MAKING THE 'MOST' OUT OF RFID TECHNOLOGY: A RESEARCH AGENDA FOR THE STUDY OF THE ADOPTION, USE AND IMPACTS OF RFID

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ABSTRACT

Radio frequency identification (RFID) technology dramatically increases the ability of the organization to acquire a vast array of data about the location and properties of any entity that can be physically tagged and wirelessly scanned within certain technical limitations. RFID can be applied to a variety of tasks, structures, work systems and contexts along the value chain, including business-to-business logistics, internal operations, business-to-consumer marketing, and after-sales service applications. As industry adoption of RFID increases there is an emerging interest by academic researchers to engage in scholarly investigation to understand how RFID relates to *mobility, organizational and systems technologies* (MOST). In this paper, we seek to make the 'most' out of RFID by proposing a research agenda to address a series of broad research questions related to how RFID technology: is developed, adopted, and implemented by organizations; is used, supported, and evolved within organizations and alliances, and; impacts individuals, business processes, organizations, and markets. As with many technology innovations, as the technical problems associated with implementing and using RFID are addressed and resolved, the managerial and organizational issues will emerge as critical areas for IS research.

Keywords and phrases: Business value, diffusion of innovations, information technology, IT impacts, radio frequency identification, RFID, technology adoption.

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Preliminary – please do not distribute. Comments from IDSc Worshop participants welcome.

INTRODUCTION

Organizations utilize modern information systems (IS) to acquire, interpret, retain, and distribute information (Huber 1991). Technological innovations in information technology (IT) continue to improve the cost-performance capabilities of organizations to perform these four basic IS tasks. For example, the Internet has dramatically altered the capability of the firm to acquire external data and to distribute it throughout and beyond the organization. Intelligent agents and knowledge management systems allow managers to interpret data and information to create useful managerial knowledge. Technical improvements in storage media allow firms to amass vast data warehouses, while ever increasing processing power allows managers to mine their data for useful information about their operations, existing customers, and potential markets. Further, advances in technology-based real-time information gathering and decision support systems promote real-time decision making and allow organizations to refine their operational performance.

Occasionally, a new technology emerges that provides a major shift in the cost-performance capabilities of one of these four basic IS tasks. *Radio frequency identification* (RFID) technology is one such technology that dramatically changes the capabilities of the organization to acquire a vast array of data about the location and properties of any entity that can be physically tagged and wirelessly scanned within certain technical limitations. RFID technology has been noted as an example of the emergence of inexpensive and highly effective *pervasive computers* that will have dramatic impacts on individuals, organizations, and society (Stanford 2003). RFID essentially allows the tagged entity to become a mobile, intelligent, communicating component of the organization's overall information internal infrastructure. In addition, the combination of the tagged mobile entity, the reader, and the infrastructure of

hardware and software that processes the transmitted data, makes RFID systems a new type of interorganizational system (IOS) that crosses company boundaries, resulting in new opportunities to transform the supply chain for real-time optimization. Such technologies are emblematic of the main theme of the 2004 INFORMS Conference on Information Systems and Technologies, which focused on *mobility, organizational and systems technologies* (MOST), where the ideas in this paper were initially presented. [1]

As the various entities associated with business processes become increasingly mobile in the presence of RFID, the ability of the organization to monitor the location, history, and changing states of these tagged entities increases the level of *process freedom* referred to by Keen and Mackintosh (2001). This further increases the flexibility, efficiency, and subsequent value created by these processes in the presence of innovative technologies. Indeed, several major buyers and retailers have come to recognize the potential usefulness of RFID technology as a way of tracking physical goods across the supply chain, which has led them to mandate its adoption to their trading partners (Bacheldor and Sullivan 2004). The potential scale benefits that accompany this mandate have accelerated the potential usage of RFID, along with a corresponding increase in attention from the popular press. Nevertheless, in spite of the attention and potential of RFID, the capabilities of the new technology have also engendered anxiety from certain segments of society, where concerns about personal privacy are rife. Consequently, there is an emerging interest by academic researchers to engage in scholarly investigation regarding

[1] For additional information on the positioning of the current research, the interested reader should refer to the recent surveys on information systems research in *Management Science* (Banker and Kauffman 2004), and on economics and electronic commerce in the *International Journal of Electronic Commerce* (Kauffman and Walden 2001). Based on the conceptualization of directions for research in these works, RFID-related research fits well with some of the other primary themes that have been studied in the past ten years. These include interorganizational information systems, technology impacts and business value, ownership and information sharing problems, decision support and decision making, organizational and strategic transformation, technology demand and supply, and systems integration with web-based systems and other infrastructural systems within the firm.

the adoption, usage, and impact of this technology on individuals, organizations, supply chains, and markets—in order to make the 'most' out of the technology.

Although it represents a specific instance of IT, RFID is generic enough in terms of its MOST capabilities and potential impacts to be of interest to researchers across a number of fields. They include mechanical and electrical engineering (Glidden et al. 2004), systems and software engineering (Juels 2004), health management (Thompson 2004), operations and supply chain management (Angeles 2005), marketing and customer relationship management (Compton 2004), ethics (Murray 2004), and legal and public policy (Flint 2004). The wide assortment of RFID-related issues associated with these fields is interesting and relevant for users and society, even though some might argue that they do not fall within the traditional domain of research within the IS research community as it pertains to the *IT artifact* (Orlikowski and Iacono 2001). In contrast, if one views RFID technologies as the basis for *IT-reliant work systems* (Alter 2003), their study becomes very central to IS research. [2]

We believe that for the IS researcher, RFID technology represents *a type of IT artifact that is embedded in IT-reliant work systems*. With this characterization in mind, we believe that

[2] Orlikowski and Iacono (2001, pp. 121-122) state that the "the field of Information Systems (IS), which is premised on the centrality of information technology in everyday life, has not deeply engaged its core subject matter—the *information technology (IT) artifact* [italics added for emphasis]. … IS researchers tend to focus their theoretical attention elsewhere, for example, on the context within which some usually unspecified technology is seen to operate, on the discrete processing capabilities of the artifacts (separate from how they operate in context), or on the dependent variable (that which the technology presumably changes as it is developed, implemented and used). … As a consequence, IT artifacts tend to be taken for granted or are presumed to be unproblematic." Alter (2003, p. 367), who also quotes Orlikowski and Iacono (2001), defines an IT-reliant work system as "work systems whose efficient and/or effective operation depends on IT." IS researchers should be undeterred by the categorizations and discussions of what is within and outside "the box" relative to RFID. Our view is that RFID technology presents a number of interesting issues at the nexus of mobility, organizations, systems, and technology, and we should make all efforts to define how the technology should be understood, invested in, implemented, managed, refined and integrated within the organization and across its business boundaries to achieve the greatest possible business and social value.

a number of research issues correspond closely to the *nomological net* [3] defined by Benbasat and Zmud (2003) – augmented by Alter's (2003) more inclusive thinking – and are therefore appropriate for IS research. Benbasat and Zmud note that the IT application creates opportunities for new tasks or may support existing tasks that exist within a given structural setting, which, in turn, exists within a broader context. For example, RFID (as an *IT artifact*) provides the opportunity to redesign traditional warehouse packing and shipping activities (the *tasks*) for a business-to-business vendor-managed inventory system (the *structure*), where there is relentless cost cutting to combat global competition (the *context*) and the need to refine the overall capabilities of the operation (the *IT-reliant work system*).

We believe that the nomological net defined by Benbasat and Zmud (2003) provides a useful lens for categorizing a variety of IS research issues associated with RFID. We also heartily encourage the reader to consider Alter's (2003) remarks, as well as a number of the articles that motivated his reconceptualization of relevance in IS research in terms of IT-reliant work systems (especially Trist 1981).[4] Specifically, this paper proposes a research agenda for studying RFID to address a series of broad research questions related to:

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[3] The idea of a "nomological net" was first developed by Cronbach and Meehl (1955) as a means to ensure construct validity in psychological research and testing. The Web Center for Social Research Methods at Cornell University defines a *nomological net* as *the representation of the concepts and constructs of interest in a study, their observable manifestations, as well as the relationships among and between these*" (see www.socialresearchmethods.net/kb/nomonet.htm.) Today, it is also viewed as a means to effectively discriminate what should be considered a "lawful" area of study in an area based upon a set of agreed to conventions.

[4] For more on the *work systems perspective*, the interested reader should see Bostrom and Heinen (1977a and 1977b), Davis and Taylor (1981), Land (2000), Mumford and Weir (1979), Mumford (2000), and Pasmore (1985). The insights offered by Trist (1981) are especially useful. He refers to several kinds of work systems that should be helpful to researchers who are looking to clarify the scope of the RFID-related research activities that they are undertaking. These include: *primary work systems* in which RFID technology investments are made and uses occur, *whole organization systems* in which the business value impacts are ultimately felt leading to higher organizational performance, and *macrosocial systems* in which social welfare impacts occur leading to the recognition of both positive and negative welfare-transforming impacts.

