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Making the 'MOST' out of RFID technology: a research agenda for the study of the adoption, usage and impact 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 explore RFID and propose a research agenda to address a series of broad research questions related to how RFID technology: (1) is developed, adopted, and implemented by organizations; (2) is used, supported, and evolved within organizations and alliances; and (3) impacts individuals, business processes, organizations, and markets. As with many technological 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 Business value · Diffusion of innovations · Information technology · IT impacts · Radio frequency identification · RFID · Technology adoption

1 Introduction

Organizations utilize modern information systems (IS) to acquire, interpret, retain, and distribute information [86]. 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 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 that allow firms to refine 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. Such technologies are emblematic of the main theme of the 2004 INFORMS Conference on Information Systems and Technologies, which focused on

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mobility, organizational and systems technologies (MOST), where the ideas in this article were presented in an earlier form.[1] *Radio frequency identification* (RFID) is one such MOST 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 [42, 161]. RFID technology also heralds the emergence of inexpensive and highly effective *pervasive computers* that will have dramatic impacts on individuals, organizations, and society [145]. RFID allows any tagged entity to become a mobile, intelligent, communicating component of the organization's overall information infrastructure. A similar theme of *automated identification systems* characterizes the research of the Auto-ID Center (now Auto-ID Labs) that was conducted in the 2002–2003 time frame with researchers associated with universities and companies around the world ([5, 41, 112, 121).[2] The combination of the tagged mobile entity, the reader, the hardware infrastructure, and the software that processes the data makes RFID systems a new type of interorganizational system (IOS) with the potential to affect the entire value chain [95]. RFID systems cross firm boundaries, resulting in new opportunities to transform the supply chain for real-time optimization [12, 67, 107].

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* [101]. This further increases the flexibility, efficiency, and subsequent value created by these processes. 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 [41]. This has led some of them to mandate its adoption by their trading partners [17]. The accompanying benefits of 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 this new technology have also engendered anxiety from certain segments of society, where concerns about personal privacy are significant [13, 122, 144]. Consequently, there is a new interest by academic researchers to engage in scholarly investigation regarding the adoption, usage, and impact of this technology on individuals, organizations, supply chains, and markets [12]. This interest is also international in its scope (e.g., based on research at Keio University in Japan by Ogawa et al. [121], and at Fudan University in China by Min et al. [114], and elsewhere).

Although it represents a specific instance of IT, RFID is quite generic in terms of its MOST capabilities. Specifically, these are: (1) the capability to capture information in settings that involve *mobility of some types of business objects* (e.g., products, pallets, people, vehicles, etc.); (2) the opportunity to use this kind of *information collection capability to span across a variety of organizational environments and business processes* that exist internal to and across operations, business units, organizations and markets; (3) the facility to interface and *bring together the functionality of key systems whose information endowments will be dramatically increased*, thereby increasing information available to managers; and (4) the capability of *innovative emerging technologies that will change our perceptions of the meaning and constraints associated with location, space and time*. The difference between RFID technology and other past technologies such as electronic data interchange (EDI), software agents, and the Internet comes with the ''sensing'' capabilities that RFID offers in an increasingly dynamic, mobile physical world. EDI has been helpful in supply chain operations, but was mostly implemented to effect operations control via standardized documents and transaction sets in interorganizational information exchange. In a similar flexible manner, software agents have the capacity to collect data over time, but unlike RFID tags they cannot stand alone to interact with their environment upon demand. While the Internet has become ubiquitous, its functionality is largely limited to the software and information retrieval capabilities within its reach. When linked with an internal infrastructure, RFID technology is able to provide automated ubiquitous monitoring of mobile activities inside and outside the firm enabling unprecedented control for greater efficiency and real-time decision making for better effectiveness.

[1] For additional information on the positioning of this research, the interested reader should refer to the recent survey on IS research in *Management Science* by Banker and Kauffman [21], and on economics and electronic commerce in the *International Journal of Electronic Commerce* by Kauffman and Walden [100]. 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 10 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.

[2] The Auto-ID Center Web site (http://www.autoid.org) reports that MIT's Auto-ID Center closed in October 2003, and transferred its technology to EPCglobal (http://www.epcglobalinc.org), which is handling the related development of EPC standards. Seven universities now participate in a follow-on research consortium, including Keio University (Japan), Information and Communication University (Korea), St. Gallen University (Switzerland), University of Adelaide (Australia), Cambridge University (United Kingdom) and Fudan University (China). There were more than 100 companies involved at the height of the Auto-ID Center's global activities, including IBM, Cap Gemini/Ernst and Young, and Accenture, which contributed to the Center's white paper series.

The potential impacts of RFID are likely to be of interest to researchers across a number of fields [161]. They include mechanical and electrical engineering [72], systems and software engineering [92], health management [151], pharmaceuticals [103, 152], marketing and customer relationship management [51], public transportation [25], ethics [118], and legal and public policy [61]. Among these, marketing and supply chain researchers and professionals should be particularly interested in the coming transformations [9]. Through the application of RFID-powered supply chain management information systems, organizations will be increasingly able to make the adjustments in their processes necessary to achieve a ''triple A supply chain'' for improved agility, adaptability and alignment as pointed out by Lee [106]. This theme also is present in the earlier work of researchers from IBM's T. J. Watson Research Center associated with MIT's Auto-ID Center for RFID-related research [3]. RFID-based environmental sensing in a temporally complex, mobile, organizational and interorganizational systems world will permit supply chain operations to be more effectively coupled with marketing, accounting and finance-related processes, and thereby permit increasing levels of business process outsourcing.

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 research. A research agenda that addresses a variety of questions related to RFID that closely corresponds to the nomological net defined by Benbasat and Zmud [28] seems appropriate at this time. IT applications create opportunities to support new tasks. It also may support tasks that exist within a given structural setting. 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*). In this paper, we propose a research agenda for studying RFID to address broad research questions related to how RFID technology:

- is developed, adopted, and implemented by organizations to solve specific problems or create business opportunities—the *adoption dimension*;
- is used and supported within processes, organizations and alliances—the *usage dimension*; and,
- impacts individuals, business processes, organizations, and markets—the *impact dimension*.

