.01$). This suggests that novices benefit more from obtaining help from others than experts. This finding is consistent with H2b. In Models 2 and 3, the interaction between the number of documents in the repository and access to personalization is positive, but not statistically significant. Thus, there is no support for hypothesis H2c.

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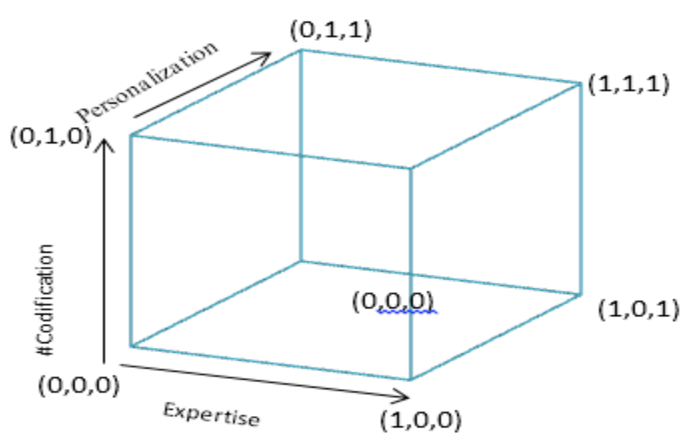
[1] Since our variables are standardized, the coefficients of first order terms are interpreted as the effect of the variable when other variables are at their means. Two-way interactions are interpreted as the effect among variables when the third variable is at its mean.

Next we examine the impact of the three-way interactions among the expertise of the technical support engineer, codification and access to personalization on call duration. As is seen in Model 3, the three-way interaction has a negative and significant impact on call duration ($p < 0.01$). This suggests that the expertise of the technical support engineer, the level of codified knowledge, and the level of access to personalized knowledge interact to reduce call duration. This is consistent with hypothesis H3.

We provide a finer-grained examination of the incremental contribution of each input in the presence of other attributes as an alternative test of complementarity along the lines of the analysis by Tambe, Hitt and Brynjolfsson, (2012). We created eight groups by splitting the sample at the mean value of expertise, codification and access to personalization. For example, one of the eight groups consists of all calls that have a high expertise (E = 1), high codification (D = 1) and low personalization (H = 0), which may be represented as (E, D, H) = (1, 1, 0) where E, D, H ∈ {0 = Low, 1 = High}. A visual description and analysis of these contrasts is presented in Figure 1. The groups of calls are represented by the corners of a cube (High/Low x High/Low x High/Low or a 2 x 2 x 2 matrix). Complementarity exists with respect to expertise if the performance difference along the edge from (0,1,1) to (1,1,1) is greater than the performance difference along the edge from (0,0,0) to (1,0,0).

Figure 1.1: Graphical Illustration of Complementarity of Expertise, Codification and, Personalization



We perform an overall test to confirm the significance of 3-way complementarity based on the system of contrasts reflecting the combined incremental contributions of expertise, the codification and personalization (Equation 1):

$$\underbrace{P(1,1,1) - P(0,1,1) + P(1,1,1) - P(1,0,1) + P(1,1,1) - P(1,1,0)}_{\text{Incremental Contributions of expertise, documents and personalization in the Presence of Other inputs}} -$$

$$\underbrace{P(1,0,0) - P(0,0,0) + P(0,1,0) - P(0,0,0) + P(0,0,1) - P(0,0,0)}_{\text{Incremental Contributions of expertise, documents and personalization in the Absence of Other inputs}} \qquad (1)$$

The combined effect (-0.237, p<.01) in Table 3, row 4, col C confirms the three-way complementarity among expertise, codification and access to personalization.

Table 1.3: Analysis of 3-way complementarities among Expertise, Codification and Access to Personalization

No.	**Factor**	**Influence on Performance in the presence of other inputs (A)**	**Influence on Performance in the absence of other inputs (B)**	**Difference (A – B) (C)**
1	Expertise	P(1,1,1) – P(0,1,1) -0.080 (0.011)***	P(1,0,0) – P(0,0,0) -0.131 (0.012)***	0.050 (0.000)***
2	Codification	P(1,1,1) – P(1, 0, 1) 0.009 (0.020)	P(0, 1,0) – P(0,0,0) 0.171 (0.019)***	-0.162(0.0002)***
3	Personalization	P(1,1,1) – P(1,1,0) -0.115 (0.01)***	P(0,0,1) – P(0,0,0) 0.010 (0.017)	-0.125(0.0001)***
4	Combined Effect			-0.237 (0.0001)***

We now examine performance differences between specific groups created as explained above. The average performance of a group is represented as P(E, D, H). In the example above, we use the notation P(1, 1, 0) for the mean performance of group (1, 1, 0). This test for complementarity examines the extent to which the incremental contribution of one input is greater in the presence of high levels of the other inputs, than the incremental contribution of that input in the relative absence of the other inputs. For example, the complementarity of expertise with respect to the other inputs can be formally written as:

$$\underbrace{P(1,1,1) - P(0,1,1)}_{\substack{\text{Incremental Contribution of Expertise} \\ \text{in the Presence of Documents } and \text{ Personalization}}} > \underbrace{P(1,0,0) - P(0,0,0)}_{\substack{\text{Incremental Contribution of Expertise} \\ \text{in the Absence of Documents } and \text{ Personalization}}} \qquad (2)$$

Expertise: Row 1 in Table 1.3 depicts the change in call duration when expertise increases in two situations: when codification and access to personalization are both High and when they are both Low. The overall difference in performance between the two groups is significant (column C, $\Delta = 0.05$, $p<0.01$), consistent with a significant 3-way interaction among expertise, codified knowledge and access to personalized knowledge.

In each case (column A, B), there is a significant reduction in call duration, reflecting the significant and positive influence of expertise on performance. The incremental change in call duration attributable to expertise when both codification and access to personalization are High (column A, difference =-0.080, $p<0.01$) is lower than the corresponding change when both codification and access to personalization are Low (column B, difference=-0.131, $p<0.01$). This pattern where the incremental contribution of expertise is higher when other resources are Low, compared to that when other resources are High suggests a substitutive effect of expertise when access to codified knowledge and personalized knowledge are limited.

Codification: Row 2 in Table 1.3 depicts the change in call duration when the level of codification increases in two situations: when expertise and access to personalization are both High and when they are both Low. The overall difference in performance between the two groups is significant (column C, $\Delta = -0.0162$, $p<0.01$), consistent with a significant 3-way interaction among expertise, codified knowledge and access to personalized knowledge.

Across the two columns (A and B), we find that access to codified knowledge increased call durations (i.e. adversely affected performance efficiency). This effect is significant only in column B, and it highlights that increasing codification significantly affects performance when expertise and access to personalization are Low. This pattern of results indicates the limitation of adopting a primarily techno centric codification approach to supporting knowledge work because codification without significant individual expertise and access to personalized knowledge adversely affects task performance.

Access to Personalization: Row 3 in Table 1.3 depicts the change in call duration when the level of access to personalization increases in two situations: when expertise and codification are both High and when they are both Low. The overall difference in the two conditions (col A, col B) is significant (column C, $\Delta = -0.125$, $p<0.01$) suggesting a significant 3-way interaction among expertise, codified knowledge and access to personalized knowledge.

A non-significant value in column B (0.01, *ns*) indicates that increased access to personalization has no significant influence on performance when expertise and codified knowledge are both low. In contrast, the negative and significant value in column A (-0.115, $p<0.01$) indicates that increased access to personalized knowledge enhances performance in the presence of high levels of expertise and codified knowledge.

In summary, the data suggests that there is significant complementarity in the combined effects of expertise, codification and access to personalized knowledge on performance. Expertise plays a unique role in also being a substitute for the availability of codification and access to personalized knowledge. Overall, the evidence points to performance enhancing benefits arising from the synergistic combination of expertise, codification and access to personalized knowledge.

1.4.3 Analysis of Robustness of Results

Additional tests were conducted to examine the robustness and consistency of our results to alternative specifications. Since a technical support engineer may take a number of calls of different complexity on a given day, error terms across these calls may be correlated. To account for this possibility, we provide the results of a robust regression model clustered around a TSE on a given day (see Model 1 in Table 1.4). Further, on a given day, the number of documents available and the opportunity to seek help are *same across all the calls handled* on the given day. Thus, the error terms across calls made on a given day may be correlated. To examine this possibility, we provide the results of a robust regression model clustered around all the calls on a given day (see Model 2 in Table 1.4). We also provide the results of ordinary least squares (see Model 3 in Table

1.4) and bootstrapped regressions (see Model 4 in Table 1.4). The results of all these models are consistent with the main results reported in Model 4 in Table 1.2 providing empirical evidence of the robustness of estimates to alternative specifications.

Table 1.4: Robustness analyses

Variables	**Model 1 DV=Call Duration**	**Model 2 DV=Call Duration**	**Model 3 DV=Call Duration**	**Model 4 DV=Call Duration**
Codification	0.126*** (0.007)	0.126*** (0.006)	0.126*** (0.006)	0.126*** (0.006)
Call Complexity	0.291*** (0.004)	0.291*** (0.004)	0.291*** (0.004)	0.291*** (0.004)
Likelihood of Calling	-0.032*** (0.005)	-0.032*** (0.005)	-0.032*** (0.005)	-0.032*** (0.005)
Total # Field Technicians	-0.025*** (0.006)	-0.025*** (0.006)	-0.025*** (0.006)	-0.025*** (0.006)
Service Contract Supported ($)	-0.007 (0.005)	-0.007 (0.005)	-0.007 (0.005)	-0.007 (0.005)
Access to Personalization	-0.019*** (0.005)	-0.019*** (0.004)	-0.019*** (0.004)	-0.019*** (0.004)
TSE Expertise	-0.104*** (0.005)	-0.104*** (0.005)	-0.104*** (0.005)	-0.104*** (0.005)
TSE Tenure (days)	-0.017*** (0.005)	-0.017*** (0.005)	-0.017*** (0.005)	-0.017*** (0.005)
Field Technician Tenure	-0.02*** (0.004)	-0.02*** (0.004)	-0.02*** (0.004)	-0.02*** (0.004)
codification * expertise	0.062*** (0.005)	0.062*** (0.005)	0.062*** (0.005)	0.062*** (0.005)
codification * personalization	0.006 (0.006)	0.006 (0.006)	0.006 (0.006)	0.006 (0.006)
expertise * personalization	0.05*** (0.005)	0.05*** (0.005)	0.05*** (0.005)	0.05*** (0.005)
codification * personalization* expertise	-0.013** (0.006)	-0.013** (0.006)	-0.013*** (0.006)	-0.013*** (0.006)
R Squared	0.1033	0.1033	0.1033	0.1033

Note: Values in columns appear to be identical because the values differ only in the 4^{th} decimal point

1.5 Discussion and Limitations

The management of knowledge work continues to be an important issue in firms. To address this complex issue, the focus of this study is to understand the separate and the combined influence of individual expertise and the resources available to support work – the level of codification and the level of personalization. The main effects of expertise and personalization on performance are both positive. Individuals with higher levels of expertise perform consistently higher than those with lower levels of expertise. Similarly, access to personalization, the availability of help from others through interpersonal interactions enhances performance. We find no support for our hypothesis that the level of codification enhances task performance; our results suggest that the availability of codified knowledge is associated with longer calls.

