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Completed Research Paper

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Abstract

In recent years, hospitals have begun to invest in RFID systems to control costs, reduce errors, and improve quality of care. Despite the transformative impact that RFID may have in healthcare settings, few studies have examined how and why this change may occur. The purpose of this study is to systematically understand how RFID can transform work practices and address cost, safety, and quality of care issues, most notably in inventory management. We leverage a sociomateriality framework to explore the causal linkages that connect the material properties of RFID with the behavioral changes that are observed through its use. By linking the material properties of RFID with innovations in existing practices, we provide a data-driven account of how and why RFID is useful in this setting. In doing so, we also contribute to recent work by IS scholars who argue for a reconfiguration of conventional assumptions regarding the role of technology in contemporary organizations. By adopting this perspective, we recast the issue of whether or not IT matters, and instead offer interesting and useful insight into how and why it does.

Keywords: RFID enabled innovation, organizational context, sociomateriality

Introduction

The adoption and use of innovative technological solutions for solving business problems have been arguably slow within the healthcare industry (Herzlinger, 2006). However, in recent years, burdened with rising healthcare costs and increased competition, hospitals have begun to invest in advanced IT systems, such as RFID-based systems, to control costs, reduce errors, and improve quality of care (Datamonitor, 2008). In fact, as referenced in Lee and Shin (2007), the global market for RFID systems in hospital settings is expected to increase from $90 million in 2006 to $2.1 billion by 2016 (Harrop and Das, 2006). Nevertheless, despite the apparent benefits of deploying RFID technology, there are some potential downsides, too. High costs, difficulties related to integrating with legacy systems, interoperability with life-saving medical equipment, incompatible communication standards across major entities in a healthcare network, and entrenched work practices are all potential obstacles to the effective adoption and use of RFID in healthcare settings (Smith, 2005).

The focus of this research project, therefore, is to understand systematically how RFID acts as a transformative technology to address cost, safety, and quality problems in this ever-important industry. To narrow our scope, this research focuses on the use of RFID within a bounded set of activities and work processes in the healthcare industry. Namely, we focus on inventory management processes that support the delivery of a particular type of healthcare service— those that exist in cardiac catheterization labs (CCLs) in three large U.S. hospitals. Inventory management is a highly researched topic among operations research scholars (Scott and Westbrook, 1991; Turner, 1993), who focus largely on functional problems (Rai et al., 2006). However, inventory management takes on a new light in hospital settings. For instance, review par levels (also termed order-up-to levels) for managing inventory (Nicholson et al., 2003), are seldom based on actual usage patterns, but instead reflect the desires of doctors and nurses, which are often based on subjective criteria (Prashant, 1991). Furthermore, the urgency of medical procedures—where the difference between life and death may be at stake—means that inventory checked out from holding bins may not be accounted for properly, thus making inventory tracking difficult.

Several researchers also argue that in order to understand the effects of technology on performance, the technology's process-level impacts need to be studied (Hitt and Brynjolffson 1994; Rai et al., 2006; Sambamurthy et al., 2003). Process-level impacts provide a means for understanding the underlying mechanisms though which the impacts of IT are causally related to performance. However, though there has been an abundance of research which examines the implementation and use of IT in healthcare (Angst and Agarwal 2009; Mantzana et al. 2007; Reardon and Davidson 2007; Menon et al. 2000), most studies continue to examine such issues through a social or organizational lens. In such studies the focus is too often on how people organize around technologies rather than paying close attention to how a technology's material features shape new behaviors (Leonardi and Barley 2008). Therefore, it is important to develop a more sophisticated understanding of the mechanisms through which RFID generates value in such healthcare settings by paying attention to the social and material dimensions of the interaction as it is situated in practice.

This study seeks to address these gaps by reporting on an in-depth multi-case study of three US hospitals, each of which has recently transitioned from a bar-code to an RFID based inventory management system. In order to address these issues, we organize this paper as follows. In the next section, we describe the organizational context and sociomateriality frameworks that will be used to guide our data collection and analysis. This is followed by a discussion of the methodology used in this study and the results. We conclude by providing a discussion of the study's findings and the implications for future research.

Theoretical Background

Organizational Context

RFID (Radio Frequency Identification) technology is a non-line-of-sight tracking technology utilizing radio frequencies to identify a particular tagged object. Consisting of a tag and a reader, it is seen as a "viable replacement" to barcode technology and is used in many industries (Ho et al., 2005, p. 70). The RFID tag is attached to the object to be tracked, and the reader can be placed anywhere within the range of the radio signal to track the tagged object. Its advantages over barcodes include batch readability, superior processing and tracking capability, superior information storage, and resistance to environmental conditions (Kapoor et al., 2009). Traditionally, manufacturing and retail environments were the earliest users of RFID technology, because of its potential use in the supply chain. For instance, retail stores such as Walmart, Target and Gillette have aggressively pursued using RFID tags in their products (Wang et al., 2006). However, recent trends point to the adoption of RFID technology in many different environments, including the healthcare context.

Several researchers contend that studying the "context" surrounding a phenomenon is extremely important for gaining a deeper understanding of that phenomenon (Johns, 2006; Mowday and Sutton, 1993; Carpelli and Sherer, 1991; Johns, 1991). Defined broadly, context refers to the set of environmental, political and social factors that have the potential to define, shape and add meaning to the phenomenon of interest (Johns, 2006; Mowday and Sutton, 1993). Building on prior research related to context, Johns (2006) provides an overview of the impacts context has on a particular phenomenon of interest. According to Johns (2006), contextual variables can have different types of impacts on the phenomenon: a context can directly impact the phenomenon (main effect); it can be a part of the causal chain (mediator); or it can increase or decrease the effect of other independent variables (moderator). Contextual variables can enable or inhibit the underlying factors that shape behavior, and can have an impact at multiple levels of analysis. In some situations, context can also reverse the causal direction of the hypothesized relationship. Because context can play such a strong role in shaping collective behavior, studying the contextual factors surrounding a particular phenomenon becomes extremely important to understanding it fully.