1. how RFID technology is developed, adopted, and implemented by organizations to solve specific problems or create new business opportunities,

2. how RFID technology is used, supported, and evolved within business processes, organizations and strategic alliances, and

3. how RFID technology impacts individuals, business processes, organizations, and markets.

As with many technology innovations, we believe that as the technical problems associated with implementing and using RFID technology are addressed and solved, the managerial and organizational issues will emerge as critical areas for IS researchers to address. A research agenda for RFID aligned with pre-defined core properties of the IS discipline and the nature of IT-reliant work systems seems appropriate at this time.

The organization of the paper is as follows. We begin in the next section with a brief overview of the important technical aspects of RFID. Because RFID can be applied to a variety of tasks, structures, work systems and contexts, we introduce a framework in Section 3 to categorize the *tagable entities* and the obstacles to value associated with various tasks within four different *structural settings* of RFID usage along the value chain. These are *business-to-business (B2B) logistics*, *internal operations*, *business-to-consumer (B2C) marketing*, and *B2C after-sales service*. By applying the research questions outlined above to these four structural settings, we are able to propose a series of research issues and themes in Section 4 to provide a roadmap for IS researchers to investigate the adoption, usage, and impact of RFID as an IT artifact. We conclude in Section 5 by putting research on RFID within the broader IS research context, as well as in an interdisciplinary context.

THE TECHNICAL BACKGROUND OF RFID

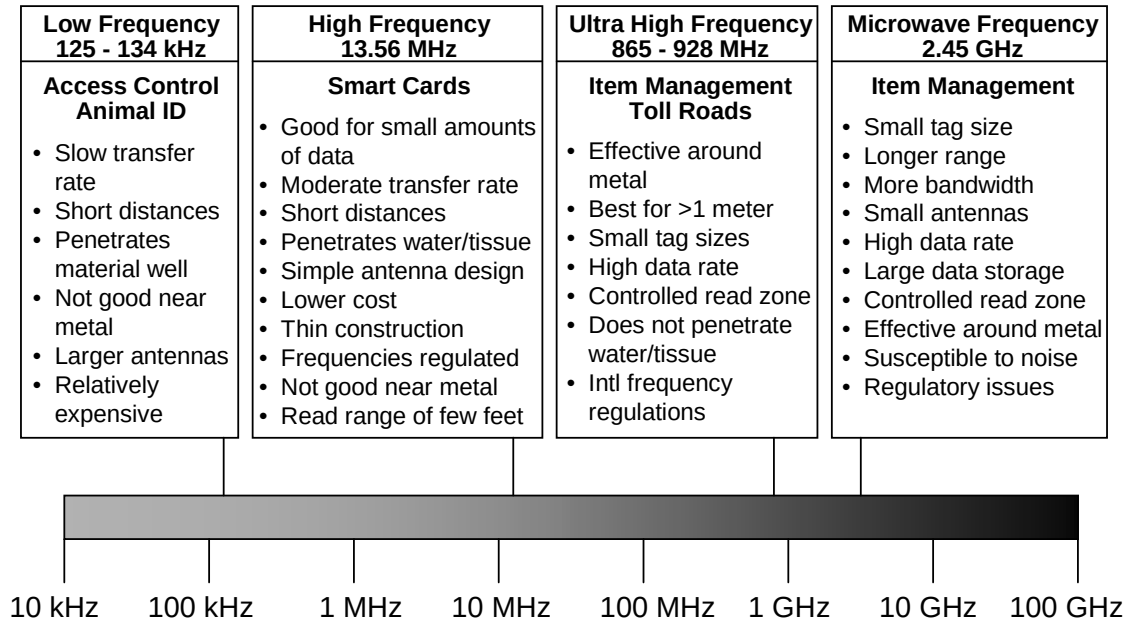
RFID or *radio frequency identification* is a wireless tracking technology that allows a

reader to activate a transponder on a radio frequency tag attached to, or embedded in, an item, allowing the reader to remotely read and/or write data to the RFID tag (ITAA 2004). This type of *passive tag* draws power from the reader and is cheaper and smaller than active tags, which have a battery used to broadcast the signal to the reader. *Semi-passive tags* use an internal battery and the signal sent from the reader to generate the power is required to transmit a signal. RFID is an extension of existing bar code technology and is fully integrated with the EPCglobal Network (www.epcglobalinc.org). The EPCglobal Network was developed by the Auto-ID Center at MIT and is a joint venture between EAN International and the Uniform Code Council (UCC) to develop, support, and promote the global adoption of the standardized Electronic Product Code (EPC) and RFID. The EPC tag itself is made up of a microchip containing the EPC and an attached antenna.

Depending upon the size of the tag and the frequency used, the current range of reception, or *read range*, of the reader is limited. As of late 2004, tags operating at the worldwide-approved 13.56 MHz high frequency (HF) level had a maximum range between the tag and reader of about one meter. At that time, pilot tests using the 915 MHz ultra high frequency (UHF) level had a range up to about 60 feet under controlled conditions. However, tags utilizing higher frequencies have a limited storage capacity and are currently prohibited from being incorporated into RFID applications in Europe (Brewin 2004b). In general, tags operating at low frequencies of around 125 kHz use much less power and have a limited read range, but are able to penetrate most non-metallic substances including liquid. UHF tags, operating in the 900 MHz range, use more power, are less expensive, and are less likely to pass through most materials. Due to the combination of tag size, read range, ability to control the read zone through directional antennas on the reader, potential to drive down tag costs, and the

beneficial read rate, most of the efforts to promote RFID at the item or pallet level currently are directed at the UHF 915 MHz tags. (See Figure 1 for a summary of the most prominent types of tag frequencies.)

Figure 1. Most Popular RFID Read Range Frequencies



Industry and public interest in RFID technology took a major leap forward in June 2003 when Wal-Mart mandated its largest 100 suppliers begin using RFID tags on shipped items at the pallet level by January 2005 (Roberti 2003). Analysts have predicted that Wal-Mart could save over $8 billion annually using RFID by reducing the labor costs of scanning items, reduction in out-of-stock items, and improvements in the supply chain and reduced item theft (Haley 2003). Indeed, it has been noted that "theft costs Wal-Mart an estimated $2 billion a year; a legitimate business of that size would rank #694 on the *Fortune* 1,000" (Boyle 2003). For this reason, the long-term notion of tagging every item in the store is appealing to many retail businesses.

Other major buyers soon followed Wal-Mart's lead in requiring suppliers to implement RFID, including the United States Department of Defense (DoD) and Target (Bacheldor and

Sullivan 2004). While these buyers have found that these mandates lack some credibility due to the technical difficulties and costs of compliance, many of their trading partners nevertheless are working to implement at least some pilot projects using RFID within the mandated timeframe.[5] Interestingly, we have also seen other technologies, such as electronic data interchange (EDI), for which a similar process of buyer-initiated mandate for adoption has occurred (Riggins, Kriebel, and Mukhopadhyay 1994). With continued pressure from these major buyers, most informed observers of emerging technologies around the world seem to believe that the cost of RFID tags will drop dramatically (e.g., Frost and Sullivan, 2004; Nikam and Satpute 2004). However, to be widely used, tag costs will need to drop from their current level of $0.50 each to about $0.05 each, with a further reduction to less than a penny within five to ten years (Singer 2005; Vollmer 2004).

As we initiated our own research project on RFID at the University of Minnesota Carlson School of Management's MIS Research Center in 2004, most organizations were focusing on utilizing passive UHF tags that have a per unit cost of under $0.50 when purchased in volumes of a million tags or more. In most cases, these tags currently have an effective read range of less than 20 feet. To make RFID tags cheaper is easily recognizable as a chicken-and-egg technology adoption and diffusion game. In order to make the tags cheaper, it will be necessary for market demand to dramatically increase, creating additional volume-based manufacturing results. However, for the demand to materialize, RFID tags will need to be cheaper and more effective than they are currently. This situation suggests that there will be considerable inertia that will hold up the move to readily available, high functioning, cheap tags capable of delivering high ROI when implemented in the appropriate work system contexts.

[5] In addition to Wal-Mart, the other retailers that announced plans during 2004 for mandated supplier adoption of RFID technologies included Target, Best Buy, Albertson's, Tesco, Metro AG, Carrefour and Ahold, among others (Vollmer 2004).