The results extend our understanding of how resources available to knowledge workers combine to effect outcomes. The 2-way interactions of expertise with codified knowledge and of expertise with personalization are both positive and significant. While prior research suggests that codified knowledge is important, these results suggest a more nuanced view; that the influence of codification on performance is contingent on the level of individual expertise with codification enhancing the task performance of novices more than that of experts. Similarly, our results indicate that personalization - the availability of help from others, enhances the performances of novices more than experts.

Further, since our data includes the task performance of helpers as well as the performance of individuals requesting help, the coefficient of the 2-way interaction between expertise and personalization provides insights on the effect of helping on helpers' performance. Since individuals with more expertise are generally the ones helping others, the positive coefficient of the interaction term indicates that helping adversely affects the performance of those who help others. This is consistent with our field observations that experienced individuals when interrupted by requests for help often put their own callers on hold. As a result, the length of their calls, increases when they help others. Prior studies that have emphasized the benefits of help seeking have failed to account for the *cost of helping* to the helper. In our study since helpers as well as those being helped are part of the same system, we are able to recognize the benefits to novices from help seeking and also the costs of helping to experts. This provides empirical support for the intuition underlying theoretical propositions of the paradox of organizational citizenship that helping hurts the performance of helpers (Bergeron 2007).

The results also highlight that the mechanisms established to support novices can have unexpected and negative effects on the performance of knowledgeable individuals. This adverse impact of codification on expert performance is consistent with the findings of one prior study that documents pose a *diversion risk* for experts (Haas and Hanson, 2002). Experts who would otherwise device solutions based on their expertise might be influenced to explore documented knowledge to construct and/or validate their own intuitions. Our finding that call durations for experienced individuals are increased by codified knowledge may be linked to patterns of use of information technologies. In our field observations of TSEs using the system, we noticed that while novices use the system to learn about prior incidents to adapt them to the current situation, knowledgeable individuals appeared to devise a rough outline of the solution based on the information provided by the caller and subsequently use the document repository to explore other solutions documented in prior instances. The pattern of appropriation of the information technologies by novices is thus more *faithful* to the intent of the design than those of experts. Information systems are known to provide greater benefits in faithful patterns of appropriations (DeSanctis and Poole 1994) and this is perhaps one explanation for the result that the availability of documents hurts the performance of experts.

The fine-grained analysis of complementarity among individual inputs provides interesting insights. Overall the data suggests that there is a three-way interaction among individual expertise, availability of codified knowledge and personalization i.e., the impact of individual inputs on performance is contingent on the presence of the other two inputs. For instance, the effect of documents on performance is enhanced in the presence of expertise and personalization. A higher level of expertise and personalization are important in deriving benefits from documented knowledge. Similarly, the effect of personalization on performance is enhanced in the presence of high levels of expertise and codified knowledge. Further, the performance of knowledgeable individuals is enhanced in the presence of documents and the availability of others willing to help. Further, experts can be more efficient in helping and minimize distractions to their own work with the availability of codified knowledge. The cost of helping in such contexts for experts is lowered when they can point help seekers to documentation instead of having to verbally explicate all details.

With codification and personalization both being increasingly enabled by information technologies, our results suggest the need for researchers to focus on micro-processes to assess outcomes of IT investments to examine questions like: "*how do IT investments payoff*" rather than the more elementary question "*do IT Investments payoff*". The results with respect to complementarities among resource inputs to knowledge work suggest that considering these three factors in unison are likely to be a more useful approach to enhance outcomes rather than attempts to isolate them individually for attention or choosing among them. The presence of complementarities suggests that a change in one resource is likely to create greater value in the presence of changes to the other two factors. While this coupling makes the creation of value through IT more difficult since firms need to simultaneously attempt to optimize resources across multiple dimensions, such a system, once in place, is also likely to be more complex and serve as barriers for competitors attempting to imitate them. In particular, since cooperative behaviors are linked to workplace and company culture and thus difficult to change in isolation from unobservable factors like citizenship behavior social norms in the workgroup and the firm, our results illustrate how IT enabled competitive advantages arising from such factors are sustainable.

1.6 Limitations and Directions for Future Research

Our analyses are based on detailed archival data from one site. While drawing on data from one complex context of knowledge work eliminates confounds from the variation of extraneous factors, replicating this study using data from multiple contexts can provide a greater understanding of the complex inter-relationships between individual expertise, codified knowledge and interpersonal knowledge sharing. The metric of performance we use - call duration - largely emphasizes the efficiency of task performance. Future work using a broader array of performance indicators can extend the insights of our study.

Our finding that the availability of documents adversely impacts the performance of experienced individuals suggests the need for research on the affordances of document repositories along the lines emphasized in recent work on socio-materiality (Feldman and Orlikowski 2011, Orlikowski 2007). The dominant design of document repositories where users can retrieve documents using keywords to describe symptoms serves novices very well since search interface designs embed the perspective of an uninformed individual attempting to link *symptoms conveyed by field technicians to potential solutions*. For experts, retrieval systems that locate prior solutions to problems they have already identified, i.e. to link *problems to prior solutions,* may be more useful. Current implementations appear to be *systems for novices*; our results highlight the need to rethink features to allow them to be *systems for experts*.

In our study, since all the TSEs were collocated, individuals could seek help by walking up to a colleague and discussing the issues face to face. Future work examining the factors that determine how individuals choose who to approach for help, and the consequences of this choice for performance can be interesting. Increasingly, with advances in communication media, firms are increasingly able to have technical support activities be performed by dispersed groups of non-collocated individuals. Future studies examining interpersonal help seeking over email or through rich video interactions among non-collocated peers can help provide a more refined understanding of the influence of obtaining and sharing knowledge through interpersonal interactions in technology mediated contexts. Replicating our study in other contexts and incorporating additional dimensions of task performance can also yield interesting insights.

1.7 Conclusions

Organizations implement document repositories and encourage technology-enabled mechanisms for knowledge sharing among employees to enhance the productivity of knowledge workers. While prior research has examined the productivity consequences of specific organizational initiatives, we adopt an integrative perspective on how the productivity of knowledge work is affected by complementarities between three important factors: (i) the degree of codification of relevant knowledge within a repository, (ii) the expertise of the knowledge workers, and (iii) the extent of personalization through availability of peers to provide help. The results highlight that novices benefit more than experts from codification and the availability of peers to provide help. A finer grained analysis of the effects of each of the factors in the presence and absence of the others provides interesting insights about their roles in influencing performance. Individual expertise is both a complement as well as a substitute for codified knowledge and personalized knowledge. Overall, the evidence suggests a view of performance of knowledge work being enhanced by the synergistic combination of expertise, codified knowledge and access to personalized knowledge.

Essay 2: Mutual Knowledge in IT Enabled Environments: A Study of Joint Problem Solving in Technical Work

2.1 Introduction

Effective collaboration among individuals requires them to solve the mutual knowledge problem (Cramton 2001). The mutual knowledge problem refers to the difficulty of individuals knowing what a communication partner knows and what the partner does not know in order to formulate what they say to each other. Individuals draw conclusions about their partner's state of knowledge only partly from the direct feedback they receive from partners in the course of communication exchanges. Much of the useful feedback to regulate interactions is from backchannels such as the observation of the other person's face, pattern of pauses in speech and body language etc. (Dennis and Kinney 1998). As a result, face to face exchanges are seen as the gold standard to support collaboration and knowledge sharing for problem solving where the ability to receive immediate feedback provided by the variety of visual, verbal and non-verbal cues available in such interactions addresses the *mutual knowledge problem*. From this perspective, communication media are viewed as being lower in the richness of cues that are available to participants (Trevino, Webster and Stein 2000, Vickery et. al 2004) or the related notion of the naturalness of interactions (Kock 2004).

With individuals and teams in organizations being increasingly dispersed geographically and interacting mainly through computer mediated communications that are lower in richness than face to face communication, maintaining mutual knowledge becomes challenging and impairs the quality of collaboration and outcomes (Cramton 2001). Mutual knowledge problems arise from the failure to communicate and retain contextual information, information asymmetries, the lack of clarity on the level of knowledge and information of partners, and difficulties in resolving the salience of shared information. Similar findings are suggested in research on geographically distributed teams where uneven information and unresolved differences in perspectives on shared knowledge lead to task conflicts and interpersonal conflicts that hamper the performance of joint work (Hinds and Bailey 2003). Research also highlights similar problems in collaboration among individuals separated by temporal distances across time zones (Carmel and Agarwal 2001).

While these results from prior research have added to our understanding of the difficulties of collaboration in the performance of knowledge work across distances, these insights are drawn largely from contexts where individuals and teams have had limited histories of prior interactions. For instance the work of Cramton (2001) is based on the examination of collaborative interactions spanning a few months in an academic term by geographically separated student teams.

As a result, we know little about scenarios common in everyday organizational life where geographically distributed individuals interact entirely over computer-mediated channels across extended periods even for complex tasks. How do individuals working with remote others, over time, build greater mutual knowledge and does this lead to enhanced outcomes in collaborative work? This is the issue we study in this paper.

We draw on two theoretical perspectives - channel expansion theory (Carlson and Zmud 1999) and the view of information and knowledge as being sticky (von Hippel 1994, Szulanski 1996) to argue that two related phenomena – one pertaining to the medium of communication and the other pertaining to the content of interactions combine to enable geographically dispersed participants to progressively enhance the efficiency of collaboration efficiency with a given medium. Channel expansion theory highlights that the level of richness of a medium for communication is directly related to the level of experience of partners in interacting over the medium (Carlson and Zmud 1999). As communication partners repeatedly interact using a specific medium e.g. email or the telephone, the extent to which the dyad can resolve ambiguities and reduce equivocality over the medium increases and therefore build greater mutual knowledge. The stickiness of knowledge and information refers to the level of difficulty experienced in sharing knowledge and information. The level of stickiness is influenced by the nature of the relationship between the source and the recipient; the greater the level of familiarity among communication partners, the lower is the stickiness and the easier it is to share knowledge and information. Repeated interactions among partners reduce stickiness, thus enabling individuals to build greater mutual knowledge.

Drawing on these theories, we hypothesize that the efficiency of joint problem solving increases over time by the development of mutual understanding between geographically distributed individuals and identify the factors that moderate the relationship between the level of mutual understanding and the efficiency of joint collaborative interactions.

The setting for our research is the set of problem solving interactions occurring over a period of three years in phone calls made by over 1500 field technicians of the *Aircom*, a large North American engineering firm and engineers in the central Technical Support Group located in a city in the Midwest. Field technicians located in over 617field locations across USA service the heating, ventilation and air-conditioning (HVAC) systems sold to commercial clients by Aircom. Field technicians call the Technical Support Center for help using their cell phones when they encounter field problems that they are unable to address. The call center of the controls division is staffed by experienced engineers who work from cubicles in a large bay in one location. The technical support center has analog and digital simulators for HVAC controllers in several locations around the room where engineers can step up to simulate specific situations being described by field technicians over the phone to aid problem diagnosis.