In the next section we begin with a brief overview of the important technical aspects of RFID. Because RFID can be applied to a variety of tasks, structures, contexts and work systems [7], we introduce a framework in Sect. 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. By applying the research questions outlined above to these several different value chain contexts, we are able to propose a series of research issues and themes in Sect. 4 to provide a roadmap for IS researchers to investigate the adoption, usage, and impact of RFID. We conclude this analysis in Sect. 5 by considering the broader IS and interdisciplinary research contexts related to RFID as a MOST technology.

2 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 ([54, 82, 89, 158]. *Passive tags* draw power from the reader and are cheaper and smaller than active tags, which have a battery used to broadcast the signal to the reader [30]. *Semi-passive tags* use an internal battery to ensure data integrity, however the signal sent from the reader generates the power to transmit the signal from the tag. RFID is an extension of existing bar code technology and is fully integrated with the EPCglobal Network (http://www.epcglobalinc.org).[3] *Active tags* typically have internal read and write capability, their own batteries, and can transmit their signals over a longer distance. Depending upon the size of the tag and the frequency used, the current range of reception, or *read range*, of the reader is limited.[4] Figure 1 provides a summary of the most popular tag frequencies.[5]

[3] The EPCglobal Network was developed by the Auto-ID Center at MIT as 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.

[4] For example, Hsi and Fait [85] report on an application of RFID in a technologically enhanced science museum exhibit setting in San Francisco, California, where the chips that are used emit a 13.56 MHz signal with a low-power signal reader that works within only a few inches of the tag.

[5] As of late 2005, tags operating at the worldwide-approved 13.56 MHz high frequency (HF) level had a maximum range between the tag and reader of about 1 m. 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 915 MHz is prohibited from being incorporated into RFID applications in Europe [37]. 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 have signals that are less likely to pass through many 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.

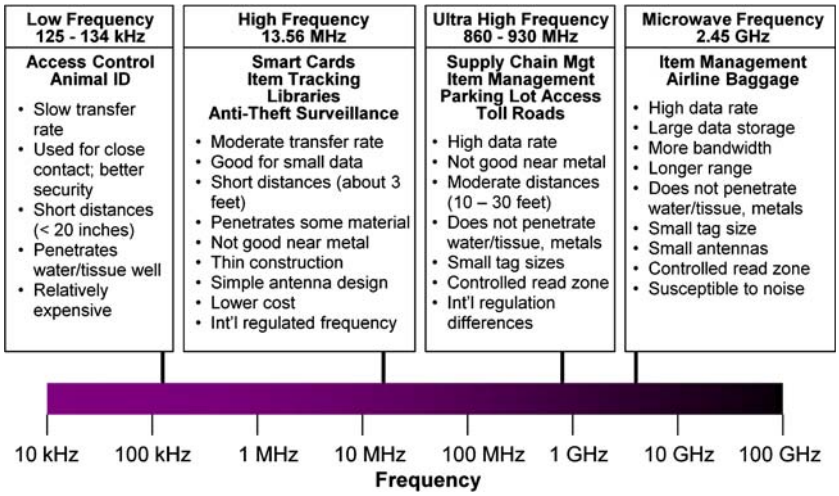

Fig. 1 Most popular RFID read range frequencies

Industry and public interest in RFID technology took a major leap forward in June 2003 when Wal-Mart mandated its largest 100 suppliers to begin using RFID tags on shipped items at the pallet level by January 2005 [22, 137]. Analysts predict Wal-Mart could save over $8 billion annually using RFID by reducing the labor costs of scanning items, out-of-stock items and item theft, while making improvements in the supply chain [77]. ''[T]heft costs Wal-Mart an estimated $2 billion a year; a legitimate business of that size would rank #694 on the *Fortune* 1,000,'' according to Boyle [35]. Clearly, the goal of tagging every item in a store is appealing to many retail businesses.

Other firms followed Wal-Mart's lead in requiring suppliers to implement RFID, including the U.S. Department of Defense (DoD) and Target [17]. The mandates lack some credibility due to technical difficulties and compliance costs, but many trading partners nevertheless worked to implement some pilot projects using RFID within the mandated timeframe.[6] Other technologies, such as EDI, have had a similar process of buyer-initiated mandates for adoption [132]. For some initiators, such mandates may be sufficient for the buyers to obtain sufficient ROI.

Most informed observers of emerging technologies believe that the cost of RFID tags will drop dramatically (e.g., [64, 119]. To be widely used, tag costs will need to drop from 50¢ each to 5¢ each in 5–10 years ([3, 139, 142, 149, 156]. As we initiated our research project on RFID at the Carlson School of Management's MIS Research Center at the University of Minnesota in 2004, most organizations were focusing on utilizing passive UHF tags that have a per unit cost of under 50¢ when purchased in volumes of a million tags or more. More recently in September 2005, *RFID Journal* reported that ''[t]here are signs that one of the biggest hurdles to widespread adoption of passive RFID technology in the supply chain—namely, tag price—is disappearing, or at least getting lower'' [120]. Avery Dennison RFID, a North Carolina-based RFID chipmaker, is now shipping second generation EPC inlays (prior to embedding in labels) for 7.9¢ each in quantities of 1 million or more. This is not far off the 5¢ per tag predicted in 2001 and 2003 simulations by the Auto-ID Center at MIT [139, 149]. In most cases, these tags 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. 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. So coordination will be required to bring together the value and ROI expectations of the different kinds of players that may be involved in adoption [16]. This situation suggests that there may be considerable inertia that will hold up the move to readily available, high functioning, cheap tags capable of delivering high ROI.

3 RFID applications along the value chain

There are many RFID applications that can be used across the value chain. To frame our research agenda, we consider applications at four different locations or *structural settings* in the value chain: *B2B logistics*, *internal operations*, *B2C marketing*, and *B2C after-sales service*. (See Fig. 2)

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

[6] In addition to Wal-Mart, other retailers announced plans during 2004 for mandated supplier adoption including Target, Best Buy, Albertson's, Tesco, Metro AG, Carrefour and Ahold, among others [156].