The IS literature relating to healthcare has acknowledged the importance of context and has focused on a variety of topics, including patient-care systems, telemedicine, inventory management and hospital information systems. Researchers have also illustrated the difficulties associated with implementing information systems in the healthcare context (Ranganathan et al., 2004; Anderson, 1997). Chiasson and Davidson (2004) argue that the healthcare context is unique because of the existence of classic duopoly between administration's management on the one hand and practitioners' duties on the other (Yajiong et al., 2008). This gives rise to possible tensions between the various centers of power in hospital settings. As a result, inertial forces in the hospital environment become exaggerated, and such complexities have important implications for resistance to change and innovation. In addition, decision making is often shaped by unusual constraints in a healthcare setting (life or death situations), that are distinct from typical cost management considerations (Chiasson and Davidson, 2004). This gives rise to the classic problem of optimizing the effectiveness of service delivery (quality) while improving operational efficiency (cost) (Chiasson and Davidson, 2004; Bodenheimer, 1999), in turn adding another layer of contextual issues. Additionally, the level of compliance enforcing safety standards in hospitals is enormous (Chiasson and Davidson, 2004). The healthcare industry, in general, is on the higher side of institutionalization and regulatory oversight (Scott et al., 2000), thus making the adherence to regulatory compliance yet another important issue in the healthcare context (Chiasson and Davidson, 2004). Consequently, the healthcare industry is slow to adopt new technology innovations, but it provides tremendously unique contextual factors for the study of IS implementation and to elaborate our understanding on the mechanisms through which IT impacts the performance of work processes.

Several researchers posit that the unique aspects of the healthcare context (Anderson, 1997) impact the potential use of IT systems and their accompanying governance structures (Madsen et al., 2006). For instance, by analyzing 57 IT investment decisions at six hospitals, Yajiong et al., (2008) developed a framework consisting of seven IT governance archetypes in a healthcare context: top management monarchy, top management-IT duopoly, IT monarchy, administration monarchy, administration-IT duopoly, professional monarchy and professional-IT duopoly. From an implementation perspective, Kohli et al. (2001), through a case study, document the implementation of a patient profiling system in a hospital, illustrating the level of institutional pressure faced by such implementation efforts. Similarly, based on an interpretive field study of a computerized physician order entry system, Davidson and Chismar (2007) state that technology-related organizational change can only be achieved by aligning two complementary capabilities, namely social structures (the interdependency, multidisciplinary cooperation and standardization among clinical departments) and technology capabilities. The findings from these studies suggest that the contextual characteristics of the healthcare industry could have an impact on specific healthcare-related processes, such as inventory management, and the corresponding IT systems and structures put in place. The importance of context for healthcare-related IS studies lead to our first research question:

> *What are the key contextual characteristics that are relevant to inventory management and how do they impact the assimilation of RFID in healthcare settings?*

Sociomateriality

Despite the commonly held belief that IT systems and their capabilities are fundamental to an organization's survival and growth, scholars note that there is lack of understanding of the underlying mechanisms that link IT to improved performance in organizational settings (Bharadwaj, 2000). Recent work in this area continues to call on researchers to investigate the causal pathways that connect IT investments and performance (Rai et al., 2006; Sambamurthy et al., 2003, Ho et al., 2002). To contribute to this line of research, this study adopts the socio-materiality framework (Orlikowski 2007; Markus and Silver 2008) as a theoretical lens to guide our investigation. Until recently, there has been a comparative few information systems studies that have adopted a material orientation to examine how IT shapes people and organizations. Some have argued that this gap in the literature stems from the ongoing debate over what matters more in shaping behavior, the material or social dimensions of information systems implementation and use (Leonardi and Barley 2008). For instance, over two decades ago Markus and Robey (1988) highlighted this apparent chasm by discussing the "technological imperative" versus the "organizational imperative" in information systems research. The former view believes IT deterimines behavior and the latter view sees humans as the drivers of behavior as they design and develop IT to meet human and organizational needs. According to Leonardi and Barley (2008), "The materiality of information technology remains grossly under-theorized (Orlikowski & Iacono, 2001; Zamutto, Griffith, Majchrzak, Dougherty, & Faraj,2007), in large part, because conflating materialism with determinism poses subsidiary challenges that make it difficult to tease apart the role of the material and the social" (p. 161).

Leonardi and Barley (2008) go on to suggest that because materialism has acquired the stigma of determinism, technology and organizational researchers focus their attention too often on how people organize around technologies (Orlikowski, 1992, 2000; Robey & Sahay, 1996), rather than paying attention to how a technology's material features might constrain and enable new behaviors. In this study we seek to counterbalance this apparent misalignment in the literature, and focus intently on the distinct material characteristics of RFID technology, while not neglecting the social dimensions of use that combine to shape RFID enabled innovation in healthcare. The materiality of RFID systems matters as our purpose is in developing a deeper understanding of how RFID technology shapes new and innovative behaviors in a healthcare context. We will pay special attention to the material properties of RFID as they are the tangible resources that afford people the opportunities to discover innovative alternatives to existing practices, while also constraining them in other ways. Put another way, RFID or any technological artifact is a "bundle of material and symbol properties packaged in some socially recognizable form, e.g., hardware, software" Orlikowski (2000, p.408) that affords and constrains behavior.

Despite the importance placed on the material properties of the technology, the socio-material framework does so without excluding the important role of human agency in IT enabled innovation. Accordingly, to gain analytical insight and rather than treating them as distinct and independent concepts, Orlikowski (2007) suggests that we should focus on the ways in which the social and material intertwine and emerge in ongoing, situated practice. In this spirit, our focus in this study is to investigate how the material properties of RFID become actualized in practice, thereby leading to observable innovations in inventory management processes. Furthermore, we examine this phenomenon in a slightly different way than much prior research that focuses on the social rather than material properties. According to Leonardi and Barley (2008), most prior research in this area leverages research designs that investigate the same technology in different contexts to illuminate the role that social dynamics play in determining technology's impacts. However, as they suggest, we are likely to learn more about materiality by changing our approach, thereby looking at two distinct technologies in the same context. Therefore, the importance of understanding the material impact of RFID in a healthcare context leads to our second research question:

> *How do the material properties of RFID (as opposed to bar code) based inventory management systems enable and constrain the work practices of clinicians?*

In the next section we describe our research methodology.

Method

We adopted a multi-case study method to explore our research questions. The case study approach was chosen because it affords the best opportunity to dive deep into the contextual conditions (Yin, 1994) that impact process performance in hospital settings as well as to explore how RFID impacts work practices in such contexts. To determine case sites, we were guided by principles of literal replication, which led us to choose sites where we predicted similar results across cases (Yin, 2003). Guided by this philosophy, we conducted three separate case studies in a linear fashion. By examining our propositions that were generated from our first case in subsequent cases, we were able to generate more compelling support for our initial findings.