With interactions between dispersed field technicians and TSEs occurring entirely over the phone, this context is particularly appropriate to the study of the development of mutual knowledge and its consequences for joint problem solving. The development of mutual knowledge between field technicians and TSEs through the interaction over time and the consequent influence on joint problem solving efficiency is the focus of this study.

We adopt the problem solving dyad – a field technician and TSE as the level of analysis and find evidence to suggest that the mutual knowledge developed over time through repeated interactions between individuals in dyads builds mutual knowledge that enhances the efficiency of joint problem solving. The influence of mutual knowledge on outcomes is influenced by characteristics of each party in the dyad; the extent to which the field technician is knowledgeable about product details and company-specific repair practices and the extent of the TSE's capability to describe details of problem solving procedures. Our results demonstrate the importance of mutual understanding that occurs through repeated interactions for technical problem solving among knowledge workers who only interact over lean media like the telephone.

2.2 Context of Research: Joint Problem Solving in Technical Support

The context that we examine is the interaction of technicians encountering unusual or unanticipated problems in repairing engineering HVAC systems in the field when they call Technical Support Engineers (TSEs) at the central support location for help. Field technicians are certified tradesmen with specialized training who take pride in being knowledgeable in resolving problems (Orr 2006). They usually call the technical support center for assistance only after attempting to resolve the problem based on their own knowledge and the procedures specified in standard maintenance manuals and realizing that they have not been able to solve the problem. Calls to technical support are thus instances when the nature of the problem is complex and unusual. Studies of engineering troubleshooting (e.g. Das 2003, Pentland and Rueter 1994) highlight the task of problem diagnosis and repair in such instances as being complex. The performance of the task is very dependent on three key components a) the ability of the field technicians to accurately describe and convey salient details of symptoms and the behavior of field equipment to technical support engineers (TSEs) from a remote location, b) the ability of TSEs to elicit relevant information to diagnose the problem and c) the overall ability of field technicians and TSEs to pool their information and knowledge to jointly evolve a solution that resolves the field problem.

The repair and maintenance of electro mechanical assemblies like air conditioning and refrigeration systems, oil and gas furnaces is recognized as being complex since the problems exhibited by these systems in operational contexts are substantively different from those anticipated in repair manuals. Restoring them to working order involves drawing more than just the knowledge of the science – the physics and the mechanics underlying their functioning, but also the specific and particular elements of the field context – the operating temperatures, the spatial orientation of the installation etc. to be able to derive clues useful in addressing the problem. Detailed ethnographic accounts of the work of field technicians highlight the divergent perspectives held by them based on their intimate knowledge of the individual behavior of equipment in field conditions and those of engineers at the company headquarters and the perspective ingrained in formal documentation. Orr's observations in his work (Orr 2006) highlight that the abstract understanding of how to repair equipment held by engineers and specified in formal documentations (the *canonical knowledge*) differs substantively from *non-canonical knowledge*, the understanding and work practices that technicians use to restore malfunctioning machines to working order. The *abstract* view is context-free, devoid of local detail while the reality confronted on the ground is influenced by the operating conditions of equipment and the particulars of the larger HVAC system where the malfunctioning equipment is installed which may differ significantly from those anticipated by design engineers. The difference between the *abstract view* of a problem based on engineering documentation and the concrete *situated view* of technicians standing next to the malfunctioning equipment in the field present a significant hurdle in knowledge sharing between individuals from these groups (Brown and Duguid 1991). Orr's describes this situation as resulting in a *"fragmented organization, with dramatically different attitudes towards knowledge in different parts of the organization"* (Orr 2006, page 1807).

Successfully executing equipment repair through the joint resources of field technicians and technical support engineers thus requires the bridging of the inherent differences in perspectives so that context specific improvisations to repair equipment can be devised by combining the resources of both parties. All interactions between field technicians and TSEs occur over the phone. Individuals come to know each other by name over successive phone interactions but there are no occasions for individuals to meet each other. Calls by field technicians to technical support are queued and automatically directed to TSEs as they become available. The field technicians have no choice regarding the TSE who takes their call.

2.3 Theory and Hypotheses

The challenge that field technicians and technical support engineers confront in their interactions to solve problems in phone calls is to overcome the inherent differences in their individual perspectives. Bridging the perspectives of the TSE assessing field problems from a distance with a scientific principle-driven mindset and the perspectives of the field technician immersed in the immediacy and the specifics of the context with an improvisational mindset is one of the key challenges. Since each of their perspectives colors the two parties' individual approach to the solution, having a constructive and open minded exchange of task-relevant information in the phone call to systematically identify potential root causes of the symptoms and investigate multiple causal paths to evolve the best solution is a complex exercise. The hurdles in the exchange are influenced by two factors a) by the limitations of communicating over a *lean* channel and b) the inherently complexity of the task; technical problem solving information is recognized as inherently difficult to transmit.

Scholars have long viewed complex tasks such as engineering problem solving as needing rich media to enable joint problem solving while others have suggested that the set of shared experiences made possible through collocation is central to the development of mutual knowledge and trust required to efficiently share knowledge. As a result, the central issue that is unresolved is how complex tasks such as engineering problem solving can be effectively performed through the development of familiarity among parties interacting over phone lines. So the question we ask is: can mutual knowledge be developed where two individuals only interact over lean media but are responsible for jointly solving a complex and context dependent problem. In this paper we draw on two theoretical perspectives and posit that the answer is yes.

2.3.1 Channel Expansion Theory

Channel expansion theory highlights that repeated interactions with a partner over a medium increases the ability of partners to share information and resolve ambiguities.

In particular, the theory suggests that repeated interaction among individuals could provide individuals with sufficient information about the partner to facilitate knowledge sharing and interaction, even when interactions occur over lean media where cues present in face-to-face interactions are not available. With repeated interaction, individuals can form a fairly accurate impression of the partner and the capacity of the channel. This helps to increase the amount of information conveyed among the dyad. For instance, individuals interacting repeatedly over a medium can learn to appropriately interpret idiosyncratic characteristics of a partner's response to situations common in exchanges, such as the comprehension of complex arguments, the lack of conviction and the extent to which other person is in agreement with them etc. This familiarity developed over multiple interactions allows complex, ambiguous information and knowledge to be transmitted, thus expanding the richness of the medium for the exchange. In general, the theory suggests that, over multiple interactions, even those over lean media, participants develop a greater level of understanding of each other's perspectives and greater mutual knowledge.

2.3.2 Stickiness of Information and Knowledge

The term *stickiness* was coined by von Hippel (1994) to characterize the difficulty information and knowledge sharing efforts to solve technical problems in instances when problem-solving capabilities required are not available at the location where problems are experienced. Typical instances of stickiness occur when field technicians repairing malfunctioning equipment at customer locations call technical support for help in solving the problem they face. In such cases, one aspect contributing to stickiness is the difficulty, technicians at the location of the problem face, in communicating the behavior of the malfunctioning unit in sufficient detail to a knowledgeable engineer over the phone. Other elements contributing to the overall stickiness include the difficulty the support engineer faces in conveying a potential solution to the technician on location to see if that fixes the problem. The overall complexity of the iterative sharing of problem details and solution details between the party onsite with the equipment and the other person offsite at the source of expertise is captured as the level of stickiness of information and knowledge. The extent of stickiness of information and knowledge is influenced by the characteristics of the sender-receiver dyad, such as the level of familiarity among them. A greater level of shared mutual knowledge among individuals provides the bridge between disparate perspectives and reduces the stickiness of the knowledge and information exchange involved in problem solving. This effect is consistent with the insights from studies of knowledge sharing in organizations that indicate that the level of familiarity between the source of knowledge and a recipient is a key determinant of the quality of knowledge transfer that occur in interactions (Hansen 1999, Levin and Cross 2004, Levin, Whitener and Cross 2006).

Overall, these arguments indicate that repeated interactions among field technicians and TSEs over phone calls leads to the development of mutual knowledge and enhances the efficiency of joint problem solving interactions. This leads to

H1: The greater the number of prior interactions between the technician-TSE dyad, the greater is the efficiency of joint problem solving in the current exchange between the technician and the TSE.

2.3.3 Influence of TSE Ability to Explicate Knowledge

The routine work of technical support has been described as being made up of the *emergencies of other people* (Das 2003); calls to technical support generally occur when field technicians and have not been able to solve the problem with the resources available to them. The base of knowledge that TSEs use to diagnose symptoms and evolve solutions is generally developed in the course of their years of experience in solving problems in prior calls. Researchers examining the cognition of experts highlight that the experts' organizing schemas for experiential knowledge are idiosyncratic rather than systematic and the logic of cause-effect relationships that they use to solve problems are consequently complex to communicate. This is a situation recognized in prior research and expressed as the truism that "*wisdom can't be told*" (Bransford, Franks, Vye and Sherwood 1989). As a result, individuals with a high level of specialized knowledge gained over time are inaccurate in judging the perspectives of others without the knowledge, leading to difficulties in sharing their knowledge (Hinds, Patterson, Pfeffer 2001).

As part of organizational efforts to build a knowledge base of equipment repair procedures, experienced individuals are encouraged to explicate their knowledge and contribute documents so that novel solutions and innovative procedures to fix field problems can be reused by others. Codifying knowledge gained through experience requires a reorganization of information and their systematic presentation. It involves the author taking the perspective of someone less knowledgeable confronting a problem, anticipating the contingencies posed by the local context and outlining a step by step description process through which another person can solve the problem using the instructions. Documenting solutions involves the ability to abstract the key knowledge involved in problem solving from all the context specific particulars that are invariably involved in specific instances of problem solving. Creating documentation also requires individuals to be able to convert the iterative process of problem solving into a linear descriptive for another person can follow, even one who does not possess the level of knowledge of the expert. Creating documentation is thus recognized as a higher order ability that is different from the ability to solve problems. This ability to explicate complex knowledge is developed and refined by individuals over time by authoring documents.

The greater the level of ability to explicate knowledge, the greater is the likelihood that the TSE can explain complex knowledge in a manner that is easily comprehended and used by the field technicians. We therefore suggest that this ability of the TSE is likely to moderate the link between the level of mutual knowledge and the efficiency of joint problem solving.

H2: The TSE's ability to explicate knowledge moderates the relationship between frequency of interaction and efficiency of joint problem solving.

2.3.4 Influence of Field Technician Absorptive Capacity

Individuals become knowledgeable by gathering inputs from multiple sources such as formal training programs and studying the technical literature. Obtaining knowledge from published documents is important means for individuals to build their knowledge and develop their personal understanding of facts, opinions and codified experiences of others. In addition to gaining inputs, individuals can develop a broader and more complete cognitive representation of equipment characteristics and their interactions with the external environment by synthesizing their knowledge gained first-hand and that those of others described in documents. Thus, documents allow individuals to develop a broader understanding of phenomena to not just broaden their understanding but also to recognize when a novel solution can be devised if they could obtain information. Knowledge gained from documents allows them to critically assess facts and interpretations of events by others and also assimilate information they receive into their own knowledge base and thus builds their absorptive capacity, the ability to learn and assimilate new information and knowledge. Greater absorptive capacity is likely to allow the technician to communicate symptoms and problems more efficiently and also engage in more meaningful discussions of potential causes and their solutions on calls to technical support. As a result, this is likely to strengthen the link between repeated interactions and the efficiency of joint problem solving. We therefore propose the following:

H3: The field technician's absorptive capacity moderates the relationship between frequency of interaction and efficiency of joint problem solving.