Fig. 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 promotional items Data flood	Cost/distance tradeoff Retrofitting equipment Labor privacy Customer privacy User alterations De(activation) Data flood

include different types of mobile *equipment* including tools, vehicles or movable parts of stationary equipment, manufacturing component *parts*, finished *products* that are transported or change states over time, *packaging* or documentation associated with such entities including pallets, crates, or promotional materials, and the *people* involved in transporting or using these entities. 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* constraints, and *legal* hurdles. Some are under the control of the organization; others are not.

3.1 B2B logistics

Most organizations have inbound and outbound logistics arrangements with external alliance partners, an application area where RFID systems can create unique value [33]. Customers receive pallets of goods from suppliers in a warehouse or 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-produced advanced shipping notices of goods from the supplier that should match a prearranged purchase order. When the pallet arrives, the internal contents must be matched visually or via bar code to ensure the shipment is as expected. When the supplier labels the outbound pallet or individual items with an RFID tag, the contents of the container can be verified immediately upon receipt. Appropriately placed readers also can track movement of the cargo throughout the facility. The operation can be streamlined by having forklifts or other transport vehicles tagged to ensure they are in proper position when they are required. Also, to support real-time process management and decision making, vehicle operators can be tagged to ensure they are in position. 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 to and departing from the port to ensure proper contents.[7]

When linked to an EDI system, an overall work system founded on RFID technology capabilities will be able to efficiently manage incoming and outgoing cargo containers. For freight transportation and logistics, we can 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.

[7] 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 [73], Lin et al. [108], Morgan [115], Stanford [145], Valentine [155], and Williams [162]. We expect to see empirical and case study research that will reveal the extent of the business value created by RFID in this context.

There are 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 [43, 55]. Researchers examining IOS usage have learned that business process redesign coupled with technology implementation helps to maximize benefits e.g., [1, 140]. Similarly, updating logistics processes to insert automatic remote scans of shipped goods may require a reorganization of 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 since these systems exhibit more risk than internal systems [134].

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—and suggests that mandated adoption is good for large buyers that can force small suppliers to adopt. Ownership of equipment and data, plus the equitable distribution of technology benefits further complicate the interorganizational adoption of the technology. Some of the key drivers of the complexity and difficulty of technology adoption under these circumstances involve non-contractible elements of technology investment [20]. They include the negotiation of post-investment value sharing [78], uncertainties associated with the technology becoming a recognized standard [98], difficulties in the transmission of information about the business value of the technology in its structural setting [15, 16], and the coordination of adoption involving different kinds of organizational participants [14].

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 (RF) 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 this context, RFID vendors will likely settle on standards for economical, small and lightweight RFID readers that simplify adoption to some extent [130].[8]

[8] During our RFID project, we spoke with a number of individuals in the industry including several who attended a standards committee meeting on small RFID reader devices in Minneapolis, MN. In an interview that took place in February 2005, a senior manager from the RFID consulting firm, Reva Systems, offered a positive assessment of the likelihood that some of the critical RFID standards issues will be sorted out and the current efforts of the related national standards body with respect to the characteristics and underlying functionality of small RFID readers.

B2B partnerships can often span international boundaries, which make international standards agreements critical. For example, most countries have adopted 13.56 MHz for HF RFID 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 [141]. But international agreements may be several years away.

Finally, potential infringement of labor privacy rights and violation of labor union agreements may exist at all phases of the value chain [70]. 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,'' even though this may be more a matter of perceptions than reality [76, 113, 144].

3.2 Internal operations

Within the manufacturing factory, RFID can be used to coordinate the flow and handling of multiple raw materials to the point of assembly to ensure a smooth process with no waiting for materials. Other efficiency benefits can be gained by tracking manufacturing equipment usage that leads to smooth inventory replenishment, improved workflows and the elimination of manufacturing bottlenecks due to materials handling delays [66]. For example, Fleisch and Tellkamp [60] point out that physical inventory and systems-based information about physical inventory often do not match. Prior to RFID systems, most companies only had two opportunities to get them aligned: when periodic physical inventory counts are taken by staff, and when a customer order can not be filled due to a stockout. Also, vehicles being assembled in an auto manufacturing plant can be tracked as they move through a series of assembly processes at different stations in the plant. The tag will tell the reader the specific operation that needs to be done at each station, resulting in much more intelligent factories and warehouses [40].

Several airlines use RFID to track bags routed through the air transport system to improve security and reduce lost bags. Delta Airlines, for example, handles 70 million pieces of luggage each year. Senior management believes 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 [36]. In addition, food manufacturing and distribution companies, and supermarket chains have the opportunity to leverage

the capabilities of RFID [127]. Sensor-equipped tags can monitor the environment surrounding perishable items and maintain a history of environmental changes [129]. This is especially relevant in the food industry, where shrink—the loss of inventory items through theft, misplacement and mistaken identification for sale—causes unnecessary operational costs [5, 6]. 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 supplied by the tags can minimize the amount of meat that must be discarded and protect consumers by accurately pinpointing the precise portions of a shipment that were subject to spoilage [62, 126]. Other applications of RFID permit checking for product obsolescence [5].

Organizations can tag expensive pieces of equipment such as PCs, laptops, and tablet computers to maintain an inventory system for movable assets [104]. This reduces the time required to conduct asset inventory checks allowing them to be done more often or in real-time. It also sets the stage for real-time decision support and business process value enhancement, as discussed by Gozycki and Johnson [74] in the case of Woolworth Inc.'s rollout of RFID to improve inventory management. Other research has suggested the potentially high business value and richness in application of RFID in inventory replenishment at the store shelf level, based on the new and different operational policies that it makes possible [163]. The system can also track maintenance activity for these assets. Large hospitals now 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 [24]. The savings of avoiding lost or stolen medical equipment, as well as reducing periodic costs for leased technical equipment, are substantial. Similarly, tags can be used to track the historical movement of hospital patients to limit contact in highly contagious disease settings [157]. Organizations also can use RFID to keep track of easily misplaced items. Libraries are using RFID tags to eliminate lost books and speed checkout [71]. Offices that must maintain physical documents also can tag binders and folders to locate them faster.