RFID APPLICATIONS ALONG THE VALUE CHAIN

There is a wide assortment of potential RFID applications that can be used across the value chain. To help frame a series of research agenda items related to RFID, we will briefly consider a series of applications at four different locations or *structural settings* in the value chain: *B2B logistics*, *internal operations*, *B2C marketing*, and *B2C after-sales service*. In thinking about potential RFID applications, it is useful to broadly consider the potential tagable entities associated with business processes or tasks within each particular value chain position. Tagable entities can include different types of mobile tools and equipment, movable parts of stationary equipment, manufacturing component parts and finished products, packaging associated with other entities (such as pallets or cargo crates), the people involved in the tasks, the vehicles that transport other entities, documentation or product promotional materials, and stationary entities that change states over time. In addition, as the technology is in its mass commercialization infancy, there are a variety of obstacles to realizing value in the value chain. These obstacles can be managerial challenges, organizational barriers, technical limitations, economic pitfalls, and legal hurdles, some of which are under the control of the organization while others are determined in the external environment. Figure 2 highlights some of these tagable entities and obstacles to value for the four identified structural settings.

B2B Logistics

Most organizations must deal with inbound and outbound logistic arrangements with external alliance partners. Customers receive pallets of goods from suppliers in a warehouse or other storage facility that must be tracked prior to receipt, as they are received through the facility door, and as they are moved within the warehouse. Buyers receive EDI-based *advanced shipping notices* (ASNs) of goods from the supplier that should match a prearranged purchase

Figure 2. Tagable Entities within Four Structural Settings across the Value Chain

Structural Setting within the Value Chain	B2B Logistics	Internal Operations	B2C Marketing	B2C Service
Task Related Tagable Entities Equipment Parts Products Packaging People	Transport vehicles Interface vehicles Vehicle operators Individual items Bundled items Item handlers Cargo containers	Transport vehicles Vehicle operators Individual items Bundled items Item handlers Mobile equipment Machine parts Documentation	Transport vehicles Individual items In-store demos Sales personnel Customers Item handlers Promotion items	Transport vehicles Individual items Service personnel Service equipment Customers
Obstacles to Value Managerial Organizational Technical Economic Legal	Trading partner compliance Governance and ownership Cost/distance tradeoff RF-unfriendly packaging Pallet transparency Off-track items Standards inconsistencies Labor privacy	Application integration Cost/distance tradeoff RF-unfriendly packaging Reader costs Reader interference Pallet transparency Off-track items Dependency risks Labor privacy	Cost/distance tradeoff RF-unfriendly packaging Reader costs Reader interference Labor privacy Customer privacy Customer sabotage Mishandled pro-motional items Data flood	Cost/distance tradeoff Retrofitting equipment Labor privacy Customer privacy User alterations De(activation) Data flood

order. When the pallet arrives, the internal contents must be matched either visually or via bar code to ensure the shipment is as expected. When the supplier labels the outbound pallet or individual items in the pallet with an RFID chip, the contents of the shipping container can be verified immediately upon receipt. Movement of the cargo throughout the facility can also be tracked by appropriately-placed readers. The operation can be further streamlined by having forklifts or other transport vehicles tagged to ensure they are in their proper position when they are required for transport. Similarly, to support real-time process management and decision making, vehicle operators can be tagged to ensure they are available and in position when needed. Furthermore, in the current era of increased attention to physical and information

security, ports are seeking ways to use RFID readers to read cargo containers coming into and departing from the port to ensure proper contents. [6]

When linked to the EDI system, an overall work system founded on RFID technology capabilities will be able to efficiently manage incoming and outgoing cargo containers. From a B2B logistics perspective, we can generically view tagable items as including transport vehicles such as long distance trucks and railroad cars, as well as short distance bins riding on conveyor belts and golf cart-sized factory vehicles. Similarly, interface vehicles that move cargo from one transport vehicle to another could be tagged to ensure proper positioning according to schedule, thereby further enhancing control in MOST settings. Vehicle operators and personnel required to lift and maneuver the goods may be tagged using an RFID-based badge. The tagged entity or object in the transportation business process could include individual items, bundled and bulk-packaged items, and specialized cargo containers of various sizes. Since transportation-focused business processes are settings in which business items and objects are highly mobile, RFID is especially well suited for the purpose of creating high performance work systems.

There are a host of issues that represent barriers to realizing the *potential value* from applying RFID technology to these tasks within a B2B logistics structural setting, resulting in *realized value* levels that may be disappointing from an investment standpoint (Chircu and Kauffman 2000; Davern and Kauffman 2000). Researchers examining IOS usage such as EDI have learned that business process redesign coupled with the technology implementation helps to maximize benefits (e.g., Shi and Doll 2001, Turner 1995). Similarly, updating logistics processes to insert automatic remote scans of shipped goods may require a reorganization of

[6] Clearly, transportation, logistics and shipping are among the most interesting and potentially valuable application areas for RFID technology. We refer the interested reader to GlobalManufacture.net (2002), Morgan (2004), Stanford (2003), Valentine (2003), and Williams (2004). We expect to see empirical and case study research that will reveal the extent of the business value created by RFID in this context.

processes on *both* ends of the supplier-customer link. Gaining the cooperation of external trading partners to tag items and pallets prior to shipment is an economic challenge (Riggins and Mukhopadhyay 1999).

Further, full realization of the value of this technology requires wide adoption among trading partners that often will require mandates or subsidies necessary to encourage full adoption. Ownership of equipment and data, plus the equitable distribution of technology benefits further complicates the interorganizational adoption of the technology. Some of the key drivers of the complexity and difficulty of technology adoption under these kinds of circumstances involve non-contractible elements of technology investment (Bakos and Nault 1997); the negotiation of post-investment value sharing (Han, Kauffman and Nault 2004), uncertainties associated with the technology becoming a recognized standard (Kauffman and Li 2005), difficulties in the transmission of information about the business value of the technology in its structural setting (Au and Kauffman 2003; 2005), and the coordination of adoption involving different kinds of organizational participants (Au and Kauffman 2001).

Across the value chain, firms must deal with the economic difficulties of this new technology. Specific process needs will determine the appropriate cost/distance tradeoff regarding the radio frequency employed, line-of-site reading requirements, number of readers necessary, and tolerance and handling of "off-track" items that may require human intervention. Also, RF-unfriendly packaging such as metals or liquids may require innovative packaging to meet or exceed the technical requirements for clear radio transmission. In addition, it will be necessary for RFID vendors to settle on standards for economical, small and lightweight RFID readers (Reva Systems 2005).

B2B partnerships can often span international boundaries, which make international

standards agreements critical. For example, most countries have adopted the 13.56 MHz frequency for high RFID frequency systems. However, Europe currently utilizes 869 MHz for UHF while the United States uses 915 MHz. Japan, on the other hand, is in the early stages of considering opening up UHF frequencies for RFID usage, and has only recently seen many of its corporations agree on domestic standards for embedding RFID in products (as reported by SiliconTrust.com 2003). Because UHF is used for a variety of purposes in different countries, international agreements may be years away.

Finally, potential infringement of labor privacy rights and violation of labor union agreements may exist at all phases of the value chain (Gilbert 2003). Tagging personnel or equipment operated by personnel may be seen as excessive oversight that may result in organizational challenges to use of the technology. Indeed, many observers of the development of RFID technologies fear that this is another step in the direction of a "surveillance society."

Internal Operations

Many companies are running pilot tests to learn how RFID can be used within their internal physical facilities. Within the manufacturing factory, RFID can be used to coordinate the flow of multiple raw materials to the point of assembly to ensure a smooth assembly process with no waiting for materials. Other efficiency benefits can be gained by tracking manufacturing equipment usage which leads to smooth workflows and the elimination of manufacturing bottlenecks. Vehicles being assembled in an auto manufacturing plant are tracked as they move through a series of assembly processes at different stations in the plant. The tag tells the reader the specific operation that needs to be done at each station.

Several airlines are using RFID to track bags being routed through the air transport system to improve security and reduce the number of lost bags. Delta Airlines, for example,

handles 70 million pieces of luggage each year overall. Its senior management believes that there will be a significant return on investment from RFID since the airline currently spends tens of millions of dollars locating 800,000 misdirected bags each year (Brewin 2004a).

Further, sensor-equipped tags can monitor the environment surrounding perishable items and maintain a history of environmental changes. For example, tagged meat being transported from a packing facility or flowing through a distribution center can be monitored for temperature readings to detect potential spoilage conditions and ensure food safety. When spoilage does occur, having the information available that is supplied by the tags can minimize the amount of meat that must be discarded, as well as protect consumers, by more accurately pinpointing the precise portions of a shipment that were subject to spoilage (*FoodProductionDaily.com* 2004; Ponemon 2004).