2.4 Methods

2.4.1 Research Setting

This study was conducted in the Service division of an engineering services company (Aircom) in the Heating, Ventilation and Air conditioning Industry. Aircom sells a range of commercial and domestic HVAC equipment and the service division provides warranty and ongoing maintenance services to US customers from field service locations throughout country. To aid service technicians in the field needing inputs, Aircom provides two resources for help. The first is a Technical Support Helpline that is staffed by experienced engineers which the technicians can call using their company issued cell phones. The second is an online repository of technical documentation on the company intranet that technicians can access using ruggedized laptops with wireless cards issued to all technicians.

The technical document repository contains repair manuals, service bulletins wiring diagrams, engineering drawings of components, part number equivalency tables, product line compatibility details, technical specifications and repair manuals for equipment. We refer to these documents providing general knowledge needed by technicians as *general documents*. General documents were created and maintained by R&D, Quality Control and Field Service groups in Aircom.

In addition to general documents, the repository also contains documents authored by TSEs with descriptions of frequently encountered field problems and their solutions documenting knowledge gained in the course of solving problems in calls for help by field technicians. The solutions evolved to solve field problems in calls often involved the combination of the knowledge, experience and ingenuity of both the TSE and field technicians. Since similar problems could recur in the field, TSEs were encouraged to document novel solutions and modifications to prescribed solutions that were evolved to make these solutions available in the repository to others confronting the same or similar problems. In many instances, TSEs also periodically created a consolidated summary of frequently occurring problems with specific field equipment and their typical solutions. Problem-solution documents providing solutions to recurring field problems were reviewed by a panel of experienced engineers for accuracy before they were published to the repository. Documents that provide solutions to specific field issues were termed *issue documents* and these were created and maintained by engineers in the Technical Support group.

The distinction between general documents and issue documents was recognized by Aircom and were assigned distinct document codes. The knowledge repository was continuously growing during the period of our study with new general and issue documents being added and existing documents being updated.

The study uses data from the archives of calls to the technical support group recorded in the call management system used by Techno. The system opens up a detailed form for each incoming call and TSEs taking calls populate the form with details of the caller, the equipment being repaired and the nature of the problem. At the end of each call, TSE's are provided a short window of time to wrap up the call and record details of how the problem was solved in the form. For calls that concluded with the caller's problem being resolved in the call, this details is recorded and the case is closed. The call management system is the central system of record for the technical support group to manage and monitor call handing.

The study also uses data from the archive of accesses of the document repository. The repository access log records the identity of users, the beginning and end times of sessions, the text of queries used for searching, details of documents retrieved in each query and the list of documents returned by each query that was opened by the user.

Combining the call management system data and repository access logs allows an examination of the resources used to address field service problems. The longitudinal dataset used for the analysis comprises all calls to technical support and all repository usage in a 25-month period from September 2008 to August 2011.

2.4.2 Measures

Dependent Variables: The length of calls recorded to the nearest second and available to us in the call logs of the technical support hotline. We use this as the measure of the *efficiency of joint problem solving.*

Independent Variables: Our main independent variable is the frequency of prior interactions, which is operationalized as the number of prior calls between each field technician and TSE dyad. We operationalize *the level of absorptive capacity of the* field technician using two variables representing the extent to which of the field technician had accessed different kinds of codified knowledge available in the repository in searches of the repository. Aircom distinguishes between two kinds of documents in the repository – i) *general documents* such as technical brochures, wiring diagrams and field repair manuals for products that were typically authored by the marketing group, the quality control group and the training group and ii) *problem solution documents* containing descriptions of problems reported for different products and their suggested solutions that were authored by technical support engineers and accepted into the repository after a technical review.

Using the repository search records that contained details of all logins and searches of the repository by field technicians, we operationalized the variable *#general documents* as the total number of general documents a field technician had opened in all searches prior to a call. The *#issue documents* was operationalized as the total number of problem solution documents that a field technician had opened prior to a call.

Using archival records of documents in the repository which were stamped when they were published in the repository and also had author details, we operationalized the level of *articulability* as the # *problem solution documents authored* by a TSE prior to a call.

Control Variables: Since problem solving on calls happens between the field technician calling and the TSE taking the call, we use a fixed effects model within field technician-TSE dyads to control for unobserved heterogeneity influencing the call duration. We also included variables to control for call related and time varying factors that may influence call durations. We include *call complexity* as a control since the time taken to solve the problem on a call is likely to be influenced by the complexity of the problem discussed. Call complexity was coded on a five-point scale by managers in Aircom using the call-reason field indicated in the record of each call. Our key independent variable is the frequency i.e., the depth of the interaction between a field technician and TSE pair. However, it is likely that breadth of a field technician's interactions with all the TSEs also influences joint problem solving. Thus, we control for the number of different TSEs a field technician had interacted at the time of the current call. We also included the number of repository documents as a control variable since this reflects the level of formalization of knowledge in the firm that is likely to influence durations of calls.

Since there is a variety of extraneous calendar related factors that influence the nature of problems in HVAC systems and also the staffing of the technical support center, we included three dummy variables to isolate effects linked to the quarter of the year in which the field technician called the technical support center. The number of field technicians in the field is likely to influence how frequently a field technician can interact with TSE. Thus we control for the number of field technicians on the day of the call. Finally, the calls from field technicians are likely to be influenced by the volume of equipment supported in the field. We control for the volume of equipment supported by the monthly dollar value of service contracts.

Estimation: Our analysis is at the level of field technician - TSE dyad; we examine the differences in problem solving times between field technician-TSE dyads over time attributable to changes in the frequency of the field technician – TSE interaction, level of externalization and internalization and other control variables. The dependent variable and main independent variables were log transformed to uniformly rescale variables and help interpretation of coefficients as elasticity of the outcome variable in response to changes in the independent variables.

2.5 Results

Our dataset contains details of 82632 calls made by 5166 technicians over 25 months; the calls were taken by 91 TSEs. Table 2.1 presents the means and standard deviations and Table 2.2 lists the correlations among variables.

Table 2.1: Distribution of Variables

Variables	**Mean**	**Standard deviation**	**Min**	**Max**
Call Duration	560.68	547.30	45	10469
# Documents in Repository	29505.59	4776.23	23332	41515
Field Technician headcount	2841.59	41.76	2750	2923
Service Revenue ($M)	47.8	5.50	37.3	59.9
#prior calls between Field Technician and TSE	2.31	3.77	0	53
#TSEs contacted by Field Techs	11.78	8.55	1	55
# Documents Authored By TSE	407.19	551.01	0	2697
# General Documents Examined by Field Technician	9.04	14.89	0	334
# Issue Documents Examined by Field Technician	128.51	226.65	0	4849
Field Technician Tenure (days)	489.65	367.54	0	1847
TSE Tenure (days)	993.87	508.88	0	2392
Call Complexity	3.20	1.42	1	5

Table 2.2: Correlations among Variables (n=82632)

#	Variable	1	2	3	4	5	6	7	8	9	10	11
1	Call Duration	1.00										
2	# Documents in Repository	0.07	1.00									
3	Field Technician headcount	0.08	0.23	1.00								
4	Service Revenue ($M)	0.02	0.53	0.21	1.00							
5	#prior calls between Field Technician and TSE	-0.05	0.15	-0.12	0.11	1.00						
6	#TSEs contacted by Field Techs	-0.07	0.37	-0.12	0.17	0.35	1.00					
7	# Documents Authored By TSE	-0.04	0.07	-0.02	0.04	-0.08	0.05	1.00				
8	# General Documents Examined by Field Technician	-0.06	0.04	-0.04	0.03	0.07	0.26	0.01	1.00			
9	# Issue Oriented Documents Examined by Field Technician	-0.08	0.10	-0.04	0.05	0.15	0.42	0.02	0.62	1.00		
10	Field Technician Tenure (days)	-0.01	0.37	-0.14	0.16	0.16	0.34	0.05	0.16	0.17	1.00	
11	TSE Tenure (days)	0.019	0.49	-0.09	0.21	0.03	0.28	0.21	0.04	0.08	0.31	1.00
12	Call Complexity	0.31	0.03	0.06	0.03	-0.06	-0.21	-0.11	-0.13	-0.19	-0.05	0.07

Table 2.3 presents the results of the fixed effects model predicting the call duration between field technician and TSE dyads. Table 2.3 presents three models – Model 1 with only the control variables; Model 2 adding main effects; and the full model (Model 3) with controls, main effects and the interaction terms.

Table 2.3: Relationship Between Call Duration and Knowledge Creating Processes

No.		**Model 1 Controls**	**Model 2 Main Effects**	**Model 3 Full Model**
		DV= ln(Call Duration)		
	Independent Variables	**Fixed effects**	**Fixed effects**	**Fixed effects**
1	ln(# Documents in Repository)	0.123*** (0.051)	0.692*** (0.062)	0.660*** (0.069)
2	ln(Field Technician headcount)	4.792*** (0.324)	2.341*** (0.341)	2.271*** (0.343)
3	ln(Service Revenue $)	-0.035 (0.045)	-.004 (0.045)	-0.005 (0.042)
4	ln(#prior calls between Field Technician and TSE dyad)		-0.057*** (0.009)	-0.057* (0.015)
5	ln(# TSEs contacted by Field Technician)	-0.031** (0.018)	-0.038* (0.016)	-0.042** (0.016)
6	ln(# Documents Authored By TSE)		-0.032*** (0.005)	-0.032*** (0.009)
7	ln(# General Docs Read by Field Technician)		-0.384* (0.017)	-0.017 (0.019)
8	ln(# Issue Docs Read by Field Technician)		-0.016 (0.014)	-0.0274 (0.015)
9	Call Complexity	0.148*** (0.006)	0.148*** (0.005)	0.148*** (0.003)
10	ln (#prior calls between dyad) * ln (#General Documents)			-0.018** (0.006)
11	ln (#prior calls between dyad * ln (#Issue Documents)			0.011** (0.006)
12	ln (#prior calls between dyad) *ln (#Docs Authored)			-0.009** (0.005)
	Calendar Dummies			
	Quarter 2	-0.035** (0.009)	-0.039*** (0.012)	-0.038** (0.016)
	Quarter 3	-0.141*** (0.009)	-0.123*** (0.012)	-0.124** (0.013)
	Quarter 4	-0.143*** (0.008)	-0.106*** (0.011)	-0.108** (0.011)

A negative coefficient for a variable in the model indicates that the variable increases the efficiency of joint problem solving (reduced times reflect greater efficiency). Since interaction terms are included in Model 3, the coefficients of main effects are interpreted as the effect on efficiency of joint problem solving when the interacting variable is zero.