Being able to track the location of employees can boost human resources management. At a major motor 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 [29, 136].

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 [12, 131]. Other major economic expenses include installing the appropriate number and placement of readers [59] within the organization's facility, as well as proper placement to avoid reader interference from other electro-magnetic radiation [90, 147]. Optimizing the appropriate placement of the RFID components is needed to create the appropriate kind of interactive environment in which RFID-related information can express its value [125].[9]

3.3 B2C marketing and sales

The opportunities to use RFID technology combined with personalization technology for B2C marketing and sales are compelling and problematic. Retailers that offer frequent customer perks cards must consider the implications of tagging the cards so that customers can be identified when the customer enters the store. Being able to track that a customer spent 10 min in Aisle 6 before moving on to spend 15 min in Aisle 4 creates new marketing opportunities. Fusaro [65] demonstrates the potential interest of clothing retailers to tag products that will be sold and 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. In these scenarios, tagable entities include individual retail items, in-store demos, promotional material, customers, sales personnel, item handlers, and transport vehicles.

[9] Some observers have written that the limit of process interactivity occurs beyond the range of sensing of objects, with the sensing of human activity and purposeful motion [143]. Such research is suggestive of the extent to which future applications of RFID are likely to emerge that involve creating audit trails for human activities in business processes (e.g., quality checking and process or transaction monitoring, standard safety checks, and so on).

In addition to the barriers to value creation that we identified previously, retailers must secure customer privacy. 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 [138]. One of the most interesting potential applications comes in support of selling with money itself—with RFID-enhanced banknotes, as proposed by Juels and Pappu [94]. The idea is to work towards reducing fraud and counterfeiting, but even this application has been subject to criticism and concerns that the devices which are used to read identification information embedded in banknotes could lead to the unexpected tracing of the people who have legally used them in their transactions, as Avoine [13] has pointed out, creating consumer concerns at the point of sale.

3.4 B2B services

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 [52]. While the capability to read tags from a distance is quite limited, continued improvements in the technology will further complicate the legal questions [65].

4 Research issues regarding RFID in business settings

In accordance with our framework in Fig. 2, we now highlight a series of research issues and questions centered on our three broad research themes of the adoption, usage and impact of RFID.

4.1 Developing, adopting and implementing RFID within organizations

RFID technology is constantly improving. Even so, there are currently many limitations 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 [12]. 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. This is the *reader collision problem*, as defined and discussed by Engels [59, pp. 1 and 5], which involves allocating frequencies over time to RFID tag readers such that their interference with one another is limited. The problem is similar to what is observed with cell phones and other more sophisticated wireless devices, which have the capacity to recognize the appropriate base stations. However, affordable RFID tags cannot make such distinctions due to their relative lack of sophistication. 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. While many technical issues are beyond the scope of our business and management-oriented research agenda, understanding the limitations and capabilities trajectory over time is critical for the appropriate rollout of this technology and achieving the business value anticipated by adopters [150].[10]

The development of standards for RFID is critical for rapid, widespread diffusion of the technology. Fortunately, vendors and users are beginning to cooperate with one another and standards development organizations (SDOs) to evolve RFID standards to ensure adoption [58]. With the limited bandwidth 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.[11] An example of such cooperation is reported by Kivikoski [102], who showcases efforts underway to develop RFID standards for the auto industry via the Auto-ID Academic Alliance. This effort has now been moved over to industry entirely. Riggins and Slaughter [135] examine the role of shared mental models in arriving at

[10] The interested reader should also see Hawkes [80], who coined the term *tag pollution* to refer to situations where different kinds of signals picked up from ''cuckoo'' and ''stranger'' transponders end up creating RFID ''noise.'' Another useful reference for additional technical background is Foster and Burberry [63].

[11] A useful reference on RFID standards issues can be found at http://www.rfida.com/apps/standard.htm. The references cover a range of industry groups and standards including the Automotive Industry Action Group, the Unites States Department of Defense, Wal-Mart, EPCglobal, Intermec, and the International Standards Organization, as well as the proprietary technology interests of Texas Instruments, Sony, and Phillips.

consensus in standards choices, with particular attention paid to the RFID context.

RFID will create additional challenges regarding the readiness and capabilities of suppliers in supplier-customer relationships as evidenced by Wal-Mart's attempts to mandate adoption [148]. Adoption of RFID on the suppliers' side involves placing RFID tags on pallets and installing RFID tag readers in appropriate places to identify inventory levels and the movement of supplies. It also involves integrating information flows between buyers and suppliers, some of which are likely to be real-time information flows. It is widely known, however, that Wal-Mart's RFID initiative was undertaken while EPCglobal was still finalizing details of its second generation standard to create better performance for read/write capabilities and transmission. This mandate brought into question the hardware and software technologies that needed to be adopted, in the absence of dominant standards. EPCglobal was pushing for the acceptance of a single global standard. Although this may have seemed unrealistic to some industry observers, others ought to have recognized the extent to which common and well-accepted standards relieve uncertainties associated with technology solution adoption and spending. 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 precisely because they diminish adopter uncertainty [99].

An interesting issue related to standards development is the role of *network externalities*—more specifically, *indirect network externalities*—in the pricing of complementary goods [57]. If the same vendor supplies both readers and tags, then the vendor may price one of the goods artificially low to increase demand in the other good. Video game manufacturers know that by pricing platform devices artificially low, they can make up the difference with higher-priced games, especially when they have near monopoly power in the market. What is important is whether games can be played on multiple platforms. For RFID, will tags be readable using readers from multiple vendors or from a proprietary seller?