Organizations can tag expensive pieces of equipment such as PCs, laptops, and tablet computers to maintain a regular asset inventory system. This greatly reduces the time required to conduct asset inventory checks allowing them to be done more often or in real-time, and also setting the stage for real-time decision support and business process value enhancement. The system can also track maintenance activity on these assets. Large hospitals are currently rolling out RFID technology to keep track of expensive medical equipment to be sure the item is in the right place at the right time (Bazzoli 2004).

In addition, the savings of avoiding lost or stolen medical equipment, as well as reducing periodic costs for leased technical equipment, are substantial. In this context, utilizing much more expensive and technically-capable tags becomes economically feasible. Similarly, equipment being checked out of a tool crib can be automatically recorded as being removed rather than needing a clerk to scan items and check them out. Organizations can make better use

of the tools since they'll know who has what tool when.

In addition to expensive equipment, organizations can use RFID to keep track of other important, easily misplaced items. Libraries are using RFID to tag individual books to eliminate lost books and speed the checkout process (Gilbert 2004). Offices that must maintain physical documents, such as legal offices and medical offices, can tag individual binders and folders to speed the time required to locate these physical items.

Being able to track the location of employees can boost human resources management. At a major scooter assembly plant in India, buses loaded with workers wearing RFID-enabled employee badges are scanned as they pass through the gates prior to the commencement of the next work shift. As the bus pulls up to the assembly plant, human resource management software calculates the efficient use of those employees based on their skill levels and the tasks requirements for the upcoming shift. As employees disembark from the buses, they are immediately assigned workstations and their assignments for the next eight hours are mapped into a larger workforce planning model for the effective operation of the plant. In a similar manner, prison facilities are now using RFID-tagged wristbands to monitor and control the location of prisoners (Best 2004; Roberti 2002). Within one's internal operations, then, there are several generic tagable entities that can be identified. They include transport vehicles, individual and bundled items, item handlers, mobile equipment and assets, machine parts on stationary equipment, valuable documents, and people.

In addition to many of the barriers to value identified for B2B logistics, realizing the full potential of this technology within the organization's internal operations will require costly integration with existing enterprise systems applications and likely business process redesign (Reynolds and Lynch 2004). Other major economic expenses include the number and

placement of readers within the organization's facility, and reader interference from other electro-magnetic radiation (Intel Corporation 2004, Sullivan 2004).

Organizations must be aware that redesigning processes will result in a dependency on the technology that increases the risks when the system breaks down and demands an extreme level of reliability. In addition to concerns over employee privacy rights identified previously, organizations must also be alert for potential sabotage of the system from employees and other tagged individuals.

B2C Marketing

The opportunities to use RFID technology combined with personalization technology for B2C marketing are both compelling and problematic. Retailers that offer frequent customer perks cards are tempted to tag the cards so that customers can be identified when the customer enters the store. Being able to track that a customer spent ten minutes in Aisle 6 before moving on to spend fifteen minutes in Aisle 4 creates new marketing opportunities. Fusaro (2004) demonstrates the potential interest of clothing retailers to tag products that will be sold and subsequently worn by customers.

Store shelf demos can transmit information to the centralized information system about changes in their state due to usage by potential customers. Sophistication of use and skill level by potential customers, length of usage of the demo, and depth of use of demo functionality can all be used to generate a personalized sales promotion to the potential customer. Further, by tagging promotional materials, readers can note that a particular customer removed a specific product flyer from the rack and can activate follow-up marketing at a later time. Tagable entities in this structural setting include some transport vehicles, individual retail items, in-store demos and other promotional material, customers, sales personnel, and item handlers.

In addition to the barriers to value creation that we identified previously, retailers must secure customer privacy in both fact and perception. If there is a perception of possible violation of privacy, potential customer sabotage of the system must be considered. Highly personalized activities of this type are sure to result in a flood of data that will require marketers to employ powerful data mining capabilities (RSA Laboratories 2005).

B2B Service

Finally, post-purchase service opportunities present additional issues related to balancing customer service and privacy. When making physical service calls on items purchased at an earlier date, maintenance personnel can save considerable time by scanning live tags on the goods to determine date of purchase, warranty status, potential abusive use, and problem diagnostic details. These opportunities for improved service generate considerable anxiety as individuals worry that mobile units may scan peoples' homes from the neighborhood streets to determine what items are inside their homes. Consumer groups are pressing for legislation to ensure that tags are appropriately deactivated at the time of sale to ensure that firms are not tracking the use of after-sale items or tracking the movements of people with live tags still on their person (CASPIAN 2003). While the capability to read tags from a distance is quite limited, continued improvements in the technology will further complicate the legal questions (Fusaro 2004).

RESEARCH ISSUES REGARDING RFID

In accordance with our framework in Figure 2, we now highlight a series of research issues and questions centered on our three board research themes of the adoption, use, and impacts of RFID.

Developing, Adopting and Implementing RFID within Organizations

RFID technology is constantly improving. Even so, there are currently many limitations of this technology related to the ability of the signal to pass through certain materials including human and animal tissue, liquids, various metals, and other types of packaging materials. The ability to read the signal at certain distances is related to the size of the antenna on the transmitting tag and, therefore, the size and cost of the tag itself, the frequency being used, and the material the signal must pass through. Further, getting an accurate reading of the signal may be hampered by the close proximity of other tags potentially limiting the number of different items that can be in the same container or that can be read at the same time. In addition, the value of tagging mobile items may be diminished if there is a limit to the speed with which the item must pass the reader in order to be read accurately. Understanding the limitations and capabilities trajectory over time is critical for the appropriate rollout of this technology.

The development of standards for RFID technology is critical for rapid, widespread diffusion of the technology. Fortunately, however, vendors and users are beginning to cooperate with standards development bodies and one another to evolve RFID standards to ensure adoption (Edwards 2003). With the limited bandwidth that is currently available to reserve for this technology, different countries are vying to promote their pre-existing RFID frequencies. International cooperation of standards development will be critical to promote uniform global usage.[7] An example of such cooperation is reported by Kivikovski (2003), who showcases

[7] A useful source for references on technology standards issues in the RFID context can be found at RFIDa.com, www.rfida.com/apps/standard.htm. The references cover a range of industry groups and standards that should be helpful for the interested reader. They include the Automotive Industry Action Group, the Unites States Department of Defense, Wal-Mart, EPC Global, Intermec, and the International Standards Organization, as well as the proprietary technology interests of Texas Instruments, Sony, and Phillips.

efforts that are underway to develop standards for auto industry uses of RFID tags via the Auto-ID Academic Alliance.

Closely related to this issue are the factors that lead to declining tag prices resulting in wider adoption. The competitive structure of the RFID industry will influence the pricing structure of both readers and tags over time. An interesting issue to consider is the role of *network externalities*—more specifically, *indirect network externalities*—in the pricing of these complementary goods (Economides 1997). If the same vendor supplies both readers and tags, then the vendor may wish to price one of the goods artificially low to increase demand in the other good. Video game manufacturers know that by pricing the platform devices artificially low, they can make up the difference with higher priced games—especially when they possess near monopoly power in the marketplace. What is important here is whether games can be played on multiple platforms. For RFID, will tags be readable using readers from multiple vendors or only from a proprietary seller?

Similarly, *direct externalities* can be either positive or negative, depending upon whether the users are cooperative or competitive. The traditional view of externalities is that the network exhibits a *positive network effect*: the more entities which use the technology, the more valuable it is to belong to the network. For RFID, we also can expect that as more companies adopt the technology, the more valuable it will be to use it. However, researchers have identified that competitive or negative externalities may exist when a major buyer introduces usage of the technology to a set of users who do not communicate with each other (Grover and Segars 1999; Riggins and Mukhopadhyay, 1999). For example, when a major auto manufacturer promotes EDI with its set of suppliers, a given supplier would like to be the only one using the technology with that supplier in order to gain more strategic benefits. As more competitors are expected to

adopt the technology the strategic benefits should be less (Riggins, Kriebel and Mukhopadhyay 1994). A similar effect should exist for buyer-mandated RFID usage (Clemons and Wang 2000). Furthermore, it is not clear whether RFID is a technology that can be implemented for competitive advantage through early adopton, or whether RFID must be adopted out of *competitive necessity* (Clemons and McFarlan 1986)—in other words, as a *hook-up-or-lose-out proposition*—to remain in business with a forceful customer, or neither.