Model 1 incorporating only control variables suggests that the number of repository documents is positively related to problem solving durations; this is also observed in all the models. Since the number of documents is increasing over time, this reflects the overall trend of increasing call durations over time during the period of the study. The positive coefficient of field technician headcount in all the models suggests that as the field technician headcounts increased with induction of new technicians, on average, problem-solving times in calls to technical support also increased. Call complexity is positively related to call length in Models 1-3, confirming the intuition that calls pertaining to problems of low complexity take less time than calls pertaining to problems of higher complexity.

Main effect of the Frequency of field technician – TSE interaction (H1): The results indicate that the frequency of the field technician - TSE interaction is negatively related to call durations (Model 2, $p < 0.001$; Model 3 $p < 0.05$). In model 2 and jn model 3 a one percent increase in the frequency of the field technician –TSE interaction is associated with a 5.7% improvement in the efficiency of joint problem solving. These results support H1.

These results provide evidence that interpersonal knowledge sharing in joint problem solving tasks is facilitated by the familiarity created by repeated interactions between partners. The analysis employs a fixed effects model (at the TSE-field technician dyad level). This controls for unobserved TSE and field technician related factors. Our results thus provide evidence that, over and above individual specific factors like the level of innate ability, educational background and job experience, greater frequency of field technician – TSE interaction is associated with more efficient joint problem solving.

Since problem complexity is also included in the model, we have evidence that these effects hold for all calls; those involving low complexity as well as those of high complexity.

2.5.1 Interaction Effects

We examine the moderating effects of externalization and absorptive capacity using the coefficients of interaction terms in Model 3.

Interaction of frequency of interaction and TSE ability to explicate (H2): The interaction effects of the frequency of field technician – TSE interaction and the *ability to explicate knowledge,* on the efficiency of joint problem solving is negative and significant ($p < 0.01$). This finding supports H2. Each 1% increase in the number documents authored by a TSE provides an incremental improvement of 1% in the efficiency of joint problem solving.

Interaction of frequency of interaction and absorptive capacity of the field technician (H3): The interaction effects of the frequency of field technician – TSE interaction and internalization on efficiency of joint problem solving are different with respect to *general* and *issue* documents. The interaction effect of frequency of field technician – TSE interaction and general documents is negative and significant ($p < 0.01$). This suggests support for H3 that frequency of field technician – TSE interaction combined with greater internalization through general documents enhances the efficiency of joint problem solving. Each 1% increase in the number of general documents accessed by a field technician provides an additional 1.8% improvement in the efficiency of joint problem solving.

However, the results indicate that the frequency of field technician – TSE interaction and greater internalization of issue documents is positive and significant ($p < 0.01$); in other words, when a technician is more knowledgeable about problem solving procedures, the combined effect of mutual knowledge from prior interactions and technicians' knowledge of solutions is associated with longer problem solving times. This finding is opposite of H3.

2.5.2 Robustness analyses

Being a panel dataset, we need to test for the possibility of both heteroskedasticity and autocorrelation. White's general test indicates the necessity to correct for heteroskedasticity; we therefore use robust standard errors in the models. The Wooldridge test for autocorrelation fails to reject the null hypothesis of no auto correlation; autocorrelation is thus not a concern in the data. As mentioned earlier, we also control for the unobserved, individual characteristics of technical support engineers. We opt for the fixed effects model since the Hausman test leads to a rejection of the null hypothesis that the random effects model provides consistent estimates. Nevertheless, the results of the random effects models are shown in table 2.4. The results of all these models are consistent with the main results reported in Table 2.3 providing empirical evidence of the robustness of estimates to alternative specifications.

Table 2.4: Robustness results for Call Duration and Knowledge Creating Processes

No.	Independent Variables	Model 1 Controls	Model 2 Main Effects	Model 3 Full Model
		DV= ln(Call Duration)		
		Random effects	Random effects	Random effects
1	ln(# Documents in Repository)	0.337*** (0.025)	0.384*** (0.025)	0.377*** (0.025)
2	ln(Field Technician headcount)	5.017*** (0.219)	4.482*** (0.224)	4.407*** (0.225)
3	ln(Service Revenue $)	-0.068* (0.036)	-0.049 (0.035)	-0.049 (0.035)
4	ln(#prior calls between Field Technician and TSE dyad)		-0.048*** (0.004)	-0.094*** (0.015)
5	ln(# TSEs contacted by Field Technician)	-0.036*** (0.005)	-0.020*** (0.006)	-0.021*** (0.002)
6	ln(# Documents Authored By TSE)		-0.018*** (0.002)	-0.032*** (0.009)
7	ln(# General Docs Read by Field Technician)		-0.017* (0.004)	-0.021 (0.004)
8	ln(# Issue Docs Read by Field Technician)		-0.042 (0.004)	-0.044 (0.004)
9	Call Complexity	0.193*** (0.002)	0.185*** (0.002)	0.185*** (0.003)
10	ln (#prior calls between dyad) * ln (#General Documents)			-0.010** (0.004)
11	ln (#prior calls between dyad * ln (#Issue Documents)			0.005* (0.003)
12	ln (#prior calls between dyad) *ln (#Docs Authored)			-0.008*** (0.003)
	Calendar Dummies			
	Quarter 2	-0.024*** (0.009)	-0.025*** (0.009)	-0.024*** (0.009)
	Quarter 3	-0.141*** (0.008)	-0.135*** (0.009)	-0.135*** (0.009)
	Quarter 4	-0.143*** (0.008)	-0.136*** (0.008)	-0.136*** (0.008)

N = 82632, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$

2.6 Discussions

The results provide a greater understanding of the contribution of knowledge creating processes to the performance of collaborative knowledge work in technical problem solving in a context where all interactions occur over a lean medium without any face-to-face interactions. Surprisingly, mutual understanding that facilitates knowledge sharing that is commonly viewed as developed through in-person interactions (Nonaka and Takeuchi 19xx) emerges as an important factor over repeated technology mediated interactions even when TSEs and field technicians never meet face to face and only know each other through telephonic interactions.

Further, *the ability to explicate knowledge,* the TSE's ability to organize and describe complex information that is gained by documenting new knowledge gained in problem solving interactions is an important contributor to the efficiency of knowledge work performance. This finding provides empirical evidence that the act of abstracting complex context-rich problem solving knowledge into a structured linear narrative required for technical documents deepens individual expertise and improves the efficiency of knowledge work. This represents an important contribution to knowledge since *know-how* has been viewed as tacit knowledge that is transferred mainly through interpersonal interactions with the direct benefits of documentation occurring to others but not to authors of documentation. Our work is the first to highlight that individuals who make the effort to organize and document their knowledge also derive significant efficiency benefits in problem solving.

Our results also provide a unique empirical examination of the model of knowledge creating processes by Nonaka (1994) that is often termed the Socialization-Externalization-Combination-Internalization model. This framework has been very influential but one that has relied more strongly relied on insightful arguments from anecdotal data for validity rather than empirical testing. Our work provides an empirical test of the influence of three of the key processes outlined in the model.

The pathways to enhancing joint problem solving that we highlight extend the views in prior research in two important ways. First, prior research views *externalization*, the documenting of knowledge (Nonaka and Takeuchi 1995) as largely creating benefits for others in firms who can access the documented knowledge rather than for individuals taking the time to document their knowledge. Externalization is also viewed as reducing the influence of individuals since others would not seek them out for their special knowledge if this knowledge could be easily accessed by searching a repository. Second, prior research views externalization largely as a mechanism to enhance the efficiency of knowledge transfer by eliminating the need for face-to-face interactions (Hansen and Haas 2007). In contrast with these perspectives, our results provide novel insights regarding externalization, highlighting it as a) an important mechanism that benefits those who document their knowledge by enhancing their *articulability* of knowledge and b) as an important source of efficiency of interpersonal problem solving interactions. Specifically, our results suggest that the benefits derived from documenting knowledge influence the strength of the relationship between mutual knowledge and the efficiency of joint problem solving interactions.

Regarding internalization and combination, our results provide a more nuanced view of the relationship between obtaining documented knowledge and task performance. Our results suggest that gaining contextual knowledge from *general documents* enhances the efficiency of task performance while there is no evidence that examining specific problem-solution documentation contributes to efficiency. The evidence suggests that the combination of technicians with greater general knowledge gained from documents interacting with familiar TSEs significantly improves the efficiency of collaborative problem solving. Our data also suggest that the efficiency of knowledge work is reduced when technicians with greater issue-specific knowledge interact with familiar TSEs. One potential explanation for this counter-intuitive observation is that the benefits of specialized knowledge and familiarity is likely to lead to more detailed discussions in the course of problem solving that lengthens call durations. It is likely that this may result in more effective problem solving outcomes but since we do not have data on the quality of solutions evolved, we are unable to empirically examine this possibility. This is an important area for further research.

Our results also suggest that the main effects of internalization and combination are not significant when the effects of interactions with depth of socialization are included in the model. This highlights that internalization and combination – the two modes of learning from documents in the SECI model (Socialization, Externalization, Combination and Internalization) do not lead to performance enhancement when individuals lack the ability to interact (even over lean media) with knowledgeable individuals. This is a potentially important insight suggesting that attempts by firms to encourage individuals to use knowledge from document repositories to substitute for help seeking from knowledgeable colleagues may not be advisable. A more useful approach suggested by our results is to recognize that knowledge obtained from documentation enhances outcomes when combined with knowledge obtained by interacting with familiar sources.

2.7 Limitations and Directions for Future Research

The results should be interpreted in the light of several limitations of the study, which also suggest areas for future research. First, the focus of the study, the efficiency of joint problem solving in calls to technical support, captures only a narrow set of the overall aspects of problem solving interactions. Incorporating a broader view of outcomes to include aspects of the quality of solutions evolved can provide additional insights. Second, this study focuses exclusively on the two formal channels for help seeking - calls to technical support and document repository use. Incorporating the use of informal channels for help seeking such as calling peers for assistance can provide a more complete view of the factors influencing the performance of knowledge work. Third, we used the number of documents opened from the list of search results as the measure of the level of internalization. A richer conceptualization such as the length of time spent reading documents and the degree of attention paid to documents are likely to provide a finer grained understanding of internalization. Fourth, a richer view of the ability to articulate knowledge by TSEs - externalization in the SECI model moving beyond number of documents authored and incorporating aspects such as the quality of insights or the novelty of solutions documented can improve our understanding of this important phenomenon. Fifth, our study examines a context where only one of the actors in the dyad, the TSE, can document and contribute knowledge for use by the other actor. Extending this study to a context where both actors contribute as well as use knowledge from repositories can extend the insights of this work. Finally, this study examines technical problem solving which is largely characterized by *problem driven* information seeking. This limits the generalizability of the results to other contexts such as the work of management consultants that involves considerable exploratory information seeking for problem framing and analysis. Studies replicating this study in such contexts are likely to provide a greater understanding of the factors influencing the performance of knowledge work in contexts different from the problem-focused interactions characterizing our study.