We identified key job roles within each study to explore the relative impact of RFID as compared to barcode technology. In doing so, we interviewed individuals who used the RFID system while engaging in tasks related to inventory management within the healthcare settings (e.g., supply coordinators, purchasing managers, and inventory clerks). Additionally, we interviewed individuals who participated in the work practices that were directly responsible for the service delivery rendered in the CCLs in major U.S. hospitals (e.g., nurses and lab attendants). Miles and Huberman (1994) refer to this as within-case sampling, which is an additional way to gain rich insight from case study research (Chu and Robey, 2008). By conducting a multi-level analysis, our interest was not only on the change that occurs within practice areas but also on the causal linkages connecting changes in inventory management practices with changes in primary work practices (i.e., those that are directly related to the delivery of key healthcare services).

Data collection

The multi-case study consisted of three data collection techniques to explore the phenomenon and to ensure adequate validity of the research findings (Yin, 2003; Miles and Huberman 1994). The primary source of data for this study was a series of semi-structured interviews. Interviews were first conducted from the perspective of a RFID solutions vendor in the healthcare industry and included discussions with C-Level employees, such as the Chief Executive Officer, the Vice President of Services for the CCL labs, and the Director of Hospital Services. Upon completion of these early exploratory interviews with the vendor, we conducted our initial interviews with members from the first site: a CCL lab from a large hospital in the northeastern part of the United States. The second site was a large Midwestern hospital that is considered one of the premier cardiac centers in their region. The final site was also a large hospital, and it was located in the southeastern United States.

The interview protocol was semi-structured and consisted of questions that were both targeted and open-ended to encourage normal conversation related to the specifics of the healthcare context and the impact of RFID on work practices and process performance. More specifically, questions asked respondents to assess aspects of the healthcare context that were most influential for their work, how their perceptions and work practices changed throughout the stages (early vs. late) of RFID adoption and use, how they used the RFID technology to alter their work practices and how the overall performance of their unit has changed (in terms of employee satisfaction, patient safety and inventory carrying costs) as a result of the RFID technology. Table 1 provides an overview of the questions from the interview protocol and their relation to the major themes in this study. Except for the early interviews focused on discovery and gaining access to case sites, interviews lasted between forty-five minutes to one hour and were all recorded and transcribed.

The second source of data was direct observation, which refers to the data collection method for which the researcher acts as a passive observer (Yin 2003). Observational evidence is particularly valuable when it acts as a supplement to other data collection strategies (Mason, 2002). Mason (2002) states that the term "observation" "usually refer to methods of generating data which entail the researcher immersing himself in a research 'setting' so that they can experience and observe at first hand a range of dimensions in and of that setting" (pg. 84). We leveraged this method to observe firsthand the activities that occur in CCLs, how RFID technology is used to alter inventory management work practices that support service areas, what procedural linkages connect inventory management practices with the work practices that enable service delivery (mediated through information technology) and what contextual characteristics shape behavior in these work domains.

The third source of data is archival, which is an important source of data for this study, as it provides the means to triangulate the findings that emerged from the semi-structured interviews and direct observations. The archival data came from Microsoft PowerPoint slides, meeting notes and white papers and reflects usage patterns and changes to inventory levels of tracked products over time.

Table 1. Interview Questions and Relationship to Major Themes	
Themes	Working definitions and key interview questions
Healthcare Context	We focused on how actors view the unique aspects of the work domain and how these aspects related to characteristics of the healthcare context. Such aspects related to time pressure, issues with consignment, situational urgency (life-and-death scenario) and process complexity. *Examples questions:* What is unique about the healthcare context that impacts inventory management? Please describe the contextual situation surrounding hospital X when they purchased the RFID solution.
RFID vs. Barcode Systems	We focused on how individuals perceived the RFID system as it compared to the barcode system it was replacing. We explored whether or not RFID enabled changes in inventory management and healthcare service delivery in specific healthcare settings. *Example questions:* How has the use of RFID afforded you the opportunity to alter your work practices? Is this different than with the barcode system. How do RFID generated reports differ from barcode generated reports in their ability to impact decision making related to inventory par levels and acquisition of new and existing assets? How do innovations in inventory management work practices impact patient care?
Process Performance	We focus on how participants viewed the impact of RFID technology on key performance outcomes within their work domain related to economic, structural and clinical outcomes. *Example questions:* How has RFID technology and any the subsequent changes in work practices impacted inventory par levels of key products in your work domain? How has RFID technology and the subsequent changes in work practices impacted patient safety in your work domain?

Table 2. Summary of interviews conducted

Organization	**Job Role**	**# Interviews**
Vendor	CEO	1
	VP Services - CCL	1
	VP Services - IR	1
	Customer Care	5
Northeaster Hospital	Unit director	2
	Inventory Manager	1
Midwestern Hospital	Executive director	1
	Unit director	1
	Process manager	1
	Inventory manager	1
Southeaster Hospital	Unit director	2
	Inventory manager	1
	Auditing department	1

Data analysis

We leveraged a hybrid analytical technique to analyze the qualitative data, incorporating both inductive and deductive coding and thematic development procedures to generate rich insight (Fereday and Cochrane, 2006; Chiasson et al., 2008). The hybrid approach is particularly useful in novel settings for which extant work is limited; it allowed us to begin the analytical process by working from the data and moving from specific cases to more general conclusions (Schwandt, 2001). Moreover, by alternating between inductive and deductive analysis, we were able to leverage the contextual (Johns, 2006) and sociomaterial (Orlikowski, 2007) frameworks to interpret emerging themes, which result in richer and more robust findings.

Two of the authors conducted the interviews for this investigation. After each interview, both of the authors met repeatedly in recap sessions to converse about the major themes that emerged from the interviews. The third author was then presented with the generated themes and offered critique for the early analysis by referencing to prior theory. During the early phases of analysis, the research team thoroughly listened to, read, coded, and discussed the data in an iterative fashion (Eisenhardt, 1989). Saliency, as an explanatory factor rather than its frequency, represented our standard for what constituted a theme (Blatt et al, 2006). Themes generated through the analysis of the individual interviews were identified by tagging text segments with codes using computer-assisted qualitative analysis tools. The themes were then organized in a conceptual with associated propositions (Figure 1).

Results

In this section, we explore our research questions in the context of cardiac catheterization labs across three distinct hospitals in the United States. In doing so, we explain the conceptual model (see Figure 1) that emerged from the findings of our first study, and that were subsequently tested in two additional hospitals.