Understanding and communicating the potential value of IT is a primary concern for managers with any new technology. In a B2B structural setting, it is important to understand who will gain what benefits. Gebauer and Buxmann (2000) note that is it is not always clear who will benefit from the B2B implementation of EDI systems. Several studies have been done to develop methods of valuing the investment in EDI (e.g., Hoogeweegen and Wagenaar 1996, Hoogeweegen, Streng and Wagenaar 1998, and Giaglis, Paul and Doukidis 1999). Similarly, methods and tools need to be developed to estimate the business value of RFID in order to help develop the overall business case for the technology.

Another aspect of RFID technology that creates tensions among senior management decision makers who are interested in high ROI for their investments is its nature as *technology infrastructure*. Although many of the business press articles that we have read suggest that RFID has some "plug-and-play" qualities and will transform business capabilities from the pallet level up, the reality is probably somewhat different—and this provides interesting opportunities for new research to weigh in with new insights. Infrastructure technologies create *real options* for additional follow-on investments in business applications later; they may not, in and of themselves, be the primary drivers of business value.

To illustrate this, we ask the reader to revisit Figure 2, and note the manner in which the

implementation of RFID facilitates data collection about entities at various places in the value chain. Critical to the creation of this value, however, is that there must be business process-centered software applications that take the data, and transform it into managerially useful information. While this might not be a major concern if there were only a small amount of data collected by an RFID-supported work system, however this technology will likely generate a *massive* amount of new information. How will such data be leveraged? What new applications will be necessary to unlock their strategic and tactical value? The real option perspective suggests that this kind of technology capability—the infrastructure qualities of RFID investments especially—will have a beneficial effect on subsequent technology investments. They will bear option value, which must be considered when developing the business case for any IT that provides opportunities for optional follow-on investments (Benaroch and Kauffman 1999, 2000).

RFID will create additional challenges regarding the readiness and capabilities of suppliers in buyer-supplier relationships as evidenced by Wal-Mart's attempts to mandate adoption (e.g., Sullivan 2005). It is widely known, for example, that Wal-Mart's RFID initiative was undertaken while EPCglobal was still in the midst of sorting out the final details of it second generation standard, involving better performance for read/write capabilities and transmission. Most notably, EPCglobal was pushing for the acceptance of <u>one</u> global standard. We have seen elsewhere with global diffusion of digital wireless telephony that the presence of a unified standard tends to lead to more rapid adoption and higher assessments of value in the marketplace (Kauffman and Techatassanasoontorn 2005).

In the absence of clearly understood or unified standards, most organizational adoption will be negatively impacted by decision makers' uncertainty. This will ultimately lead to what economists (e.g., Stiglitz and Weiss 1981) and accounting theorists (Kaplan 1986) have called

the *underinvestment problem.* Applied to RFID technology, the underinvestment problem suggests that profit-maximizing firms will invest less than the socially-optimal amount of capital, leading to a less-than-desired level of new business value (and social welfare). Thus, an important aspect of the research that should be conducted on RFID should span the firm-to-market link. At the firm level, it is critical that we determine how to construct the appropriate incentives to help ensure that RFID investment practices are effective or "right-sized"—in the words of Aron, Clemons and Reddi (2005). From a market perspective, it is critical that RFID technology be properly sponsored, so that value-rational subsidies and value-sharing arrangements can be effected leading to widespread market adoption. Failure to communicate effectively with the market about the future trajectory of RFID technology (e.g., in terms of vendor capabilities, the likelihood that a proposed standard will take hold, or the decline in RFID tag costs) will lead to information transmission difficulties at the market level (Au and Kauffman 2005), reducing the likelihood that the technology will diffuse as rapidly as is socially optimal.

Recent research has begun to examine the adoption of RFID within a consortium setting. Yang and Jarvenpaa (2005) examine the characteristics of individual organizations that make up the consortium and ask how a consortium member's collective trust of consortium members is based on previous experience with the consortium. Quaadgras (2005) examines what firm characteristics impact the firm's interest in joining an RFID consortium. The findings show that the propensity to form alliances and the extent to which slack resources are available leads to more alliance formation and membership.

We now summarize a series of research questions related to the development, adoption, and implementation of RFID technology that researchers and their corporate sponsors and business partners should examine. (See Table 3.)

Table 3. Research Questions on Developing, Adopting and Implementing RFID

ISSUE AREAS AND RESEARCH QUESTIONS ON RFID
Understanding the Technical Capabilities and Limitations
o How does radio interference by the physical items (solids, liquids, etc) impact the potential application of this technology within the supply chain? o What are the technical difficulties of reading across organizational boundaries and how might interface standards emerge? o What limitations exist for the reading of tags in a mobile environment? How fast can an item be traveling and still achieve an accurate tag reading? What is the physical proximity margin of error? o What is the rate of technical advancement in terms of RFID signal fidelity over longer distances?
Understanding the Role of Standards for the Proliferation of RFID
o How should RFID standards development organizations (SDOs) be structured? Who determines membership? The role of members? o How should international standards best be coordinated? How will they interact with domestic standards? What can and should be done to harmonize the two? o What is the role of large developing countries that have a potentially large critical mass of users that could impact externalities? Are there likely to be regional standards or industry-specific standards? o What is the appropriate role for companies in standards setting? How do individual companies with proprietary standards intentions impact the development of standards? o How can SDOs reduce implementation complexity and promote RFID investment risk management? o What is the market risk to an organization of being stranded with an obsolete RFID standard? o How do standards impact the reduction in cost of tags and readers over time?
Developing the Business Case for RFID Adoption
o What exactly does this technology include? How should the overall investment project be bounded? o How should an appropriate business case be constructed? What parts of the organization potentially can and should be affected? o How can a business case be developed under uncertain market and technical conditions? o What future options does establishing an RFID infrastructure create? Is RFID real option bearing? o How do we convince other internal and external stakeholders to move ahead? o Must the business case involve using RFID both inside and outside the organization? o What is the role of senior management, individual champion or change agent in promoting RFID?
Understanding the Pattern and Dynamics of Adoption
o What factors facilitate adoption of RFID within the firm? Within the interorganizational context? o How important is the installed base of RFID users for promotion of this technology? What is the nature of externalities in this context? o What is the role of mandates and subsidies to entice trading partners to adopt this technology? What is the timing of these actions and to whom should they be directed? o What is the role of a major player that promotes adoption? How might they incentivize partner R&D in this technology? o Can the technology be implemented in stages? What are the standard "chunks"? In what order? o How long does it take to implement RFID technologies and when can value begin to be generated? o Will RFID be subject to underinvestment? What can be done to mitigate this for social welfare? o How are patterns of adoption of RFID similar or different than other technologies? Why? o Are traditional IT adoption research paradigms, such as the technology acceptance model (TAM) and the diffusion of innovations theory, appropriate in this context? o What new adoption paradigms will be appropriate; for example rational expectations adoption theory involving the dynamics of standards uncertainty, market signaling and information sharing; informational cascades, rational herding theory and other behavior economics theories of adoption?

Using, Supporting, and Evolving RFID within Organizations and Alliances

Research in EDI usage has shown that integrating EDI with process redesign results in many more benefits than EDI alone (Clark and Stoddard 1996, Riggins and Mukhopadhyay 1994). Similarly, RFID will require considerable process redesign at all places in the value chain where the technology is applied. Related to this, Davern and Kauffman (2000) show that the managerial environment and the political climate within the firm will impact the extent to which the firm achieves what Weill (1992) calls *conversion effectiveness* when implementing new systems. Similar studies that deal with conversion effectiveness are required for RFID usage.

Clearly, an important element of realizing value from RFID technology will be with the integration with other internal and external systems. Since RFID is an emerging technology, most observers expect that the standards associated with it will migrate over the course of the next several years, as the support for different technological capabilities improves. In this context, it is important to consider the kinds of costs that will be associated with such systems integration efforts. We expect there to be new issues in two areas, similar to what Dai and Kauffman (2005) have discussed in the B2B electronic market technology context: *cross-application integration* and *cross-platform middleware connectivity*. The primary issue with cross-application integration will be the extent to which today's systems are capable of handling the new real-time capabilities of the potentially enormous data stream produced by next-generation RFID-reliant work systems. We recognize the potential for new intermediaries and infomediaries to supply systems integration and analytical software capabilities to bring the flood of data from RFID into focus. The issue of cross-platform middleware potentially is a very vexing one. Many of the work system structural settings that RFID implementations will treat have legacy systems aspects that will need to be simultaneously addressed. Without the

assistance of new third-party RFID middleware vendors who can ease the infrastructure transition and provide the patches that are necessary to make old systems work with new ones, the cost of the required changes and updates will be too large for many firms to absorb.