Overall, the results contribute to a more detailed view of the role of knowledge creating processes in contexts of joint problem solving in technical contexts.

Essay 3: IT, Knowledge Transfer, and Organization of Work

3.1 Introduction

Drucker (1999) has stated that the most important contribution management needs to make in the 21st Century is to increase the productivity of Knowledge Work and Knowledge Workers. Correspondingly, studies suggest that human capital and learning are the source of sustainable competitive advantage (e.g., Hatch and Dyer, 2004). Similarly, a significant body of research in knowledge management studies how knowledge is developed, stored, and shared (Alavi and Leidner, 2001). In this regard, Nonaka (1994) suggests that knowledge is shared (converted) in four modes: (i) socialization, (ii) externalization, (ii) internalization, and (iv) combination. Socialization is the process of sharing tacit knowledge through interpersonal interaction. Externalization refers to the process converting tacit knowledge into explicit knowledge through codification. Internalization on the other hand is the act of developing tacit knowledge by processing and assimilating explicit knowledge stored in repositories. Finally, combination refers to transforming explicit knowledge from one form to another.

Given the importance of knowledge work and the productivity of knowledge workers, what is the role of IT in the development of skill and expertise of knowledge workers? From one point of view since IT is used to standardize and automate processes, IT reduces interpersonal interactions, shrinks the level of autonomy of individuals and leads to deskilling (Ritzer, 1996). From this point of view, though IT may improve productivity, IT does not directly affect the skill and expertise of knowledge workers. Oher research suggests that firms that adopt IT tend to use more skilled labor (Bresnahan, Brynjolfsson and Hitt, 2002). This may suggest that skilled labor may be required to leverage the benefits from IT. Similarly, the research on skill-biased technological change suggests that IT may be a substitute for structured routine tasks (i.e., low skill labor/work) and IT may complement non-routine analytical (i.e., high skill labor/work) task (Autor et al, 1998).

However, the above streams of literature do not examine if IT may be associated with the generation/transfer of human capital. We address this question in the context of field technicians engaged in the service of industrial HVAC systems distributed across the United States. These field technicians are knowledge workers as they use their knowledge and expertise of HVAC systems to fix problems in the functioning of these systems. In our context IT can enable these field technicians to develop their knowledge and expertise in two different ways. First, field technicians can acquire/develop technical skills by accessing and internalizing technical documents stored in a knowledge repository. Second, these field technicians also have access to a centralized help desk where they can call and speak to a technical support engineer (TSE). Thus, the field technicians can also develop their skills through socialization with TSE.

In this study we examine whether internalization (i.e., reading documents) and socialization (i.e., talking to different TSE) helps field technicians develop human capital that affect their work. Specifically, by analyzing the repository accesses and calling behavior of 18,020 field technicians over 1,086 days we study whether internalization and socialization affect the calling behavior of the field technicians. The analysis suggests that internalization of specific knowledge is negatively associated with a likelihood of making a call, the total number of calls made, and the number of high complexity calls made on a given day. However, the internalization of general knowledge is negatively associated with the number of low complexity calls made on a given day, but positively associated with a number of high complexity calls made on a given day. Similarly, we find that socialization is associated with a decrease in the total number of calls made as wells as the number of low complexity calls made on a given day but socialization is associated with an increase in the number of high complexity calls made on a given day. This study provides evidence that field technicians develop human capital through internalization of general and specific knowledge and through socialization in ways that affects knowledge work.

3.2 Empirical Context

The setting for our research is the technical support unit of Aircom, a large North American engineering firm that manufactures, sells and services heating, ventilation and air conditioning (HVAC) systems for commercial clients. The warranty and ongoing maintenance services to US customers are provided by around 18,000 field technicians spread across 617 office locations throughout the 50 states. The field technicians have access to a central document repository that provides access to expertise in the form of documents related to equipment maintenance and troubleshooting. This repository contains engineering documents needed for problem solving as well as the documentation of commonly occurring problems and their solutions. The repository also contains troubleshooting and repair manuals as well as support documents authored by technical support engineers. The knowledge repository is accessible to field technicians over the web. All field technicians carry company issued ruggedized laptops with wireless cards that they could use to access the knowledge repository from client sites. All field technicians also carry company issued cell phones in case they needed to call the technical support center when they could not solve a problem on their own. The field technicians were encouraged to look up solutions in the knowledge repository over the web before calling the technical support center.

The technical support center is staffed by experienced technical support engineers (TSEs) who work from cubicles in a large bay. TSEs are the source of last resort for field technicians confronting repair or maintenance problems in the field. When field technicians call technical support, the problems are usually ambiguous. Thus, calls from field technicians often involve novel issues that are not covered in equipment troubleshooting and repair manuals. The steps followed in technical diagnosis and problem solving may require processes that go beyond the formally recommended procedures available in repair manuals and often involve improvisation and bricolage (Das 2003). The technical support center has analog and digital simulators in several locations around the room where TSEs can step up to simulate specific situations being described by field technicians to aid problem diagnosis. Thus calls from field technicians tax the expertise of individual TSEs, and they can benefit from the availability of codified knowledge and the ability to interact with other TSEs. Therefore, the technical support group is also expected to codify and document new solutions so that they can be reused by others (field technicians as well as TSEs) in the future.

A TSE taking calls from field technicians often involves improvised solutions with considerable knowledge, experience and ingenuity. The goal of the firm was to have such solutions documented so that others field technicians facing the same or similar problems could potentially reuse the solution. Though document submissions were voluntary and not compensated; TSEs were encouraged to document solutions and novel approaches they had devised in solving field problems and submit them for inclusion in the knowledge repository. The knowledge repository was continuously growing with new documents being added to the repository every week. Field technicians were encouraged to look up solutions over the web before calling the technical support center. Service contracts were managed by the field service organization and the performance of field technicians was assessed based on their service call resolution times as well as service contract renewals for their customer accounts.

3.3 Theory and Hypotheses

Field technicians can develop their expertise by accumulating knowledge over the course of their tenure. Kim et al. 2012 studied technical support in a computing call center and found that consultants learn over time by answering more calls. Likewise Subramanyam and Krishnan (2001) examined customer service /technical support in the IT arena and found that the capability/expertise of the support staff reduced response/resolution time. In our context also field technicians can learn over time by servicing more HVAC systems. However, in this study we are particularly interested in understanding if field technicians develop skill and expertise in two specific ways: (i) internalization, and (ii) socialization (Nonaka, 1994). Field technicians can acquire knowledge and develop expertise through internalization by accessing and reading documents stored in the knowledge repository. Field technicians can develop general knowledge (Becker, 1992) by reading product documents and user manuals. Likewise, field technicians develop specific knowledge (Becker, 1992) by reading more problem solution documents. Field technicians can acquire knowledge through socialization when field technicians call the technical support center and interact with TSEs. The social interaction between the field technician and the TSE transfers tacit knowledge from the TSE to the field technician.

Field technicians are employed to fix malfunctioning HVAC systems. In their work field technicians use all their experience, knowledge, and expertise to solve problems. However, if they are not able to fix a specific HVAC system on their own they can call the technical support center for help. As field technicians acquire knowledge through internalization and socialization they are likely to be able to solve more problems on their own and not need to call the technical support center. Thus, we expect that as field technicians' access and read a greater number of general and specific documents they acquire explicit knowledge stored in the knowledge repository, they need to call the technical support center less and less. Similarly, as the field technicians interact with a larger number of TSEs, they acquire tacit knowledge from the TSEs and they need to call the technical support center less and less. This is consistent with Aral et al. (2012) who find that knowledge worker performance improves with access to heterogeneous knowledge. Thus we hypothesize the following:

> *H1a (Internalization of General Knowledge): As the cumulative number of general documents accessed by a field technician increases; the less likely that that field technician will call the technical support center.*
>
> *H1b (Internalization of Specific Knowledge): As the cumulative number of specific documents accessed by a field technician increases; the less likely that that field technician will call the technical support center.*
>
> *H1c (Socialization of Tacit Knowledge): As the cumulative number of different TSEs a field technician interacts with increases; the less likely that that field technician will call the technical support center.*

It is very difficult for manufacturers to anticipate all the different conditions and ways in which equipment will be used in the field and to ensure that equipment behaves exactly as intended under varying field conditions (Orr 2006, Harper 1992). Thus, field technicians sometimes need simple information such as those arising from the need to clarify technical service bulletins and notices about changes to prescribed procedures etc.; and sometimes they need to call the TSE regarding complex problems requiring the creation of novel solutions to problems (Pentland 1992). In this regard, knowledge repositories play a useful role in expediting problem solving and the handling of support calls by TSEs (Gray and Durcikova 2006).

Prior literature on technical support (Pentland 1992, Das 2003) views technical support as comprising of four categories of problem solving tasks – information retrieval, plan synthesis, state abstraction, and abductive diagnosis. Similarly, this literature views the work of field technicians and TSEs as comprising a mix of actions involving location of prior solutions, adaptation of prior solutions, and generation of new solutions. This categorization of problem solving tasks and corresponding problem solving actions is useful in clarifying both the nature of field technician tasks and the work of TSEs. The four types of tasks involve increasing levels of problem complexity – information retrieval being the simplest with plan synthesis, state abstraction and abductive diagnosis increasing in the level of problem complexity, and this classification of types of problem solving tasks maps closely with the problem solving actions i.e., the location of prior solutions, adaptation of prior solutions and generation of new solutions.

For information retrieval problems field technicians often need specific information to perform field maintenance. The dominant move to address information retrieval tasks is locate –looking up the knowledge repository to find prior incidents of a problem and retrieving details of solutions used in the past. For plan synthesis problems the field technician needs to formulate a plan to perform specific tasks or achieve particular goals. For state abstraction problems the field technician needs to formulate the logic and reasoning to assess the current state so that the problem at hand can be addressed. Solving plan synthesis and state abstraction tasks involve a combination of locate and adapt moves. For abductive diagnosis problems the field technician needs to formulate a diagnostic explanation so that the problem at hand can be addressed. Abductive diagnosis involves a deeper understanding of cause-effect relationships. Solving problems of this kind largely involves generate moves i.e., the creation of a new solution to the specific problem at hand.

Field observation at Aircom's technical support center and interactions with field technicians indicated that the ability of field technicians to access the knowledge repository influenced the nature of their calls to technical support. Field technicians are often able to address simple information retrieval and plan syntheses problems through information location in the repository without needing to call the technical support center. However, field technicians sought the expertise of technical support engineers when facing more complex state abstraction and abductive diagnosis problems. This is consistent with the prior research on call centers. Using case study of two call centers Schefe and Timbrell (2004) found that problems of uncertainty are about the lack of information and that they can be addressed using repository searches; whereas problems of ambiguity and equivocality are about the lack of knowledge and such problems can be solved by rich interactive conversation with experts i.e., TSEs.