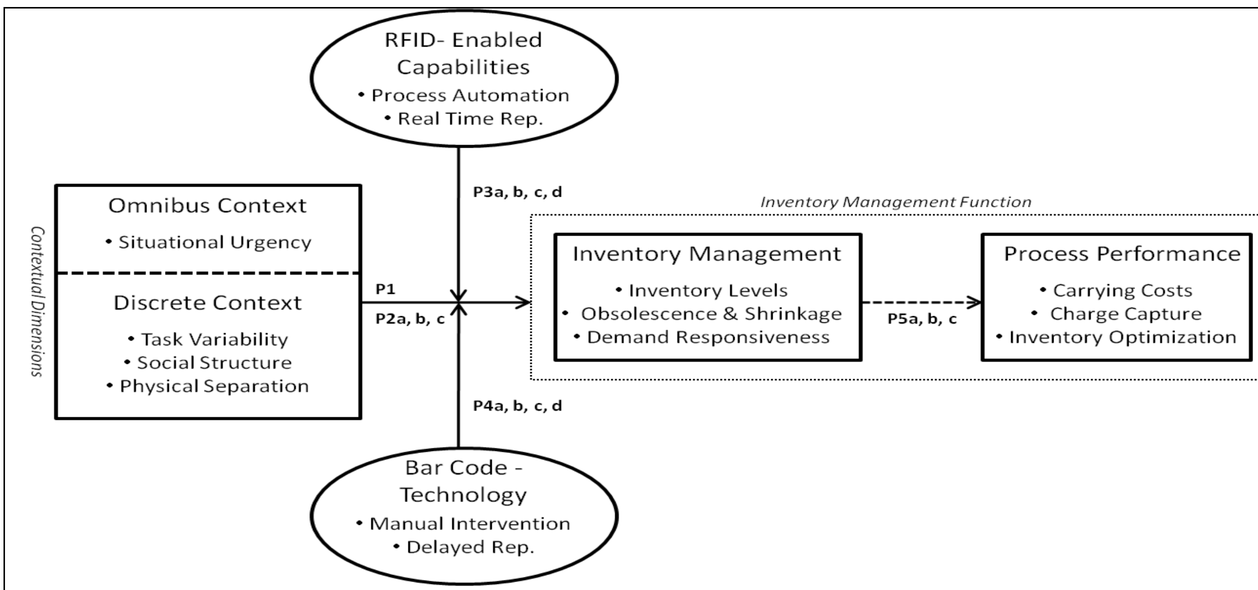

Figure 1: RFID-Enabled Capabilities and Process Performance

Impact of Organizational Context

To explore our first research question, we draw on the work of Johns (2006) who offers two distinct dimensions of context. The first, the omnibus context, can be considered a higher-order construct, as it operates at a higher level of analysis and comprises many features or aspects. Second, the discrete context refers to "the particular contextual variables or levers that shape behavior and attitudes" (p. 391). Together, both dimensions work in a mesotypic relationship to link the more general contextual attributes with the more specific contextual attributes (Johns, 2006). The multi-dimensional contextual framework proved useful for our study, as it helped to classify our contextual findings at two levels.

Omnibus Context

According to Johns (2006), one should adopt a journalistic mentality when describing the omnibus dimensions of a context—describing who, where, when, and why. We used Johns' framework to identify the relevant stakeholders who interacted with the inventory management functions. We found that across all three cases, there were similar job roles, though not identical, that were associated with such functions. In each case, there was one individual strictly responsible for inventory in the CCL lab. These individuals reported to business managers who oversaw the operational aspects of each lab, which was another common role across all cases. However, in two of the cases, this individual had broader responsibilities and was charged with managing the entire cardiovascular services area across a larger hospital network. To these managers, inventory management was one component of a much broader responsibility. For instance, these managers were not only responsible for ensuring that the requisite products were in the right place at the right time; they were also tasked with negotiating purchasing and consignment agreements with vendors.

In addition to those responsible for managing inventory, there were also the individuals who used it. Thus, we identified key individuals across all three cases that were on the clinical side of service operations. The clinicians were the individuals responsible for prepping procedure rooms before patients arrived and for gathering supplies based on doctors' requests during operations.

We performed our study in three CCL labs across the U.S. Typically, CCL labs use minimally invasive techniques to perform diagnostic procedures for treating vascular diseases. When we asked one interviewee for a more thorough explanation of what happened in CCL labs, he commented:

> *These procedures are catheter-based. Access into a blood vessel, usually the femoral artery in the groin, is obtained by inserting a hollow needle into the blood vessel. A thin wire, usually 0.35-0.38" in diameter is passed through the needle. A catheter, which is a hollow tube of varying lengths, shapes and size is placed over this guide wire and manipulated to the specific blood vessel that is to be studied. In the case of the CCL, this is most often the arteries that supply blood to the heart muscle.*

By elaborating on CCL activities, he illustrated why one procedure may require many different types of products:

> *When the artery is selected with the catheter, contrast (x-ray dye) is injected. X-Ray films are obtained during this injection, showing any narrowing or deformity of the blood vessel. If there is a narrowing that is significant, a thinner catheter can be inserted through a guide catheter across the narrowing or lesion. This catheter can have a balloon-mounted stent (a thin metal mesh tubing that creates a scaffold for the artery narrowing) that can be deployed to open the artery.*

It is important to note that each catheter used in a procedure can easily exceed three thousand dollars, which explains why inventory management is so crucial for improving the financial performance of CCL labs.

In terms of when we conducted this research, we focused on two aspects. First, we did not conduct this research during an actual CCL procedure. Instead, we relied on retrospective accounts from interviewees. However, in our questioning we did make a point to ask the interviewees "to travel back in time" in order to describe situational characteristics in great detail. Second, the time heuristic focused our attention on the notion of when our study was conducted in relation to the implementation of the RFID system. In this case we designed variability into our study, as we wanted cases that represented both recent and more mature implementations.

We chose to do this research in CCL labs because they are generally early adopters of RFID technology in hospital settings. In doing so, we provide insight into a very important contextual variable that shapes behavior in these settings. Simply, across all cases and interviews, one central theme was constant: namely, that CCL labs deal with life-and-death situations that put great pressure on every individual who is either directly or indirectly involved with inventory management in CCL labs. As one interviewee commented:

> *Try to imagine you're in a life-and-death situation. You're the doctor; you're the clinical person, attending. You know the person or patient needs this device. Had it been without that issue, it's so easy to*

> *walk to the cabinets and grab the device. But I've observed, it's a different scenario when there is this critical need. You would see…the blood rush that you must find that device.*

Proposition 1*:* Situational urgency will increase the uncertainty of the inventory management function that supports the CCLs

Discrete Context

Discrete contextual variables provide a link between the general omnibus characteristics and actual organizational behaviors and attitudes (Johns, 2006). When we searched for actual examples of how the general context shapes behaviors that impact the inventory management function, we found recurring themes across the cases. When using Johns' (2006) dimensions of context as a sensitizing device to interpret our data, we were able to align our observations with his salient dimensions of discrete context, including task, social and physical contexts.