As firms redesign their business processes around the emerging capabilities of RFID, they will become ever more dependent upon the technology in several ways. The primary dependency is highly positive, of course: organizations will come to operate in a managerial environment that is endowed with a new abundance of relevant information for business process control and perfection. This in itself will spawn its own research questions. Realistically, however, we expect RFID-adopting organizations to become somewhat reliant on external providers (including their RFID tag and reader vendors) to provide new systems capabilities to make sense of the data stream, lest the benefits be left on the table after the RFID systems investments have already been expensed. A second concern has to do with the extent to which vendors will control the RFID technologies. Will RFID tag technology eventually be controlled in monopolistic or oligopolistic market structures, negating the benefits associated with a competitive marketplace? Will the vendors of RFID readers have considerable market power? To what extent will uncertainties about their control and market power diminish organizational enthusiasm for RFID investments? Clearly, giving consideration to issues of market control, vendor market power, right-sized process outsourcing and market structure should all be within the domain of research on RFID (Aron, Clemons and Reddi 2005).

Organizations also want to be sure that they adopt technology and develop relationships with vendors that have long-term viability and that act in good faith on their behalf. The issues that arise bring into focus the need for research involving different approaches to managing risk in vendor relationships (Clemons and Reddi 1994). Clearly, adopting organizations will need to

calibrate the risk associated with becoming involved in any relationships involving the provision of RFID technology and services, where vendor staying power is an issue. Related to this, Aron, Clemons and Reddi (2005) have recently written about the importance of shirking, poaching and opportunistic renegotiation in the context of interorganizational relationships for outsourcing and systems support.

The latter two concerns strike us as being of particular potential importance in the RFID context. *Poaching*, according to the authors, is "the misuse of information that was originally provided for a legitimate contract purpose" (p. 7 in manuscript). With so much information in play of such potentially strategic value to the organization, it is possible that a vendor could take advantage of the adopting organization through inappropriate parallel use (much as individuals are concerning about Microsoft's and Google's use of ancillary private information in the process of providing their main services). *Opportunistic renegotiation* of vendor contracts occurs when the adopting organization determines that its operations are so dependent on the vendor's services and support that it has no choice but to pay the prices quoted by the vendor. This may come through *technological lock-in* or *process dependencies* of varying sorts, but the upshot is a loss of *bargaining power* by the adopter that is referred to as *vendor holdup*. So, what risks will an organization take by selecting a vendor, when there is some probability that any RFID technology vendor may not be able to stem the tide of technological change?

RFID technology potentially could result in information overload leading to opportunities and challenges in data analysis. Research that examines new techniques for data mining and organizing massive data warehouses is needed to help organizations take advantage of the huge data collection capabilities that emerge with RFID usage. Knowing where every process-related entity is at all times creates the possibility of new real-time decision making opportunities.

Decision scientists can help managers understand how this technology permits organizations to make decisions in real-time as the information float in supply chain processes is reduced to zero. Further, data collection from customer-directed RFID applications can be mined to generate new business intelligence to better service the customer. Understanding how organizations can use this flood of data to engage in more effective customer relationship management is critical for B2C marketing efforts.

The reader should also recognize RFID as an IOS technology that can result in closer alliance partnerships and increased transparency in data sharing across the value chain. However, several questions emerge that complicate the interorganizational dimension of RFID usage. For example, how do firms share the benefits derived from interorganizational RFID implementation? Iocovou, Benbasat and Dexter (1995) show that small firms are less likely to adopt EDI technology, which impacts gains realized by large firms doing business with these smaller firms. Riggins and Mukhopadhyay (1999) point out that because interorganizational systems cross company boundaries and extend beyond a manager's span of control, these systems are inherently more risky than internal information systems. Similarly, RFID technology implemented in the B2B structural setting poses new risks that need to be considered in terms of providing incentives to ensure proper trading partner usage. For example, what penalties will be imposed when trading partners misapply or misuse the technology? What costs will result from improperly tagging items? How might purposeful blocking of the reading of RFID tags result in errors at the other end of the B2B supply chain linkage.

Another important question to ask when RFID is implemented in the B2B structural setting is who owns the technology? Bakos and Nault (1997) apply the *theory of incomplete contracts* to show that in the absence of an *indispensable asset* or *indispensable participant—*

these control the flow of value—sole ownership is not the optimal ownership structure. Instead, joint ownership should occur. Within the RFID context, then, do the RFID tag and the RFID reader represent indispensable assets? If so, should the entire RFID system be owned by one firm? For example, should the buyer provide and own the tags for the supplier's items?

Thus, it should be clear to the reader that there are many issues that fall within the overall scope of the work systems and structural settings that are associated with RFID implementations. They cover the firm-to-firm, firm-to-market and firm-to-industry levels of analysis, and all develop based on the different incentives, perspectives and potential actions of the technology adopter and the technology solutions vendor, and suggest the value of a research agenda that focuses on vendor relationship management and the financial return on interorganizational trust (Clemons and Gray 2000). Research questions related to using, supporting, and evolving RFID within organizations and across industry alliances, as well as the related incentives and vendor relationship management issues, include the following. (See Table 4.)

The Impact of RFID on Individuals, Organizations, and Markets

Work system and process redesign ultimately impacts the individual workers that are involved. Understanding the impact on workers and others in society is critical to ensure the adoption and appropriate use of RFID. We envision a number of issues that will be of significant research interest that are related to the role of the worker. The first of them involves the qualities of RFID technologies, and the extent to which they will substitute for the capabilities of human labor and be able to provide continuous surveillance. The substitution of labor with a technology such as RFID should be a largely positive social welfare-creating endeavor. Gone will be the need for human labor to do repetitive barcode scans of warehouse and retail shelf inventory, and in its place will be newly-capable RFID readers that will permit similar information to be

Table 4. Research Questions on Using, Supporting and Evolving RFID

ISSUE AREAS AND RESEARCH QUESTIONS ON RFID
The Role of Process Redesign When RFID Is Used
o How are business processes and work systems changed due to RFID at all points in the value chain? Who initiates these process changes and why? o To what extent should initiators encourage process redesign at their trading partner facilities? o To what extent can business value be realized without process redesign? What strategies work best? o To what extent should initiators encourage process redesign at their trading partner facilities? o How does RFID change the job description and processes of managers vs. line employees?
Technical Integration with Other Applications
o How should RFID be integrated with other applications? With inventory systems? Electronic shelf space pricing systems? Personnel planning systems? o What are the technical challenges of achieving application integration? Internally? Externally? o How does application integration at the trading partner's organization impact usage? o What real options are created with increasing application integration?
Costs and Risks Associated with Becoming Dependent
o How costly are errors in an RFID-based work system? How will the errors drive costs in interorganizational systems? What can be done to control the costs? How will they be shared? o What are the risks of becoming dependent upon RFID systems where 100% accuracy is not assured? o How much should organizations invest in redundant reading systems? Manual back-up systems? o How much should be invested in "off-track" conditions such that human intervention is required? o How do more expensive systems make the system more flexible and self-recoverable? o Will the possibility of technological dependency diminish investment levels? Will the hidden costs of information exploitation significantly affect management's perceptions of the cost of RFID? o How can the long-term viability of tag manufacturers be measured? Reader manufacturers?
Taking Advantage of Voluminous Data Collection
o How can managers leverage the data flood organizations will experience with RFID? o How can a firm use all of this data to create process innovation? New customer value? o Will new performance measurement approaches be required to realize value from RFID? o Given the large volume of data, how can managers determine what data should be examined? o How can this data effectively be mined to create business intelligence and promote CRM? o How can researchers take advantage of this new flood of data? o What techniques in data analysis and data mining can be used to make use of all of this data?
Facilitating Decision Making Capabilities in Real-Time
o How can the firm make efficient use of real-time item/operator entity placement? o What process redesign is required to ensure that all associated items are appropriately located? o How will real-time entity location management add value to business processes? o How can organizations make use of real-time systems-based decision-making? o How will RFID and real-time decision making change the types of decisions managers face?
Aligning Interorganizational Governance, Incentives, and Ownership
o Who does the tagging? Who owns the technology? Who owns the data? o Who gets the primary value of the technology? Does firm size impact the gains from RFID? o Who will pay for readers that benefit multiple parties? Who supports the effort to build standards? o When can one party block data read from readers across the value chain? Will readers be cross compliant? How can incentives be put in place to avoid exploitative behavior? o How contractible are joint RFID initiatives? How will the resulting business value be split? How will this be measured? Will successful value-sharing negotiations be difficult to achieve?

collected passively. One expects that there will be some impacts on the workforce composition and size, however, there still will be many other human activities that need to take place in the same work systems settings, so the pressures may not be as large as some have come to expect.