The literature on task - technology fit (Goodhue, 1995; Goodhue and Thompson, 1995) also helps us understand which type of knowledge acquisition strategies may help the field technician improve their performance in specific circumstances. The task-technology fit concept may indicate that the simpler information retrieval and plan synthesis problems may be solved by accessing and internalizing general documents whereas accessing and internalizing specific documents may help solve the more complex state abstraction and abductive diagnosis problems. Likewise, socialization, which helps in transferring tacit knowledge from TSEs to the field technicians, may be more helpful in addressing the more complex state abstraction and abductive diagnosis problems. This is consistent with the findings of Becerra-Fernandez and Sabherwal (2001) who found that socialization may be useful for broader tasks whereas internalization may be more appropriate for narrow focused tasks; and the findings of

Kowtha (2008) who found that socialization enables engineers to develop mastery. Thus we state the following hypotheses:

H2a (Internalization of General Knowledge): As the cumulative number of general documents accessed by a field technician increases; the less likely that that field technician will call the technical support center for simple problems.

H2b (Internalization of Specific Knowledge): As the cumulative number of specific documents accessed by a field technician increases; the less likely that that field technician will call the technical support center for complex problems.

H2c (Socialization of Tacit Knowledge): As the cumulative number of different TSEs a field technician interacts with increases; the less likely that that field technician will call the technical support center for complex problems.

Firm-specific human capital improves firm performance (Hatch and Dyer, 2004). However, firms have to provide incentive to knowledge workers to develop firm specific human capital (Fairburn and Malcomson, 1994). Promotion to a higher paying job is one way for firms to incent field technicians to develop firm-specific human capital (Prendergast, 1993). As discussed above the level of internalization and socialization may affect the likelihood and nature of calls to the technical support center i.e., improve field technician performance as they solve problems in the field without needing to call the technical support center. This is the immediate impact of internalization and socialization. However, by internalizing documents in the knowledge repository and by transferring tacit knowledge from the TSE by socialization, if field technicians improve their skill and expertise then such accumulation of skill and expertise may be rewarded with a promotion. Thus, we expect that the field technicians who access and read a cumulatively greater number of general and specific documents are more likely to be promoted. Similarly, the field technicians who interact with a larger number of TSEs are more likely to be promoted. Thus, we test the following hypotheses.

H3a (Internalization of General Knowledge): As the cumulative number of general documents accessed by a field technician increases; the likelihood of promotion for the field technician increases.

H3b (Internalization of Specific Knowledge): As the cumulative number of specific documents accessed by a field technician increases; the likelihood of promotion for the field technician increases.

H3c (Socialization of Tacit Knowledge): As the cumulative number of different TSEs a field technician interacts with increases; the likelihood of promotion for the field technician increases.

3.4 Data and Variables

As discussed earlier the setting for our research is the technical support unit of Aircom, a large North American engineering firm that manufactures, sells and services heating, ventilation and air conditioning (HVAC) systems for commercial clients. The warranty and ongoing maintenance services to US customers are provided by around 18,000field technicians spread across 617 office locations throughout the 50 states. The field technicians have access to a central document repository that provides access to expertise in the form of documents related to equipment maintenance and troubleshooting. All field technicians carried company issued ruggedized laptops with wireless cards that they could use to access the knowledge repository from client sites. All field technicians also carried company issued cell phones in case they needed to call the technical support center. Field technicians were encouraged to look up solutions in the knowledge repository over the web before calling the technical support group. In this research we are interested in examining whether the field technicians accumulate knowledge by internalizing the documents accessed from the repository and whether socialization with TSEs affects their calling behavior. We are also interested in studying whether the accumulation of knowledge through internalization and socialization is related field technician with promotion.

Dependent variables: We track field technicians from the first day they started work at the company to the last day they worked for the company. Our first dependent variable is *whether a field technician calls* on a given day. If field technicians develop sufficient knowledge and skills by internalizing documents and by socialization with TSEs, they are less likely to call on a given day. Thus, the most basic way internalization and socialization would affect the field technician is to affect the likelihood of calling the technical support center on a given day. Our second dependent variable is the *total number of calls* made by the field technician on a given day. If field technicians accumulate more knowledge through internalization and socialization they would need to make fewer calls to the technical support center.

The complexity of the call was coded on a five point scale based on the Call Reason field recorded in the ticket management system. This 5-point system mapped very closely with the information retrieval – plan synthesis – state abstraction – abductive analysis scale discussed earlier. For example, product information calls were considered simple (and coded as having a complexity of 1) and problem diagnosis calls were considered the most complex (and coded as 5). Thus we divided the company's 5-point scale into low and high complexity call where calls of complexity from 1 to 3 were more like information retrieval and plan synthesis calls and were classified as low complexity calls, and calls of complexity of 4 and 5 were more like state abstraction and abductive analysis calls and were classified as high complexity calls. Thus we also examine the impact of internalization and socialization on the number of *high complexity* as well as the number of *low complexity* calls made by a field technician on a given day.

The first sets of dependent variables (likelihood of making a call on a given day, total number of calls on a given day, the number of low complexity and high complexity calls on a given day) reflect the immediate short-term effects of knowledge accumulation. We also examine the long-term effect of knowledge accumulation. Specifically, we examine if the accumulation of knowledge is related with field technician promotion. Thus, the second main dependent variable – field technician promotion is an event that reflects the quality of the field technician's performance over time. In our dataset a field technician can have the following designations:

- Estimator I - Service
- Project Manager-Service

- HVAC Field Technician
- HVAC Field Technician-Team Ldr
- Service Operations Manager 1
- Estimator III - Equipment
- HVAC Field Tech Apprn/EntryLev
- Service Coordinator I
- Area Service Manager I
- Estimator II - Controls
- Estimator II - Equipment
- Sr. HVAC Field Technician
- Project Admin - Equipment I
- Estimator II - Service
- Estimator III - Controls
- Estimator I - Equipment
- HVAC Maintenance Technician I
- Service Helper
- Estimator I - Controls

Whenever a field technician gets promoted their designation changes. We had quarterly records on field technicians and coded changes in designation as "1" whenever a field technician was promoted.

Independent variables: Our main independent variables are the measures of socialization, and internalization. We operationalize socialization as the number of different technical support engineers that the field technician has interacted with over the phone. Thus, the measure of socialization on a given day is the cumulative number of distinct TSEs a field technician has talked to till today. Even if a field technician calls and talks to a TSE multiple times over their tenure we effectively only count / consider the last interaction between the field technician and the TSE. We operationalize internalization using two variables representing the extent to which the field technician had accessed different kinds of codified knowledge available in the repository. The company distinguishes between two kinds of documents in the repository – (i) general documents such as technical brochures, wiring diagrams and field repair manuals for products that were typically authored by the marketing group, the quality control group and the training group and (ii) problem solution documents containing descriptions of problems reported for different products and their suggested solutions that were authored by technical support engineers and accepted into the repository after a technical review. Using the repository search records that contained details of all logins and searches of the repository by field technicians, we use the cumulative number of general documents accessed till today as the measure for internalization of general knowledge, and the cumulative number of problem solution documents accessed till today as the measure for internalization of specific knowledge.

Control variables: The experience of a field technician may influence the ability of a field technician to solve problems in the field and their need to call the technical support center. Hence, we control for the work experience of the field technician by taking into account the number of days that the field technician has been working for the organization. Field technicians may also differ in their strategy to solve problems in the field. Some field technicians may strive harder on their own before calling the technical support center whereas other field technicians may resort to calling the technical support center much earlier. Thus we control for the propensity to call by including the total number of calls made by the field technician prior to the current call. A field technician's ability to solve a problem is likely to be influenced by the level of codified knowledge in the repository. If the repository includes the general and specific knowledge a field technician requires to solve a problem, it may reduce a field technician's need to call the technical support center. Thus, we also include the number of repository documents as a control variable since this reflects the level of formalization of knowledge in the firm that is likely to influence the likelihood of call. The number of calls to the technical support center are also likely to be influenced by the volume of equipment supported in the field and the total number of field technicians available to support the equipment. Thus we also control for the total volume of equipment supported by including the monthly dollar value of maintenance contracts and we control for the number of field technicians available to support the equipment in the field using the actual number of field technicians available to support the equipment. Finally, field technicians may call the technical support center if there are TSEs available in the technical support center to answer field technicians' calls. We control for the TSEs' availability using the totals hours of TSE time available on a given day. Table 3.1 presents the summary statistics and correlations between the dependent, independent, and control variables.

Table 3.1: Means, standard deviations and correlations between key variables

No.	**Variable**	**Mean (standard deviation)**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
1	Made A Call	0.05 (0.23)									
2	# Issue Documents Accessed	29.07 (110.63)	0.11								
3	# General Documents Accessed	35.03 (100.84)	0.11	0.71							
4	Likelihood of Calling	53.43 (101.51)	0.31	0.35	0.34						
5	#TSEs contacted by Field Techs	15.28 (17.68)	0.27	0.39	0.38	0.81					
6	Field Technician Tenure (days)	972.58 (511.55)	0.06	0.21	0.24	0.39	0.52				
7	Total labor hours of TSEs	1988790 (499163.5)	0.01	-0.05	-0.05	-0.09	-0.08	-0.23			
8	Field Technician headcount	2836.79 (45.27)	0.02	-0.01	-0.01	-0.01	-0.02	-0.11	0.36		
9	Service Revenue ($M)	47165325 (5373300)	0.02	0.05	0.05	0.09	0.08	0.21	-0.16	0.16	
10	# Documents in Repository	28392.39 (4327.82)	0.03	0.1	0.11	0.19	0.17	0.41	-0.36	0.07	0.51

3.5.1 Analysis and Results

Our analysis employs a fixed effect model at the field technician–day level. This controls for individual specific, unobserved field technician factors. Please see table 3.2 for the results with regard to the impact of internalization and socialization on calls.

Table 3.2: Impact of internalization and socialization on calls

Variables	**Model 1: Made a Call fixed effects**	**Model 2: Total # calls fixed effects**	**Model 3: Total # of High Complexity Calls fixed effects**	**Model 4: Total # of Low Complexity Calls fixed effects**
# TSEs contacted by Filed Technician	0.964*** (0.018)	-0.020*** (0.005)	0.014** (0.006)	-0.021*** (0.006)
# Issue Documents Accessed	-0.128*** (0.007)	-0.008*** (0.002)	-0.004** (0.002)	-0.001 (0.002)
# General Documents Accessed	-0.030*** (0.007)	-0.001 (0.002)	0.005** (0.002)	-0.005** (0.002)
Field Technician Experience	-0.891*** (0.005)	-0.022*** (0.001)	-0.011*** (0.001)	-0.004*** (0.001)
Propensity to Call	0.826*** (0.011)	0.073*** (0.004)	0.018*** (0.004)	0.029*** (0.004)
Total Available Documents	-1.099*** (0.022)	-0.092*** (0.007)	-0.099*** (0.007)	0.035*** (0.007)
Number of Field Technicians (Head#)	8.060*** (0.133)	0.487*** (0.050)	0.825*** (0.043)	-0.426*** (0.047)
Volume of Equipment Supported (Sales)	-0.035** (0.018)	-0.009 (0.006)	0.009** (0.004)	-0.015*** (0.005)
Available Technical Support (Total Labor)	0.054*** (0.003)	0.001** (0.001)	0.001 (0.001)	0.001 (0.001)

We use a logit model (xtlogit) for model 1 where the dependent variable is binary: whether a field technician made a call on a given day; and regression models (xtreg) for models 2, 3 and 4 where the dependent variables are the total number of calls on a given day (model 2), the number of high complexity calls on a given day, and the number of low complexity calls on a given day, respectively. We used models 1 and 2 to test hypothesis 1 and models 3 and 4 to test hypothesis 2. Please see table 3.3 for the impact of internalization and externalization on promotion of field technicians.