We learned early on in our investigation that the inventory management function in CCL labs has one core purpose: to ensure that doctors have the right supplies, at the right time and in the right location. As one interviewee suggested:

> *It is a constant struggle…but when they [the patient] are on the table… you want everything available…not that we're not going to fail sometimes because you can't predict what's going to come through the door next; you just can't.*

In light of the life-or-death omnibus context in which our interviewees operated, we wanted to develop deeper insight into the factors that impacted their objectives in terms of products, time and place. Our findings suggest that there were three key drivers of variability that impacted their ability to optimize inventory, or balance their objectives with the need to lower costs. First, there appeared to be significant patient variability, or changes in the number of specific patient procedures that would be performed on any given day. As one interviewee commented in regard to a recent experience, "The day started with 10 cases planned, we ended with 22…so 12 cases were added on that day. There is a lot of variability in what we do."

The second factor related to procedural variability, or distinctions in the type of procedure performed on a patient. As a result of innovations in medical practice, CCL labs continue to experience greater procedural variability. As one interviewee mentioned:

> *As the doctors keep on the cutting edge of the procedures, the complexity of the procedures increases. The supplies have grown much more than they used to be. For example, when we do a coronary angiogram—which is just a diagnostic angiogram—the supplies required for that are relatively cheap and are going to be fairly limited. But as we evolve into the angioplasty, those supplies have just boomeranged, and 90% of the CCL budget is supplies.*

Another interviewee reiterated this point when she distinguished the CCL lab from other areas of the hospital. She commented:

> *CCL is unique in the fact that not only do we have syringes, Band-Aids and needles to treat our patients, but we have catheters and stents and balloons and pacemaker devices and lots of interventional items…you go to surgery and the doctor opens a set of instruments, he goes in and takes out your gall bladder and you're done.*

Moreover, one case may consist of multiple procedures, as the following interviewee commented: "We may do multiple things on one case, multiple procedures on one case."

The third factor that impacts the inventory manager's ability to right size inventory relates to product variability, or distinctiveness in terms of the type or brand of a supply that a doctor might use during a procedure. Our findings suggest that initiatives to engage in vendor-sponsored research studies actually exacerbate product variability, as there is a positive correlation between the number of studies they participate in, vendors, and product variability. One interviewee explained:

> *We're involved in a lot of research studies here, clinical research studies, so our physicians are well versed in all new technologies coming out and new drugs coming out and that kind of thing. Well, the down side to that is, you can have a lot of vendors in the lab and the downside of that is that you can have a lot of supplies.*

Proposition 2a: Task variability (related to patient, procedure and product) can increase the uncertainty placed on the inventory management function.

Social structure is a key contextual dimension that was illuminated in Johns' (2006) framework and evident in our findings. It manifested in two key ways across cases: power asymmetry between doctors and between those responsible for managing inventory in the CCL labs. It was clear throughout our investigation that there was a distinct ingroup/outgroup status between these social groups. As expected, those responsible for inventory management seemed to be focused on meeting the perceived needs of the doctors, even if they did not agree with them at times. The following interviewee highlights such a relationship:

> *I have a medical director that gives us medical direction for what we need to do. His favorite expression is "he's the quarterback and it's my job to catch the ball." I keep trying to tell him there's going to be a quarterback sack some day.*

Proposition 2b: Power asymmetry between doctors and staff can increase the uncertainty placed on the inventory management function.

Johns (2006) acknowledges a growing awareness by management scholars that the effect of the physical world on collective behavior is understudied in organizational research (Orlikowski, 2007; Pfeffer, 1997). Our findings illuminate the importance of paying attention to the physical context, as we continually detected the interrelationship between product placement and the execution of clinical procedures. For instance, the following interviewee commented on the benefit of a mobile supply cart:

> *It's a long walk from number six [procedure room six] to the central core [central stocking room]. So there will be days where you're forced to open lab six…if you want to have the same type of efficiencies [as you do in rooms closer to the core], we can grab the portable cabinet and move in.*

Another individual commented on the impact of physical location on the quality of care:

> *It's our goal to keep the door to balloon time [referring to an angioplasty procedure] to under 90 minutes. One of our focuses has been: How can we improve the delivery of care from a quality perspective? And my contribution to that can be limiting the number of times an employee leaves the room to gather products for this case.*

Proposition 2c: Physical separation between a given supply and a procedure will increase lead times and increase the uncertainty placed on the inventory management function.

Impact of Information Technology

Our second research question is focused on investigating the causal pathways that connect IT investments and performance (Rai et al., 2006; Sambamurthy et al., 2003, Ho et al., 2002). To explore these complex linkages, we draw on a growing body of research related to sociomateriality in information systems research (Orlikowski, 2007). Orlikowski acknowledges the value created by past organizational scholars but says that "these insights are limited in large part because the field has traditionally overlooked the ways in which organizing is bound up with material forms and spaces through which humans act and interact" (p. 1435). She cautions that sociomateriality does not relate to a techno-centric or a human-centric view of human (or social) computer interaction[1]; rather, it focuses on the constitutive entanglement between the social and technological components of organizing.

We realized early on in our investigation that there was an interesting distinction that needed to be understood. On the surface, there seemed to be only slight differences between the RFID systems and the barcode technology that they replaced. Yet, we also detected major shifts in behavior that occurred across all three sites, which were seemingly the result of this new technology. According to one interviewee:

> *We wanted a better way to track our devices…which was really the primary driver behind why we wanted to fold in this technology into our current process. Prior to RFID and because of the manual [bar code]*

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[1] According to Orlokowski (2007), "The techno-centric perspective is interested in understanding how technology leverages human action, taking a largely functional or instrumental approach….the human-centered perspective focuses on how humans make sense of and interact with technology in various circumstances…while this grounds the use of the technology itself, it tends to minimize the role of the technology itself" (p. 1437).