The maturation of the technology, the role of the SDO, and the strategies of technology vendors all impact the cost and speed of diffusion, which influences the way managers develop the business case for RFID. In addition to indirect externalities, managers must also consider *direct externalities*, which 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 parties that use the technology, the more valuable it is to belong to the network. For RFID, we might 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 [75, 134]. For example, when a major manufacturer promotes EDI with its suppliers, a given supplier would like to be the only one using the technology with that customer in order to gain more strategic benefits. However, as more competing suppliers are expected to adopt, the strategic benefits should be less [132]. A similar effect should exist for buyer-mandated RFID usage [49]. Furthermore, it is not clear whether RFID can be adopted early for competitive advantage or whether it must be adopted out of competitive necessity as a *hook-up-or-lose-out* proposition [46].

To build the business case managers need to understand and bound the extent of the RFID system. Toward this end, Hassan and Chatterjee [79] propose a taxonomy of RFID systems. They propose that the taxonomy consists of four system components, including the usage of the system, the frequency with which the system is employed, the data requirements of the system, and the physical pieces making up the system. In addition, managers need to communicate the potential value of any new IT application. In a B2B structural setting, it is important to understand who will gain what benefits. Gebauer and Buxmann [68] note that is it is not always clear who will benefit from implementation of EDI systems. Several studies have developed methods of valuing the investment in EDI (e.g., [69, 83, 84]). Similarly, methods and tools need to be developed to estimate RFID value to develop the business case.

Another aspect of RFID technology that creates tensions among senior management decision makers interested in high ROI is its nature as *technology infrastructure*. Although much of the business press suggests that RFID has some ''plug-and-play'' qualities and will transform business capabilities from the pallet level up, the reality is probably somewhat different. This provides interesting opportunities for new research. For example, researchers could test the notion that infrastructure technologies may not be the primary drivers of business value themselves, but rather create *real options* for additional follow-on investments. These real options opportunities need to be calculated into the rationale of the original business case [26, 27].

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., [146]) and accounting theorists [96] 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'' [11]. From a market perspective, it is critical that RFID technology be properly sponsored, so that value-rational subsidies and value-sharing arrangements can be enacted leading to widespread market adoption. Failure to communicate effectively with the market about the future trajectory of RFID technology—for example, in terms of vendor capabilities, the likelihood that a proposed standard will take hold, or the decline in RFID tag costs to the 5¢ per tag threshold [139, 149]—will lead to information transmission difficulties at the market level [16], 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 consortium settings. Yang and Jarvenpaa [164] examine the characteristics of individual organizations that make up the consortium and ask how a member's collective trust is based on previous experience. Quaadgras [128] examines what firm characteristics impact the firm's interest in joining an RFID consortium. The findings show that the extent to which slack resources are available leads to more alliance formation and membership. These and other factors related to the pattern and dynamics of RFID adoption need to be examined and compared with other information technologies.

In Table 1, we summarize a series of research questions related to the development, adoption, and implementation of RFID that researchers should examine.

4.2 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 [44, 133]. 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 [55] show that the managerial environment and the political climate within the firm will impact the extent to which the firm achieves what Weill [159] calls *conversion effectiveness* when implementing new systems. Similar studies that deal with conversion effectiveness are required for RFID usage. Based on the prior work, we expect there to be significant issues associated with organizational capabilities and absorptive capacity for integrating emerging technologies into the organization and making them pay off rapidly in an organization's business processes [23, 160].

An important element of realizing value from RFID technology will be integration with other internal and external systems. Since RFID is an emerging technology, the standards associated with it will migrate over the course of the next several years, as the support for different technological capabilities improves. We expect there to be new issues in two areas similar to what Dai and Kauffman [53] 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 new real-time capabilities of the enormous data stream produced by next-generation RFID-reliant work systems. We recognize the potential for new intermediaries and infomediaries to systems integration and analytical software capabilities to bring this new flood of data into focus. The issue of cross-platform middleware potentially is a very vexing one [12]. Many of the work system structural settings that RFID will impact 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 patches necessary to make old systems work with new ones, the cost of the required changes and updates may 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. Of course the primary dependency is highly positive in that 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. However, we expect 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 if organizations are to make full use of their RFID investments. A second concern has to do with the extent to which vendors will continue to control the technology. Will tag technology continue to be controlled in an oligopolistic market structure? Will a more competitive marketplace for RFID equipment emerge? Will the vendors of RFID readers continue to 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 is within the domain of RFID business research [11].

Organizations also want to be sure that they adopt technology and develop relationships with RFID equipment, systems and services vendors that have long-term viability and that act in good faith on their behalf. The

Table 1 Research Questions on developing, adopting and implementing RFID

Issue Areas and Research Questions on RFID
Understanding the Technical Capabilities and Limitations[a]
○ How does radio interference by physical items impact usage of RFID in the business context?
○ What other forms of interference may occur that prevent reading multiple items simultaneously?
○ What are the technical difficulties of reading across organizational boundaries? What standards will emerge?
○ 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?
○ What is the rate of technical advancement in terms of RFID signal fidelity over longer distances?
○ Will different industry settings require different technical capabilities from RFID systems?
○ How do technical limitations impact the value achieved from this technology?
Understanding the Role of Standards for the Proliferation of RFID
○ How should RFID standards development organizations (SDOs) be structured?
○ How can SDOs reduce implementation complexity and promote RFID investment risk management?
○ How should international standards best be coordinated? Will they migrate to become global in scope?
○ What is the role of developing countries that have a potentially large critical mass of users that could impact externalities? Are there likely to be regional standards? Industry-specific standards? Vendor standards?
○ What is the appropriate role for companies in standards setting? How do individual companies with proprietary standards intentions impact the development of standards? Will industries embrace standards?
○ What is the market risk to an organization of being stranded with an obsolete RFID standard? Economic cost?
○ How do standards impact the evolution of the cost of tags and readers? What will make them economical?
Developing the Business Case for RFID Adoption
○ What exactly does this technology include? How should the overall investment project be bounded?
○ How should an appropriate business case be constructed? What parts of the organization are affected?
○ How can a business case for RFID be developed under uncertain market and technical conditions?
○ How expensive is adopting RFID at a minimal or integrated level? How should investments be governed?
○ What is the impact on the firm when RFID is used with only a portion of one's trading partners?
○ What is the economic value of integration with other applications? Inventory? Logistics? CRM? Others?
○ How does RFID increase the ROI of existing or prior IT investments in related work systems?
○ What future options does establishing an RFID infrastructure create? How can the options be identified?
○ Will RFID have similar impacts inside and outside the organization? Are there industry considerations?
○ What are the roles of senior management, individual champions or change agents in promoting RFID?
Understanding the Pattern and Dynamics of Adoption
○ What factors facilitate adoption of RFID within the firm? In an interorganizational context? Internationally?
○ How important is the installed base of RFID users for promoting adoption? What is the role of externalities?
○ Can the technology be implemented in stages? What are the standard ''chunks''? In what order? Why?
○ How long does it take to implement RFID technologies and how long are the value lags?
○ Will RFID be subject to underinvestment? What can be done to mitigate this for social welfare?
○ How are patterns of adoption of RFID similar or different than other technologies? Does industry matter?
○ Are traditional IT adoption research paradigms appropriate? What new adoption paradigms make sense?
○ Is rational expectations theory applicable? Standards uncertainty, market signaling and information sharing theory? Informational cascades? Rational herding theory? Other behavioral economics theories of adoption?