Table 3.3: Impact of internalization and externalization for promotion of field technicians

Variables	Model 5: Promotion
# General Documents Accessed	-0.27 (0.21)
# Issue Documents Accessed	0.52** (0.28)
Field Technician Experience	-0.26* (0.15)
Number of TSEs contacted by Field Technician	1.02* (0.58)

Model 5 in table 3.3 tests hypothesis 3. Across all the models the dependent and independent variables were logged for ease of interpretation (except for the dependent variable in model 1 and model 5). Being a panel dataset, we need to test for the possibility of both heteroskedasticity and autocorrelation. White's general test indicates the necessity to correct for heteroskedasticity; we therefore use robust standard errors in the models. The Wooldridge test for autocorrelation fails to reject the null hypothesis of no auto correlation; autocorrelation is thus not a concern in the data. As mentioned earlier, we also control for the unobserved, individual characteristics of technical support engineers. We opt for the fixed effects model since the Hausman test leads to a rejection of the null hypothesis that the random effects model provides consistent estimates.

We first discuss the results in table 3.2. Across all the 4 models, the experience of the field technician is negatively related with the likelihood of making a call on a given day and the total number of calls, and the number of high and low complexity calls. Similarly, a field technician's propensity of a making a call is positively associated with the likelihood of making a call on a given day and the total number of calls, and the number of high and low complexity calls. The total number of documents available in the repository is negatively related with the likelihood of making a call on a given day and the total number of calls, and the number of high complexity calls. Finally, the volume of equipment supported is positively associated with the number of high complexity calls on a given day. These findings provide prima facie support for the face validity of the empirical models.

Model 1 suggests that the cumulative number of general documents accessed (p = 0.001 level) and the cumulative number of problem solution documents accessed (p = 0.001 level) are negatively associated with making a call on a given day. These findings are consistent with H1a and H1b respectively. However, the number of unique TSEs a field technician has talked to is positively associated (p = 0.001 level) with making a call on a given day. This finding is opposite of H1c. Model 2 suggests that the cumulative number of problem solution documents accessed (p = 0.001 level) and the number of unique TSEs a field technician has talked to (p = 0.001 level) are negatively associated with the total number of calls on a given day. A one-percentage increase in the number of problem solution documents accessed is associated with a 0.8 percentage decrease in the total number of calls on a given day. Similarly, a one-percentage increase in the number of unique TSEs talked to is associated with a two-percentage decrease in the total number of calls on a given day. These findings are consistent with H1b and H1c respectively.

We used models 3 and 4 in table 3.2 to test hypothesis 2. Model 3 suggests that the cumulative number of problem solution documents accessed by a field technician is negatively associated (p = 0.05 level) with the number of high complexity calls on a given day. A one percentage increase in the number of problem solution documents accessed is associated with a 0.4 percentage decrease in the number of high complexity calls on a given day. This finding is consistent with H2b. However, the number of unique TSEs a field technician has talked to is positively associated (p = 0.05 level) with the number of high complexity calls on a given day. A one-percentage increase in the number of unique TSEs talked to is associated with a 1.4 percentage increase in the number of high complexity calls on a given day. This finding is opposite of H2c. Surprisingly, model 3 also suggests that the cumulative number of general documents accessed is positively associated (p = 0.05 level) with the number of high complexity calls on a given day. A one-percentage increase in the number of general documents accessed is associated with a 0.5 percentage decrease in the number of high complexity calls on a given day.

In model 4 the cumulative number of general documents accessed is negatively associated (p = 0.05 level) with the number of low complexity calls on a given day. A one-percentage increase in the number of general documents accessed is associated with a 0.5 percentage decrease in the number of low complexity calls on a given day. This finding is consistent with H1a. Model 4 also suggests that the number of unique TSEs talked to by a field technician is also negatively associated (p = 0.001 level) with the number of low complexity calls on a given day. A one percentage increase in the number of unique TSEs talked to is associated with a 2.1 percentage decrease in the number of low complexity calls on a given day.

To examine the relationship between internalization and socialization and field technician's promotion, we use a rare event logistic regression. In the field technician force of around 417 technicians in our sample, we observed only 48 promotions indicating that a promotion within the 36-month period of our data is an infrequent occurrence. Hence, we use rare event logit, an alternative estimation method developed for contexts where events of interest such as wars, infectious disease outbreaks etc. may be observed a few thousand times less frequently than non-events such as peace and no disease outbreak (King and Zeng 2001a, King and Zeng 2001b). This analysis is presented in table 3.3. The dependent variable is whether a field technician got promoted in a given quarter. All the independent variables are also at the quarter level. Table 3 indicates that the number of general documents accessed is not related with promotion. So there is no support for H3a. However, the number of problem solution documents accessed (p = 0.05 level) and the number of unique TSEs talked to (p = 0.1 level) are positively related with promotion. This is consistent with H3b and H3c, respectively.

3.5.2 Robustness of results

Since we have a dataset that varies over time, the dynamic model provides several different reasons for correlation in the dependent variable over time: a) directly through the dependent variable in preceding periods, called true state dependence; b) directly through observable independent variables, called observed heterogeneity; and c) indirectly through the time-invariant individual effect, called unobserved heterogeneity (Cameron and Trivedi, 2010). Hence, we follow Arellano and Bover (1995) and Blundell and Bond (1998) to incorporate first differences of the dependent variable as instruments. We use the xtdpdsys command in Stata with the Generalized Method of Moments (GMM) in order to obtain consistent estimates. We test for the assumption of no error correlation and reject at order 1, the hypothesis that the errors are serially uncorrelated. The results are shown in table 3.4. The results of all these models are consistent with the main results reported in Table 3.2 providing empirical evidence of the robustness of estimates to alternative specifications.

Table 3.4: Dynamic panel models

Variables	Made a Call Arellano Bond model	Total # calls Arellano Bond model	Total # of high Complexity Calls Arellano Bond model	Total # of Low Complexity Calls Arellano Bond model
Number of TSEs contacted by Field Technician	0.299*** (0.039)	-0.089** (0.044)	0.019* (0.052)	-0.152*** (0.045)
Num of Issue Documents	-1.102*** (0.101)	-0.027* (0.025)	-0.164*** (0.026)	-0.065 (0.021)
Num of General Documents	-0.084* (0.099)	-0.031 (0.024)	0.137*** (0.025)	-0.049*** (0.021)
Field Technician Experience	-0.117*** (0.010)	-0.141*** (0.034)	-0.045* (0.035)	-0.149*** (0.031)
Propensity to Call	0.773*** (0.032)	0.277*** (0.030)	0.110*** (0.035)	0.224*** (0.030)
Total Available Documents	-0.572*** (0.145)	-0.018* (0.135)	-0.155* (0.130)	0.030* (0.127)
Number of Field Technicians (Head#)	2.181*** (0.386)	0.297* (1.057)	1.847* (1.026)	-0.398* (1.041)
Volume of Equipment Supported (Sales)	-0.035*** (0.008)	-0.110 (0.128)	0.130* (0.106)	-0.145* (0.112)
Available Technical Support (Total Labor)	0.006*** (0.001)	0.022** (0.010)	0.016* (0.007)	0.007 (0.007)

3.6 Discussion and Conclusion

Knowledge work and the productivity of knowledge workers are increasing in importance. In this research we examine how field technicians develop skill and expertise and how this skill and expertise affects their immediate and long term performance. The analysis suggests that internalization of general knowledge by a field technician is associated with a reduced likelihood of making a call on a given day and a reduction in the number of low complexity calls in a given day. This suggests that accessing and reading general documents helps field technician develop general knowledge and solve low complexity problems. However, developing general knowledge is not associated with promotions. It is likely that field technicians are expected to solve the low complexity problems using all the resources at their disposal such as the general knowledge in the repository but they are not rewarded for solving low complexity problems i.e., solving low complexity problems is a satisficing condition for employment as field technicians and solving such problems is not rewarded with promotions. However, quite surprisingly, accumulation of general knowledge is associated with more high complexity calls on a given day (see model 3 in table 2). This may suggest that accessing general knowledge increases the capability to recognize symptoms and frame problems but does not provide the necessary capability to solve complex problems, and this capability to frame problems just encourages field technicians to call the technical support center.

In contrast with general knowledge, reading problem solution documents i.e., internalization of specific knowledge is associated with the reduced likelihood of making a call on a given day, reduction in the total number of calls on a given day, and the reduction in the number of high complexity calls on a given day. This suggest that accessing and reading problem solution documents helps field technician develop firm specific knowledge and expertise that helps field technicians to solve a large number of problems including high complexity problems without calling the technical support center. Thus, we find that the accumulation of specific knowledge is also positively related with promotion for field technicians.

Finally, we find that though socialization is associated with reduction of total number of calls on a given day and the number of low complexity calls on a given day, socialization of tacit knowledge is positively associated with calling the technical support center on a given day and the number of high complexity calls on a given day. This suggests that socialization of tacit knowledge helps field technicians in solving a significant number of low complexity problems. Thus, the influence of socialization in reducing a significant number of calls to the technical support center is associated with promotion for the field technician. But quite surprisingly socialization encourages field technicians to call the technical support center for more complex calls. It is plausible that with socialization field technicians develop tacit knowledge and develop a better understanding of the problem domain and are able to identify complex problems. With socialization field technicians also become familiar with the expertise of TSEs. Hence, when they recognize complex problems they are more prone to calling the TSE. Hence, for more complex problems field technicians with higher levels of socialization reach out to the technical support center more frequently thereby increasing their number of calls of higher complexity.

The analysis suggests that internalization of general and specific knowledge and socialization of tacit knowledge all allow field technicians to develop skill and expertise in solving problems in different ways. Internalization of general knowledge and socialization, both help in addressing low complexity problems, but socialization also reduces the total number of calls to the technical support center. Thus, we find that socialization is associated with promotion whereas internalization of general knowledge is not. However, in contrast to internalization of general knowledge and socialization of tacit knowledge, internalization of specific knowledge is associated with reduction in the number of high complexity calls and the total number of calls on a given day, as well as the likelihood of calling on a given day. Thus, problem solution documents seem to be the most efficient mechanism to develop firm-specific knowledge and to transfer knowledge from TSEs to field technicians. Socialization however, seems to be more efficient than internalization of general knowledge in developing firm specific knowledge.

In summary our results thus provide evidence that, over and above individual specific factors like the level of innate ability, educational background and job experience, greater levels of a) socialization and b) internalization are significantly associated with accumulation of knowledge and more efficient problem solving. The type of knowledge repository document (general documents vs. problem solution documents) also has a differential impact on the type of calls made by the field technician (calls of high complexity vs. calls of low complexity).

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