> *process, we would send back $50,000 to $60,000 of product per month to the manufacturers.*

We investigated what the real distinctions were, to understand why they were shaping these new behaviors and leading to greater adoption of RFID. We knew we could not simply focus on the technology itself. Through the lens of socio-materiality we began to examine the complex linkages between human action, the technological systems under investigation, and the material world. In our view, the technology was mediating the relationship between action (inventory management practices) and the material world (physical inventory) by digitally representing materiality. Through this analysis we were able to uncover distinct differences between the RFID and barcode technologies, which helped to explain the performance improvements that were seen in each of the three sites.

Impact on task variability— automation vs. manual processes

At a first glance, both RFID and barcode systems appear to have similar technological capabilities. Both of these systems store information in electronically readable formats, use readers for accessing the information stores and can be linked with database systems to capture live usage behaviors for further analysis. However, the fundamental capabilities enabled by these two systems are drastically different.

Barcode systems are line-of-sight technologies and require that the reader be placed in front of the code to be read. RFID systems work through radio frequency identification, thereby placing no such constraints on reader placement. Inventory managers and nurses do not need to scan each and every item they store or retrieve from shelves because the system automatically tracks such storage and retrieval. Even this relatively simple shift in the readability of codes between bar-codes and RFID tags frees up valuable time and effort for inventory managers and nurses and has contributed significantly to labor savings (Dutta et al., 2007). RFID systems also provide higher order information visibility. While barcode systems demand constant manual inventory checking because managers cannot rely on workers accurately decrementing products during actual procedures, RFID systems provide automated, round-the-clock tracking of inventory (see appendix A). This information visibility can be used by inventory managers to make important decisions apart from checking inventory (Dutta et al., 2007). They can also be used for understanding and modifying inventory stock levels, solving inventory discrepancy problems, visualizing demand situations for patients based on usage patterns, proactively predicting future trends, and as the following inventory manager describes, enable recalls to be quickly dealt with:

> *We just actually got a recall with a Boston Scientific product that was a guiding catheter. I was able to go into the RFID system and locate these products with an item locator. We were able to remove them probably within a 15-minute time frame, as opposed to spending hours trying to weed through and make sure that we've caught everything. And it's really shifted the way we approach those recalls.*

Another interviewee discussed how moving away from the manual bar code system helps to reduce errors and improve performance:

> *So it really became, for me, a money saving, cost efficient way of managing inventory plus it takes the manual [bar code] piece out of it…and the human error and it does actually ensure that you have the right product on the shelf for the patients when they need it as opposed to the manual process. [With the manual bar code system] you just couldn't keep track.*

Proposition 3a: The automated aspect of the RFID system engenders the trust of information representation (i.e., managers believe that the system actually reflects inventory levels), thus reducing the uncertainty placed on the inventory management function.

Proposition 4a: The manual aspect of the barcode system generates mistrust and uncertainty of information representation, increasing uncertainty placed on the inventory management function.

"Near" real-time vs. time-delayed representation

The manual process required for capturing inventory through the barcode system led to many errors, and thereby attenuated confidence in the system data. According to one interviewee:

The piece that the RFID system did take away was that every morning the inventory guy, Bill, would get in at 5:30 AM and go out and literally count the products that were on the shelf. Now …he was probably looking at 3000 products a day and trying to see where he needed to order and then if he saw the product he needed to order he had a separate book of all these barcodes and he would scan the barcode of the product, so he would have to look it up in his book, find the barcode use his hand held scanner , scan that barcode and then enter in that PDA, the number that he needed to order and at the end of going through this 2 hour process, he would get back to his desk to [to begin placing orders]. This was an incredibly error prone process because sometimes he'd scan the wrong barcode or as you know, PDA's are really terrible for writing on and he'd write a 6 and it would put in a 5 and he also had to fake it out because he'd have to keep a separate track of what was on order .

Unlike the barcode system that was not only very manual but created significant time delays, the RFID system we investigated counts inventory 50 times per day, creating the perception of real-time visibility of the products that were on hand, missing or nearing expiration. As individuals viewed the reports that were generated through the RFID system, they described feeling as though they were viewing the actual inventory through a digital lens. In fact, because of this new perception, they began to develop insight into how the inventory had changed over time. For instance, one interviewee commented:

But with the RFID technology—since it's real time—it's easy for him to go to the system, see what we have and see the movements of the product. That way, when he speaks with a vendor he can negotiate for volume and price.

Another interviewee commented on how the RFID system helped her detect trends:

I can tell you that, from a practical perspective, some of the things that I now focus on are a true mirroring of the clinical practice. So, if I have a trend in the last 30 days, where I know that shifts are moving from one product category to another or from one vendor to another, I can respond to that pretty proactively.

While continuing to probe these issues across the three cases, we were amazed at how the RFID systems generate completely different perceived representations of the material world. Interestingly, if the barcode system was perceived to be used effectively (so that products were incremented and decremented when placed on or removed from a shelf) the data generated by that system would be nearly identical to that generated from the RFID system. Yet, the constitutive entanglement between the human and the barcode system and the human in the RFID system was different and perceived to be so.

Proposition 3b: Perceived real-time information representation generates trust and reduces uncertainty, thus reducing the uncertainty placed on the inventory management function.

Proposition 4b: Perceived time delays in information representation generate mistrust and uncertainty, thereby increasing the uncertainty placed on the inventory management function.

Impact on social structures

Our early findings showed that those individuals on the non-clinical side of the CCL lab were often in power struggles with two main constituencies: doctors and vendors. Consequently, we wanted to explore how the use of RFID versus barcode systems impacted these relationships. Our findings indicate that the information generated by the RFID systems gave the clinical staff confidence to approach and negotiate with the doctors and vendors. For instance, one interviewee commented:

Sometimes I have to be the impetus for the change, or go to the physicians and say, "You know, based on your trend or the practice here, maybe we can try looking at another product category, or what do you think about this?"

Another interviewee commented on a recent discussion with another physician:

I had a physician come to me and request a product that he thought he needed. Yet, in looking at actual usage, I was able to show him that he hadn't actually used that product in six months. This kept us from carrying a product that we didn't even need.

In addition to negotiating with doctors, clinical staff are often responsible for negotiating deals with vendors. We probed these relationships too, asking how the RFID system effects these interactions. According to one interviewee:

> *You go to some hospitals, and there will be an adversarial relationship with the vendors or companies that they partner with, but I really try to see it as a way to deliver additional value.*

He continued to comment on the role the RFID-generated information plays in negotiations:

> *The data has become a third person in the room….So when we sit down and we talk to vendors, I'm like, "I'm looking at this product category, and I think there are some opportunities to do something different." I'll pull up the system, and we'll look at the trends…they pretty much are open to advocating any types of changes that I recommend.*

Proposition3c. RFID-enabled information reports generate useful knowledge for staff, arming them with new information that reduces information asymmetries, and therefore power asymmetries, between staff and doctors and vendors, enabling them to collaborate more effectively.