Note: [a] The reader should note that this first set of research questions falls at the intersection of IS research and Computer Science and Electrical Engineering research suggesting the need for shared interdisciplinary inquiry

issues that arise bring into focus the need for research involving different approaches to managing risk in RFID-related vendor relationships [47]. 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. Today, this seems especially important for RFID chip and hardware vendors. But in the future, as RFID database and software services become more prominent the concerns will shift to different kinds of

vendors. Related to this, Aron et al. [11] 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 particularly important in the RFID context. *Poaching*, according to Aron et al. [11], is ''the misuse of information that was originally provided for a legitimate contract purpose.'' With so much strategic information within RFID systems, 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 various types of *technological lock-in* or *process dependencies*, but the result is a loss of *bargaining power* by the adopter that is referred to as *vendor holdup*. An important research question then is, 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? How can we determine what approach to risk is appropriate in this context?

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, this technology will likely generate a *massive* amount of new data. How will such data be leveraged? What new applications will be necessary to unlock their strategic and tactical value?

This massive flood of RFID-collected data 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. 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 serve the customer. Understanding how to use this data for more effective customer relationship management is critical for B2C marketing too.

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? Iacovou et al. [88] show that small firms are less likely to adopt EDI technology, which impact gains realized by large firms doing business with these smaller firms. Riggins and Mukhopadhyay [134] point out that because IOSs cross company boundaries and extend beyond a manager's span of control, they are inherently more risky than internal information systems. Similarly, RFID 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, how might purposeful blocking of the reading of tags result in errors at the other end of the B2B linkage?[12] What penalties will be imposed when trading partners misapply or misuse the technology? What costs will result from improperly tagged items?

Another important question to ask when RFID is implemented in the B2B structural setting is who owns the technology? Bakos and Nault [20] apply the *theory of incomplete contracts* to show that in the absence of an *indispensable asset* or*indispensable participant* that controls 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/or 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 are developed 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

[12] Considerable discussion on the public policy and computer science sides has emerged regarding approaches to blocking RFID tags, especially among citizen groups that express concerns about potentially inappropriate use [56]. One of the most interesting is a technical approach, involving the creation of a ''blocker tag'' that is able to generate many numbers so that it is impossible for an RFID reader to effectively identify the tag [91, 92, 93].

trust [45]. In Table 2, we summarize the key 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.

4.3 The impact of RFID on individuals, organizations and markets

Work system and process redesign ultimately impacts the individual workers that are involved. Understanding the

Table 2 Research questions on using, supporting and evolving RFID

Issue Areas and Research Questions on RFID
The Role of Process Redesign When RFID Is Used
○ How are business processes and work systems changed due to RFID at all points in the value chain?
○ To what extent should initiators encourage process redesign at their trading partner facilities?
○ Can business value be realized without RFID-focused process redesign? What strategies will yield value?
○ How does RFID change the job descriptions and work roles? Are the impacts similar across industries?
○ Will process design for outsourced business processes be affected by the capabilities that RFID offers?
Technical Integration with Other Applications
○ How difficult will RFID be to integrate with other applications? With inventory systems? Electronic shelf space pricing systems? Personnel planning systems? What capabilities in the firm will mitigate the impacts?
○ What are the technical challenges of achieving application integration? Internally and externally? The costs?
○ How does application integration at the trading partner's organization impact usage? Are the impacts large?
○ What real options are created with increasing application integration? Is business value enhanced?
○ Will technical integration be differentially costly depending on the industry setting of the application?
Costs and Risks Associated with Becoming Dependent on RFID
○ How costly are errors in an RFID-based work system? How will the errors drive costs in RFID-based IOS?
○ What roles do redundancy, back-up, exception processing, and human intervention play?
○ What analysis approach is appropriate for optimizing RFID costs?
○ Will the possibility of RFID dependency diminish investment levels? Will there be ''underinvestment''?
○ Will the hidden costs of information exploitation affect the real cost of RFID?
Taking Advantage of Voluminous Data Collection
○ How can managers leverage the data flood organizations will experience with RFID?
○ Will new performance measurement approaches be required to realize value from RFID?
○ How can this data effectively be mined to create business intelligence and promote CRM?
○ Will new data processing intermediaries arise to help organizations manage this flood of data?
○ What new data mining techniques will make the data usable?
○ Will different industry settings offer unique opportunities for leveraging voluminous data collection?
○ Will RFID add value for information sharing in outsourced business processes, such as logistics and supply?
Facilitating Decision Making Capabilities in Real-Time
○ How can the firm make efficient use of real-time item/operator entity RFID tag placement?
○ How will real-time entity location management add value to business processes?
○ How can organizations make use of real-time systems-based decision-making? Industries?
○ How will RFID and real-time decision making change managerial capabilities?
Aligning Interorganizational Governance, Incentives, and Ownership
○ Who does the tagging? Who owns the technology? Who owns the data? Who gets the value?
○ What is the role of mandates and subsidies to entice trading partner adoption? Usage in a particular manner?
○ What is the role of a major player promoting adoption? How might they incent partner R&D?
○ Who will pay for readers that benefit multiple parties? Who will drive the effort to build standards?
○ How can incentives be put in place to avoid exploitative behavior when RFID supports information collection?
○ How contractible are joint RFID initiatives? How will the resulting business value be measured and split?
○ Will RFID provide a basis for cross-organizational control in business process outsourcing?