Perhaps a greater concern may come on the surveillance side. Already we have seen an outcry in the United States about the extent to which RFID tags may compromise consumer privacy in a variety of normal retail business settings, including supermarkets, groceries and department stores (Albrecht 2002). In addition, Barry Steinhart, Director of the American Civil Liberties Union's (ACLU) Technology and Liberty Program notes in his 2004 testimony to the Commerce, Trade and Consumer Protection Committee of the United States House of Representative Subcommittee on Energy and Commerce that "[t]he privacy issues raised by RFID tags are vitally important because they are representative of a larger trend in the United States: the seemingly inexorable drift toward a surveillance society. As Congress considers the privacy issues posed by RFID chips, I urge you to view them in the larger context—a world that is increasingly becoming a sea of data and databases, where the government and private corporations alike are gathering more and more details about our everyday existence" (ACLU 2004).

Another interesting story is told about the unannounced use of RFID in delegates' badges for the World Summit on the Information Society (WSIS), held in Geneva, Switzerland in mid-December 2003, and reported by the *Washington Post* (Hudson 2003). The delegates included prime ministers, presidents, and other senior government officials from 174 countries, who were not told that RFID would be used to track their movements. The irony of this story relative to Steinhart's claim of a "drift to a surveillance society" is that one of the primary roles of the WSIS is to act as an international standard-bearer for intellectual property rights and individual

privacy. We foresee similar concerns in organizational work systems environments, where employees may object to unnecessary tracking and surveillance, and other intrusive collection of private information about their work habits—even though management may have the best intentions.

One of the main components of the projected value from the technology is the expected cost reductions from using RFID. Prior research on EDI has shown that in certain cases major cost reductions were not realized, especially for firms with little market power (Truman 1998). If EDI is not implemented with all trading partners, then the user must continue to run manual systems in parallel to the EDI system. Therefore, EDI may be just another layer of costs, rather than a major cost reduction tool. In the case of RFID, if some shipments entering the factory are tagged, but others are not and must be handled manually, to what extent will RFID actually result in reduced costs?

Organizations are likely to see other somewhat different impacts from RFID. For example, within the B2B setting, Malone, Yates and Benjamin (1987) predicted that dramatic reductions in costs due to IT would result in an increase in the number of suppliers, as firms move away from hierarchical structure for sourcing and business organization toward a market-focused approach. In the supply procurement context, Bakos and Brynjolfsson (1993a, 1993b) have shown that the optimal number of suppliers is not necessarily increased, since the initiator of the technology needs to maintain a relatively small number of suppliers in order to get them to invest an appropriate amount in the new technology. Clemons, Reddi and Row's (1993) '*move to the middle' hypothesis* perspective also suggests the countervailing risks associated with the move to pure market-based forms for procurement. The authors believe that the observed outcomes should be "in the middle," mixing a combination of greater access to the lower prices

of a competitive market while taking advantage of the risk mitigation benefits associated with strong, long-term procurement partnerships.

Another issue that must be considered when the impacts of RFID technologies and RFID-enhanced work systems are evaluated is the presence of network externality effects. Like many technologies, RFID exhibits a direct network externality (Economides 1997) in that the more adopters of a specific RFID standard, the more valuable it is to adopt that standard. This perspective is based on the general interpretation that network externalities arise from complementarities among the components of a network. So in addition to adopters of RFID tags and the associated readers (e.g., buyers and suppliers), it is also possible to consider the network externalities that arise from other kinds of components in a network, for example, the multiple kinds of software solutions that translate RFID data into managerial information in a variety of different operational settings (e.g., hospitals, railroad rolling stock or trucks, industrial plants and warehouses, pharmacies, retail stores and so on), or the complementarities that exist between different kinds of RFID tags that are compliant with widely-available RFID multi-readers.

With the rapid technological advances that are occurring, estimating the business value of RFID technology and knowing when to invest are critical in achieving high performance RFID-reliant work systems. The difficulties in value estimation stem from the uncertainties associated with the future cost and future benefit flows, the likelihood of the underlying technologies reaching acceptance as standards, and the extent to which others adopt the technology, leading to positive network externalities. Kauffman and Li (2005) modeled a setting involving competing technology standards that are viewed by potential adopters in terms of their stochastic move closer to or away from a threshold, which is perceived to represent viable critical mass for the standard. Another issue can be readily seen in the context of the measurement of the resulting

value flows, once they begin to materialize. If adoption is mandated, as in the case of the suppliers of Wal-Mart and the United States Department of Defense, then issues will arise about how the resulting value flows should be split up. But value with respect to RFID implementations will not be all tangible; instead, some portion of it will be intangible and diffused widely across the related work system and the firm, and potentially over to its business partners as well. Thus, we believe that there will a number of very rich issues that are worthwhile to pursue in research related to both the prospective and the retrospective impacts and value assessment for RFID.

With the increased concerns about personal privacy protection, identity theft, and the intrusion of various organizations into people's personal lives, much more research needs to be conducted that examines the role and impact of RFID on invasion of personal privacy. The ability to tag individual products that will eventually be brought into consumer's homes raises questions of trust that must be examined. How will consumers gain confidence that sellers will respect their privacy? Should government step in and mandate stricter compliance on the part of sellers? Would that result in increased consumer confidence?

Related to the last point, further research needs to be conducted on the impact of individual's health when many more items are being subjected to electromagnetic scans. How will individuals feel confident that their health is being protected? Again, what is the role of government in ensuring this public safety? Because these issues will directly affect adoption and usage of this technology, understanding the impact of RFID related to these issues is relevant for the IS research community.

We summarize a number of research questions that deal with the impacts of RFID on individuals, organizations and markets in Table 5. (See Table 5.)

Table 5. Research Questions on the Impact of RFID

ISSUE AREAS AND RESEARCH QUESTIONS ON RFID
Impact on Employees and Related Work Systems
o How does employee efficiency improve with real-time entity location management? o What will be the impact on labor? Will RFID provide substitution capabilities for human labor? o What is the impact on worker productivity with increased worker surveillance? o How will employee compensation be altered due to the use of this technology?
Estimating the Business Value of the Technology
o How can firms best understand and monitor the distance/cost factors as RFID capabilities advance? o How will network externalities affect the value generated by RFID? Positively? Negatively? Both? o What is the optimal allocation of investment money for readers? Where should they be located? How can the firm adapt by relocating readers as the price declines? What will be value maximizing? o How expensive is it to adopt RFID at a minimal level? At a fully integrated level? o What is the impact on the firm when RFID is used with only a portion of one's trading partners? o What is the economic value of integration with other applications? Inventory? Logistics? Others? o How does RFID increase the ROI of existing or prior IT investments in related work systems?
Forecasting Technical Evolution and the Dynamic Nature of Value Creation
o How can organizations appropriately forecast technology advances? o What will be the likely cost trajectory of RFID tags, readers, and other components? o What is the time value of data generated by the technology and how long does this data have value due to the progression of an information life cycle? o Are there other technology evolutionary patterns that might be applicable to this situation? Wi-fi technology? Bluetooth? How can we learn from the examples they have set?
Understanding the Impacts of RFID on Market Structure
o In a B2B structural setting, will the reduced cost and leaner supply chain result in a change in the number of suppliers to the buyer? Will RFID be another "move-to-the-middle" force? o Will the value potential of RFID result in new RFID information processing intermediaries? Will the impetus for improved operational control lead to RFID-focused risk management intermediaries? o Will the real costs of RFID make it so that fewer firms are able to compete in the marketplace? o Will the value surplus from RFID that accrues become available as improved social welfare? Or will the value gains mostly benefit businesses, leading to higher profitability?
Safeguarding Personal Privacy
o What is the long-term potential of remote monitoring and the compromise of individual privacy? o Should governments be involved in developing regulations to ensure privacy rights are not violated? o What is the potential impact on the adoption of RFID should such policy initiatives be enacted? o How will users of goods be ensured that tags have appropriately been deactivated? o How will users of goods be ensured that tags have not been secretly embedded in products? o How will worker's rights of personal privacy be protected? What are the rights of the firm to encroach on work systems and business processes? What role will unions play in the policy debate?
Safeguarding People's Physical Health
o What are the physical risks associated with RFID technology? Are there rules and limitations that need to be in place for usage in health care environments? What approach will be taken here? o How will potential advancements in RFIS and usage of various frequencies potentially compromise physical health? What kind of evidence will it take to affect corporate and public policy? o What role with the government play with respect to these issues? Can we expect an aggressive or a passive monitoring of the situation? Will the likely of restrictive regulations be low?