Proposition 4c: Barcode systems generate information that is mistrusted by staff, reinforcing the information and power asymmetries that exist between the staff and doctors and vendors, challenging the staff's ability to collaborate effectively.

Impact on physical context

In the course of interviews and data analysis, we began to investigate how (if at all) the RFID systems mediated the relationship between human action and the inventory itself. Thus, we wanted to see if and how the RFID technology allowed the physical location of inventory to be adjusted or moved in an effort to mitigate the effect of the physical context on operational processes. We found that RFID did have an impact, one that was likely to become more important in the near future as new product innovations are beginning to enter the market. For instance, one hospital was beginning to pilot the use of mobile cabinets that could be easily moved around the CCL facility. By leveraging wireless technology, the mobile cabinet could continue to monitor inventory every 20 minutes and send updates to a central server wirelessly. Interestingly, the hospitals did not think that adding wireless cabinets would add to their existing fleet of stationary ones. Instead, as one interviewee noted,

> *We're not going to add cabinets. We are going to rationalize on how we use the system, and we just need to cut that number of cabinets in there. That way it will finance the mobile carts.*

By being able to move supplies around, they were able to get better service while not requiring any additional inventory. Further, another individual commented on how the mobile cabinets would allow them to put supplies closer to the patients, which would be especially beneficial for those in the direst circumstances. He said:

> *When you have a critically ill patient there is X amount of time from the time they pick up the patient until he is treated that must be met. That way, nothing bad is going to happen to the patient…there are some situations where if you fail to give the best medical attention, the patient's brain or nerve or heart might be affected. So you have to meet that standard. So [the mobile cabinets] will be key for us to deliver that type of critical care.*

Proposition 3d: RFID-enabled mobile cabinets reduce the physical proximity between supplies and procedures, reducing the need for local stores of inventory and, consequently, the total safety stock in the system, thereby improving the efficiency of the inventory management function.

Proposition 4d: Barcode systems increase the physical proximity between supplies and procedures, increasing the need for local stores of inventory and, consequently, the total safety stock in the system, thereby reducing the efficiency of the inventory management function.

The Impact of RFID on Inventory Management and Process Performance

We also wanted to understand how RFID technology differed from barcode technology in terms of the overall performance of the inventory management function. Thus, we explored issues related to return on investment and the overall impact of RFID as it compared to the barcode technology it replaced. Though each hospital had rather poor accounts of prior performance due to issues related to data quality, there were three core areas in which RFID impacted performance.

Carrying costs

The most obvious impact of RFID investment in each of the sites related to inventory carrying costs. RFID allowed the labs to lower the number of products that they were carrying and were responsible for, thereby eliminating the costs associated with managing unneeded inventory. As one individual commented, "[prior to RFID] we had to keep a lot more things on the shelf than we really necessarily needed." Another said, "instead of having 10 of something on the shelf, we send it back and now have two." In short, the information generated by the RFID system allows the hospitals to lower par levels across major product categories.

Since some of the inventory in the CCL labs was owned by the vendors themselves in consignment agreements, we were initially confused as to why lowering par levels really mattered. Yet, as one interviewee explained,

> *There's still not a dollar amount associated with it [consignment] for the actual supply sitting on the shelf…there is a management component that costs. It's the staff having to take care of it, it's having to switch out the expired, all of that.*

At the end of each month, the staff would be charged by the vendor for the products they used, but this was simply based on the difference between the on-hand product levels at the beginning and end of the month. By reducing needless inventory, CCL labs were not only able to reduce the costs associated with managing these products, they also reduced the risk of being charged for products they did not use, as it was easier to keep track of the smaller number of products.

Proposition 5a: RFID technology will reduce inventory levels and, in turn, reduce carrying costs leading to improved financial performance for CCL labs.

Charge capture

With exploding healthcare costs, a big concern for hospital managers is to ensure that patients are billed accurately. We were able to discern from our interviews that prior to RFID, there was a large concern around inventory shrinkage. Due to the contextual characteristics discussed above, it was not uncommon for a nurse to grab a handful of stents from a supply cabinet during a procedure. When the doctor was unsure about the stent size needed and when a procedure was especially urgent, nurses would grab a range of stent sizes to meet the uncertain demand and all too often forget to "sign each product out" by decrementing them from the inventory by shooting them with the barcode scanner.

Of course, if the product was then returned to the shelf after the procedure, there would be no negative impacts to the hospital. However, there was a concern that too often, the unused products never made it back to the cabinets. With the RFID system, there was no need for nurses to decrement the inventory because the RFID made it automatic. Therefore, when employees would reconcile what was used in a procedure with what was taken off the shelf, they could easily determine if there was something missing. Since the RFID system would tell when the product was taken off the shelf, managers could then determine who was working at that point and trace down which nurse removed the product from the shelf. From our many discussions, we learned that RFID had an impact in this area. For instance, one interviewee commented:

> *Before [RFID] there is no Big Brother looking at you. When you grab an item, you can put it underneath your chair or underneath your desk without feeling bad because nobody would know.*

He went on to say:

> *If somebody would know, it would be later on. So there's no urgency for me to keep it here, maybe tomorrow, a few days from now, or maybe I'll forget it. But right now you grab something, you're responsible for it. So that changes the behavior.*

As one interviewee said, "There was always potential of revenue loss if you weren't able to keep track of a particular item that may have or could have been charged to a patient." By reducing shrinkage, the hospitals were improving performance, both in terms of lowering costs and increasing revenue.

Proposition 5b: RFID technology will reduce inventory shrinkage, leading to increased charge capture and improved financial performance for CCL labs.

Inventory optimization

As we continued to investigate how RFID compared to barcode technology in enabling the inventory management function to operate more efficiently, we realized that the hospitals were after something more. They saw technology as a means for improving effectiveness, too. For instance, one interviewee commented that he was motivated by more than just lowering inventory levels and the related costs. He said:

> *What I like to look at is the right sizing or allocation of product type. So if I have $2.5 million on the shelf on any given day—do I have the right selection of $2.5 million in product? Do I have the right mix?*

His comments portray the dual challenge that inventory managers face in this context. They must not only improve operational efficiencies to reduce costs, but their number one objective is to make sure that a given product is on the shelf when it is needed. The comment above expresses this inherent paradox that challenges inventory managers in such contexts. Yet, as is evident, information technology can mitigate these contextual effects and allow inventory managers to pursue dual objectives, even if they do represent opposing forces.