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 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 collected passively [4, 163]. There will be some impacts on the workforce composition and size. For example, it will be useful to explore the extent to which RFID systems lead to workforce deskilling. By the same token, the opposite may occur: it is more likely in our view that RFID systems will require complementary skilled labor. So the pressures may not be as large as some expect.

Perhaps a greater concern may come on the surveillance side. We have already seen concerns in the United States about the extent to which RFID tags may compromise consumer privacy in a variety of normal retail business settings [2], including supermarkets, groceries and department stores where RFID has been recognized as being of potentially high payoff [97]. The 2003 protest against Gillette Corporation's insertion of RFID tags into men's shaver packages is one such instance [34, 56]. 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 U.S. 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'' [8].[13] 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.

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 consumers' 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?

Further research needs to be conducted on the impact on an individual's health when many more items are being subjected to electromagnetic scans. Will the public feel confident that their health is being protected? What is the role of government in ensuring public safety? Cantwell [39] points to the history of public concerns with emerging technologies—from cellular phones to food-related genetically modified organisms to Pentium III processor serial numbers—and reminds us that success is often path-dependent, in spite of the beneficial qualities of the technologies themselves. Because these issues will directly affect business adoption and usage of this technology, understanding the impact of RFID related to these issues is relevant for the IS research and business communities.

Many issues related to developing the original business case must be revisited after implementation to verify the business value generated by RFID. A main component of the projected value from RFID use is the expected cost reduction. Prior research on EDI has shown that in certain cases major cost reductions were not realized, especially for firms with little market power [154]. 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?

Another issue related to value is the presence of network externality effects. We already mentioned the notion that RFID likely exhibits a direct network externality in that the more adopters of a specific RFID standard, the more valuable it is to adopt [57]. Such network externalities arise from complementarities among the components of a network. 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

[13] 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 as reported by the *Washington Post* [87]. 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.

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 readers.

With the rapid technological advances, 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 benefit flows, the likelihood of the underlying technologies reaching acceptance as standards, and the extent to which others adopt the technology leading to positive externalities. Kauffman and Li [98] model 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 a viable critical mass for the standard. Another issue for the measurement of value is who gets what benefit? If adoption is mandated, as in the case of the suppliers of Wal-Mart and the United States Department of Defense, how should the resulting value flows be shared? And how is value related to the specific direction and volume of information transmitted? Further, some value will be intangible and diffused widely across the related work system, the firm, and to other business partners. Thus, a number of rich issues are worthwhile to pursue in research related to both the prospective assessment and the retrospective impacts for RFID.

Organizations are likely to see other impacts from RFID at the market structure level. Within the B2B setting, Malone et al. [111] 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 supply procurement, Bakos and Brynjolfsson [18, 19] 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 et al.'s [48] *move-to-the-middle hypothesis* perspective also suggests the countervailing risks associated with the move to pure market-based forms for procurement. We 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.

In Table 3, we summarize a number of research questions that deal with the impacts of RFID on individuals, organizations and markets.

5 Conclusion

As the year 2006 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 that RFID technology should be thought of as a member of a new class of technologies with multiple mobility, organizational and systems technologies—MOST—characteristics. We argued that RFID supports informational mobility for the range of tagable entities that 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 difficult and costly.

The wide assortment of RFID-related issues we have raised here are consistent with the nomological net proposed by Benbasat and Zmud [28]. However, some might argue that many of these issues do not fall within the traditional domain of research within the IS research community as it pertains to the *IT artifact* [123]. In this paper, we have described RFID technology as the basis for many *IT-reliant work systems* [7], in which case their study becomes very central to IS research. We believe that for the IS researcher, RFID technology represents *a type of IT artifact that is embedded in IT-reliant work systems*. By augmenting Benbasat and Zmud's [28] nomological net with Alter's [7] more inclusive thinking, the RFID-related research issues proposed here become even more pertinent to IS researchers.[14] Benbasat and Zmud [28] further note

[14] Orlikowski and Iacono [121, 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 [7, p. 367], who also quotes Orlikowski and Iacono [121], 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, organizational and systems technologies, and we should seek 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.

Table 3 Research questions on the impact of RFID

Issue Areas and Research Questions on RFID
Impact on Employees and Related Work Systems
○ How does employee efficiency improve with real-time entity location management?
○ What impact will this technology have on changes in the number of employees required?
○ What will be the impact on labor? Will RFID provide substitution capabilities for human labor?
○ What is the impact on worker productivity with increased worker surveillance?
○ How will employee compensation be altered due to the use of this technology?
Safeguarding Personal Privacy
○ What is the long-term potential of remote monitoring and the compromise of individual privacy?
○ Should governments be involved in developing regulations to ensure privacy rights are not violated?
○ How will users of goods be ensured that tags have appropriately been deactivated?
○ How will users of goods be ensured that tags have not been secretly embedded in products?
○ 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?
Creating Responsible Business Policy to Safeguard Against Health Risks
○ What role should business play in monitoring the physical risks associated with RFID technology?
○ What potential advancements in RFID and usage of various frequencies potentially will compromise physical health? What kind of evidence on this will affect corporate and public policy?
○ What role will the government play with respect to these issues? Should we expect regulations?
Estimating the Business Value of the Technology
○ How can firms best understand and monitor the distance/cost factors as RFID capabilities advance?
○ How will network externalities affect the value generated by RFID?
○ How can the firm best measure the impacts when RFID is integrated with other applications?
○ How is value related to the direction and volume of information transmitted? Is usage a key factor?
○ How will the business value of RFID technology implementations be mediated by other organizational capabilities that drive value conversion?
○ It may be easy to measure new data availability and operational transparency, but how will the decision making capabilities of the firm actually be transformed? How can those be quantified?
○ How will B2B logistics, internal operations, B2C marketing and B2C service be impacted?
Forecasting Technical Evolution and the Dynamic Nature of Value Creation
○ How can organizations appropriately forecast technology advances that will affect their businesses?
○ What will be the likely cost trajectory of RFID tags, readers, and other components?
○ 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
○ 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?
○ Will new information processing intermediaries alter the balance of power in the marketplace?
○ Will the need for improved operational control lead to RFID-based risk management intermediaries?
○ Will the real costs of RFID make it so that fewer firms are able to compete in the marketplace?
○ 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?