CONCLUSION

As the year 2005 inaugurates a new era of RFID technology usage, these and other research questions will emerge that must be examined by IS researchers. This paper outlines a broad agenda for considering a variety of issues related to the firm, industry relationships, RFID technology innovation, and customer and worker privacy. We also recognized the features of RFID technology as one that ought to be thought of as a member of a new class of technologies with multiple mobility, organizational and systems characteristics. In the case of RFID, we argues that RFID supports informational mobility for the range of tagable entities which suit the managerial needs of firms that wish to track them. We also pointed out that such tagging and tracking may lead to an increasingly real-time practice for decision support in contexts where the temporal control of the collection of relevant data traditionally has been difficulty and costly.

We anticipate that research directions on RFID will continue to evolve over the next decade. Investigation into the use of this technology should include a variety of research approaches, reflecting modern research methodologies in the organizational, behavioral, technical, and economic disciplines. RFID technology creates a natural (if ethically challenging) setting for the study of behavioral issues in workforce management. It will also provide a means for firms to study their organizational boundaries and their relationships with other organizations in terms that can be defined by the movement of tagged items close to or beyond the boundaries. Just as we think of marking data as it moves across system boundaries, or people and employees as they move into and out of a firm's physical facilities, now, with RFID managers will have a means to measure and manage other kinds of entities that are relevant to their business performance (e.g., pilfered inventory items, mistakenly moved equipment, the movement of trucks into a repair facility, and so on).

Moreover, RFID will offer researchers many opportunities for unique research designs and very large-scale data collection—perhaps larger in size than we have seen in supply chain management contexts to date. We believe that new methods associated with quasi-experimental research designs and analysis methods will be especially useful, as will be newly-emerging statistical methods that are intended for very large samples. With so much data on hand, researchers will be able to identify the specific kinds of conditions under which they wish to study the variety of issues that arise around RFID tagging—interorganizational systems performance, information quality and value relative to specific managerial goals, and the risks and value losses associated with imperfections in RFID-based work systems.

In RFID-reliant work systems, researchers also will be able to take advantage of the newly-available instrumentation for measuring supply chain entities (e.g., packages, pallets, containers, trucks, etc.) in a manner that will create managerially-relevant information about "entity trajectories" that has not been available before without prohibitive costs. This is similar to what companies such as United Parcel Services and Federal Express already do for packages that they handle in the controlled environments of their trucks, processing centers and airline cargo containers. They confirm for the customer when a package was received, where it is in the shipment process, and when it is likely to be delivered. However, the difference in RFID settings is that the movement of the relevant entities will be far less "scripted" than with package transshipment. Indeed, the kinds of managerial information that will be sought will often not be pre-specified.

We further expect that RFID-delivered entity information will become relevant on a "management-by-query" basis. This might occur, for example, in hospital operations settings, where there is a need to identify the whereabouts of expensive medical equipment, when the time

comes to track it down and use it in support of some medical or surgical procedure. In addition, with a longer-term perspective in mind, hospital managers will be able to construct query-driven naturally-occurring quasi-experiments within their RFID-reliant work systems to determine the extent to which RFID provides leverage for minimizing misplacement of expensive medical devices, controlling leasing expenses for extra equipment, or identifying the conditions under which medical samples fail to be properly processed in support of a variety of healthcare management services.

Our current effort to reveal the issues and set the agenda for future research on RFID and its various managerial challenges and potential impacts underlines the importance of such research in the interdisciplinary context. Although the IS field is the natural domain for this kind of research when the issues that are emphasized are IT artifact, work system design and performance-related, still there are many other issues that will span to other disciplines. We expect other disciplines to pick up on the issues that their theoretical perspectives and methodologies offer competitive advantage to understand well. Economics, for example, is well positioned to make sense of the value of information in informationally-abundant decision making environments. Operations management, on the other hand, will be uniquely able to identify how to refine workforce management practices to take advantage of RFID badges and employee tracking, just as they will be able to create new managerial approaches to the control of inventory replenishment in the presence of RFID. Similarly, we expect marketing researchers to explore the ways that applications of RFID can improve in-store operations, just as they examine issues related to Internet technology to understand its potential and pitfalls in selling.

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Appendix 1. Definitions of Key RFID Terms and Concepts

TERM	DEFINITION
Active tag	An RFID tag that has a transmitter to send back information, rather than reflecting back a signal from the reader, as a passive tag does. Most active tags use a battery to transmit a signal to a reader. However, some tags can gather energy from other sources. Active tags can be read from 300 feet (100 meters) or more, but they're expensive (typically more than US$20 each). They're used for tracking expensive items over long ranges. For instance, the U.S. military uses active tags to track containers of supplies arriving in ports.
Antenna	The tag antenna is the conductive element that enables the tag to send and receive data. Passive, low- (135 kHz) and high-frequency (13.56 MHz) tags usually have a coiled antenna that couples with the coiled antenna of the reader to form a magnetic field. UHF tag antennas can be a variety of shapes. Readers also have antennas which are used to emit radio waves. The RF energy from the reader antenna is "harvested" by the antenna and used to power up the microchip, which then changes the electrical load on the antenna to reflect back its own signals.
Compatibility	Two RFID systems are considered compatible if they use the same protocols, frequencies and voltage levels and are able to operate together within the same overall application
Edge server	A computer for running middleware or applications that is close to the edge of the network, where the digital world meets the real world. Edge servers are put in warehouses, distribution centers and factories, as opposed to corporate headquarters.
EPCglobal	A non-profit organization set up the Uniform Code Council and EAN International, the two organizations that maintain barcode standards, to commercialize EPC technology. EPCglobal is made up of chapters in different countries and regions. It is commercializing the technology originally developed by the Auto-ID Center.
Frequency	The number of repetitions of a complete wave within one second. 1 Hz equals one complete waveform in one second. 1KHz equals 1,000 waves in a second. RFID tags use low, high, ultra-high and microwave frequencies. Each frequency has advantages and disadvantages that make them more suitable for some applications than for others.
High-frequency	This is generally considered to be from 3 MHz to 30 MHz. HF RFID tags typically operate at 13.56 MHz. They can be read from less than 3 feet away and transmit data faster than low-frequency tags. But they consume more power than low-frequency tags.
Interoperability	In computing, the term refers to the ability to exchange and use information among disparate software systems. In RFID, the term generally refers to the ability of tags and readers from different vendors to communicate.
Low-frequency	From 30 kHz to 300 kHz. Low-frequency tags typical operate at 125 kHz or 134 kHz. The main disadvantages of low-frequency tags are they have to be read from within three feet and the rate of data transfer is slow. But they are less subject to interference than UHF tags.
Middleware	In the RFID world, this term is generally used to refer to software that resides on a server between readers and enterprise applications. The middleware is used to filter data and pass on only useful information to enterprise applications. Some middleware can also be used to manage readers on a network.
Nominal range	The read range at which the tag can be read reliably.

TERM	DEFINITION
Passive tag	An RFID tag without its own power source and transmitter. When radio waves from the reader reach the chip's antenna, the energy is converted by the antenna into electricity that can power up the microchip in the tag. The tag is able to send back information stored on the chip. Today, simple passive tags cost from U.S. 20 cents to several dollars, depending on the amount of memory on the tag, packaging and other features.
Radio frequency identification	A method of identifying unique items using radio waves. Typically, a reader communicates with a tag, which holds digital information in a microchip. But there are chipless forms of RFID tags that use material to reflect back a portion of the radio waves beamed at them.
Reader	A device used to communicate with RFID tags. The reader has one or more antennas, which emit radio waves and receive signals back from the tag. The reader is also sometimes called an interrogator because it "interrogates" the tag.
	A microchip attached to an antenna that is packaged in a way that it can be applied to an object. The tag picks up signals from and sends signals to a reader. The tag contains a unique serial number, but may have other information, such as a customers' account number. Tags come in many forms, such smart labels that can have a barcode printed on it, or the tag can simply be mounted inside a carton or embedded in plastic. RFID tags can be active, passive or semi-passive.
Semi-passive tag	Similar to active tags, but the battery is used to run the microchip's circuitry but not to broadcast a signal to the reader. Some semi-passive tags sleep until they are woken up by a signal from the reader, which conserves battery life. Semi-passive tags can cost a dollar or more. These tags are sometimes called battery-assisted tags.
Silent commerce	This term covers all business solutions enabled by tagging, tracking, sensing and other technologies, including RFID, which make everyday objects intelligent and interactive. When combined with continuous and pervasive Internet connectivity, they form a new infrastructure that enables companies to collect data and deliver services without human interaction.
Ultra-high-frequency	From 300 MHz to 3 GHz. Typically, RFID tags that operate between 866 MHz to 960 MHz. They can send information faster and farther than high- and low-frequency tags. But radio waves don't pass through items with high water content, such as fruit, at these frequencies.
Note: The definitions in this glossary are adapted from the "Glossary of RFID Terms" on the website of *RFID Journal*, and are used by permission.	