Proposition 5c: RFID technology will improve demand responsiveness (or the ability to have the right product, at the right time, in the right location), which will improve operational efficiencies and enhance quality of care.

Discussion

The primary objective of our research study is to explore the fundamental impacts of the RFID-enabled systems in healthcare, looking specifically at one process – inventory management in CCLs. We conducted an extensive literature review to seek potential gaps in research. First, we sought to gain a thorough understanding of the 'contextual issues' in our research, by heeding the call of several researchers such as Johns (2006), Mowday and Sutton (1993), and Carpelli and Sherer (1991). Second, we sought to fill an important gap in literature by gaining a thorough understanding of the *interaction* of RFID-systems with the identified contextual dimensions in healthcare. Although prior research has advanced the notion of the interaction of systems and context, a systematic examination of the *process* by which such impacts occur – especially in the healthcare context, has not been given due consideration.

Consistent with the definitions of the omnibus and discrete context (Johns, 2006), our findings indicate that contextual characteristics impact the inventory management process through multiple modalities. At the omnibus context level, situational urgency places enormous burden on the inventory management function. This becomes especially salient in situations when personnel are tagged with multiple activities. For instance, nurses could be responsible for not only assisting in a procedure in an operating room, but also removing inventory from cabinets. This dual-role expectation could exacerbate the already existing tensions related to life-and-death situation in hospital settings. At the discrete context level, task variability, social structure and physical separation have enormous impacts on the inventory management function. Several different procedures could be performed in hospitals, even on the same day. Such increase in procedural (task) variability in turn increases the complexity in the inventory management function. Similarly, the existence of administration-practitioner duopoly (Yajiong et al., 2008; Kohli and Kettinger, 2004), and the resulting power-asymmetry are found to play an important role in the ordering, placement and utilization of inventory in hospitals. Our findings are also consistent with studies in other healthcare settings that found contextual characteristics impacting behavioral intentions and work practices. For instance, Hu et al. (1999) studied the physician's intention to adopt telemedicine, using the technology acceptance model (TAM). Performance expectancy and effort expectancy explained the physician's intention to use CDSS and actual use behavior, while social influence marginally impacted on physician intention. Similar results extolling the uniqueness of the context affecting physician behavior are also reported by other studies (Sillince and Frost, 1993, Bloomfield et al., 1992).

Our working assumption is that RFID-enabled systems and their capabilities, arguably, can improve inventory management in specialty hospital settings. Such settings relate to practice areas where high risk procedures are conducted and high value (greater than $2000) products are likely used. This is based on the fundamental premise that organizations can leverage the functionalities of IT resources to create capabilities, such as innovating business processes, shaping new strategy, and extending the enterprise network (Sambamurthy et al., 2003; Powell and Dent-Micallef, 1997; Zara and Covin, 1993). Adopting similar logical explanations, Braa et al., (2007) and Hanseth et al., (2006) argue that IT standards need to be tailored specifically to the healthcare context and the specific country situation. Angst and Agarwal (2009) also highlight the importance of contextual characteristics, as concern for privacy 'interacts' with arguments framing to predict adoption behavior of the system. Similarly, Miscione (2007) documents the implementation of a telemedicine system in a remote international context (northeastern Peru), and argues that for telemedicine projects to be successful the mental health model of patients (beliefs, attitudes) specific to the context should be identified and incorporated in the design.

Consistent with our working assumption, our research study shows that by using RFID in hospital settings, the collection of information across activities— those that are coordinated within a specialty process (such as CCL labs) - is automated. This improves a number of aspects in the hospital setting, because it increases the trust in the 'information representation' (sociomateriality) as compared to other legacy systems such as barcode technologies. As a result of the limited human intervention necessary for information collection, materials managers could potentially get a near real time digital representation of material flow within practice areas. This newfound visibility helps *mitigate* the negative impacts of context such as power-asymmetry and physical separation. Material managers are now fully equipped to make important inventory decisions, effect better negotiations with partners, and highlight inventory usage details with their doctors and nurses. This information trait has helped the three hospitals in our study, by consistently decreasing their inventory levels and inventory shrinkage and increasing their demand responsiveness (Dutta et al., 2007).

As is always the case with research conducted in complex organizational settings, our study has specific limitations. First, we drew on retrospective accounts of organizational situations from our interviewees. Such accounts can undoubtedly be subject to a host of cognitive biases that may distort what really happened in a particular situation. To address this concern, we tried to corroborate findings by interviewing multiple individuals about the same situation and collecting multiple types of data. Nevertheless, retrospective accounts can always lead to confounded findings. Second, the nature of our research questions, which principally sought to explore the causal linkages between the use of RFID and process performance in healthcare settings, required that we make some methodological compromises that may impact the generalizability of our results. Though our results are useful and interesting, future studies that adopt new methods with larger samples sizes may provide a deeper explanation into the complicated linkages that that connect IT use and process performance in distinct contexts. For instance, we are currently planning a longitudinal study to investigate how these linkages unravel over time in a healthcare context.

In conclusion, our findings provide practicing managers with important suggestions for improving their business practices. First, from the perspective of vendors of RFID solutions, we have provided a more detailed account of how RFID can be useful in hospital settings. By moving forward and tying these observations to quantitative measures, such managers will likely develop a more sophisticated model to explain the return on investment that future clients may get if they invest in RFID technology. Second, from the perspective of the inventory manager in a CCL lab or in a broader healthcare context, we have explicated and categorized the contextual dimensions that impact the inventory management function in these areas. These findings can assist managers as they seek to design more focused interventions to mitigate these potentially detrimental forces. In a sense, we have illuminated key levers that need to be paid attention too, so that technology can be used more effectively to adjust the task, social, and physical dimensions of a given context. Our study should also be particularly interesting to IS researchers, as it begins to dissect the causal linkages that explain how IT can create value in specific contexts. In doing so, we have begun to eradicate the black box that separates technology from the human aspects of organizing. Adopting a sociomateriality framework, this study sheds light on the mitigating influences of RFID-enabled system on the negative influences of context, thereby extending the literature on RFID-enabled systems. We have forgone past perspectives and made a point to treat materiality as an important component of organizational research (Orlikowski, 2007). We have shown how RFID shapes a distinct constitutive entanglement between the social and material aspects of CCLs as compared to barcode systems, and how these distinctions are useful for explaining performance outcomes associated with RFID use in a healthcare context.

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