that the IT application creates opportunities for new tasks or may support tasks that exist within a given structural setting, which maps the study of RFID into an even broader context. Alter [7] suggests an even broader context—the study of socio-technical systems ([31, 32, 105, 116, 117, 124, 153].

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 firm 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, with RFID managers will soon have the means to measure and manage other kinds of entities that are relevant to their business performance in this way (e.g., pilfered inventory items, mistakenly moved equipment, the movement of trucks into a repair facility, and so on).

The opportunities for research should be of significant interest to both doctoral students who are interested in developing high quality thesis research, as well junior faculty, whom we encourage to seek out new opportunities for carrying out theory-building, theory-testing, theory-extending and theory-challenging research. As Clemons and Weber [50] have reminded us, some of the most interesting opportunities in research come about when technology changes the underlying market equilibrium for interfirm competition. 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 data mining and 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, including 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. The recent work by Loebbecke [109, 110] that examines the applications of RFID tagging in a retail supply chain setting offers useful perspectives on the kinds of problems that arise. Case studies of this sort will continue to be of great value to the research community in the coming years.

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.[15] This is similar to what companies such as Federal Express already do for packages they handle in the controlled environments of their trucks, airline cargo containers and processing centers. 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 to its destination. However, the difference in RFID settings is that the movement of the relevant entities will be far less ''scripted'' than with package transshipments. Nor will the appropriate managerial information be pre-specified. However, using RFID may soon allow managers to develop such scripts for the various tagable entities in their operations.

We further expect that RFID-delivered entity information will become relevant on a ''management-by-query'' basis. This might occur in hospital operations settings where there is a need to identify the location of expensive medical equipment to ensure its availability for a specific medical or surgical procedure. In addition, hospital managers will be able to construct query-driven naturally occurring experiments within 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.

In closing, we should point out that there is a significant body of literature on IS and IT that points to the role of emerging technologies in operating and business process settings as being important complements in the production of value. As Brynjolfsson et al. [38] remind us, the extraordinary expenditures associated with the ''IT investment iceberg'' lurk beneath the surface of the many process, organizational, logistics and market settings in which RFID-based systems will be deployed. So it stands to reason that many process-enabling complementary investments will be necessary to release the value associated with RFID. These are likely to include training, configuration and deployment controls, and other managerial support approaches. Although it will take time to show empirical results, we nevertheless predict that process-enabling IT investments will be critical for high business

[15] Current technical research that is underway suggests that the various design dimensions and chip and reader performance requirements are already fairly well understood in the supply chain context. Glidden et al. [72] point to a set of ''top 10'' factors that will drive the implementability of RFID in supply chain settings. These include: open standards and interoperability, high reliability in operation, global regulatory compliance, low costs for tags and equipment, tags that are writable by end users in operational environments, requirements for RFID systems specified on the basis of appropriate use cases, predictable performance, solutions to the problem of reader collisions, database connectivity to RFID systems, and effective security and appropriate privacy.

value outcomes in extended enterprise systems environments involving RFID [10, 81].

Our current effort to reveal the issues and set an 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 type of research when the issues are directly related to the IT artifact, work system design, or related system performance, there are other issues that span to other disciplines. 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 using RFID can improve in-store operations, just as they examine issues related to Internet technology to understand its potential and pitfalls in Internet-based advertising and selling. The extent to which IS researchers can collaborate with researchers in these other disciplines will generate a deeper and more meaningful stream of managerially relevant research.

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Appendix Definitions of key RFID terms and concepts (adapted from *RFID Journal*)

Term	Definition
Active tag	RFID tag with 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 m) or more, but they're expensive (typically more than US$20 each)
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. The RF energy from the reader antenna is ''harvested'' by the antenna and used to power the microchip
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—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. Commercializing Auto-ID Center RFID technology
Frequency	The number of repetitions of a complete wave within one second. 1 Hz equals one complete waveform in one second. RFID tags use low, high, ultra-high and microwave frequencies
High-frequency	From 3 MHz to 30 MHz. HF RFID tags typically operate at 13.56 MHz. Can be read from less than 3 feet away and transmit data faster than low-frequency tags
Interoperability	In computing, refers to the ability to exchange and use information among disparate software systems. In RFID, refers to ability of tags/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 RFID, software that resides on a server between readers and enterprise applications. Filters data and passes on only useful information to enterprise applications. Used to manage network readers
Nominal range	The read range at which the tag can be read reliably
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

Appendix continued

Term	Definition
RFID	Method of identifying items using radio waves. A reader communicates with a tag, which holds information in a microchip. Chipless tags reflect back some of the radio waves beamed at them
RFID tag	Microchip attached to an antenna that is packaged in a way that it can be applied to an object. Tag picks up signals from and sends signals to a reader; contains a unique serial number, but may have other information (e.g., customer account number). Come in many forms: smart labels with a printed barcode, tag in a carton or embedded in plastic. Can be active, passive or semi-passive
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 called an *interrogator*
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 receive a signal from the reader
Silent commerce	Business solutions enabled by tagging, tracking, sensing and other technologies, including RFID, which make everyday objects intelligent and interactive. 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

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