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www.emeraldinsight.com/0144-3577.htm

Received May 2008
Revised March 2009,
June 2009
Accepted June 2009

Empirical evidence of RFID impacts on supply chain performance

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Abstract

Purpose – The purpose of this paper is to investigate the actual benefits of radio frequency identification (RFID) on supply chain performance through the empirical evidence.

Design/methodology/approach – The research reviews and classifies the existing quantitative empirical evidence of RFID on supply chain performance. The evidence is classified by process (operational or managerial) and for each process by effect (automational, informational, and transformational).

Findings – The empirical evidence shows that the major effects from the implementation of RFID are automational effects on operational processes followed by informational effects on managerial processes. The RFID implementation has not reached transformational level on either operational or managerial processes. RFID has an automational effect on operational processes through inventory control and efficiency improvements. An informational effect for managerial processes is observed for improved decision quality, production control and the effectiveness of retail sales and promotions coordination. In addition, a three-stage model is proposed to explain the effects of RFID on the supply chain.

Research limitations/implications – Limitations of this research include the use of secondary sources and the lack of consistency in performance measure definitions. Future research could focus on detailed case studies that investigate cross-functional applications across the organization and the supply chain.

Practical implications – For managers, the empirical evidence presented can help them identify implementation areas where RFID can have the greatest impact. The data can be used to build the business case for RFID and therefore better estimate ROI and the payback period.

Originality/value – This research fills a void in the literature by providing practitioners and researchers with a better understanding of the quantitative benefits of RFID in the supply chain.

Keywords Radio frequencies, Identification, Supply chain management, Performance measurement (quality)

Paper type General review

International Journal of Operations & Production Management
Vol. 29 No. 12, 2009
pp. 1290-1315

0144-3577
DOI 10.1108/01443570911006009

1. Introduction

Radio frequency identification (RFID) has received increased attention from practitioners and academics. Due to the mandates from Wal-Mart (O'Connor, 2005) and the US Department of Defense (Collins, 2004a), January 2005 can be considered as the "big bang" for RFID. Other early adopters of RFID include Target, Metro Group, Tesco, Boeing and Michelin (Reyes and Frazier, 2007). In addition, the US Food and Drug Administration (FDA) has strongly recommended that the pharmaceutical and health care industries adopt RFID as a way to protect the drug supply chain from terrorist actions and counterfeiting (FDA, 2004).

Wal-Mart's objective was to replace bar codes and scanners with RFID tags and readers in order to increase speed, efficiency and security in the supply chain (Weil, 2004), and to reduce inventory, out of stock merchandise, and labor cost in stores and warehouses (Seideman, 2003). Other published supply chain performance benefits include: improved accuracy and security of information sharing across the supply chain (Jones *et al.*, 2004); reduced storage, handling and distribution expenses; increased sales through reduced stock outs; improved cash flow through increased inventory turns and improved utilization of assets (Kärkkäinen, 2003); and improved customer service and satisfaction; and increased collaboration and planning (Li and Visich, 2006). Due to these reputed benefits and the quantitative estimates of benefits provided in numerous consulting and solution provider white papers, companies have begun to show an increased interest in deploying RFID systems.

But these benefits of RFID implementation are not achieved immediately and there are a number of issues impeding RFID adoption. For example, a December 2004 survey by Logistics Management of companies involved in Wal-Mart's RFID mandate found that the number one concern of the 93 respondents was a lack of ROI (42.3 percent). Other top concerns were cost (23.1 percent), no benefit to us (11.5 percent) and lack of support from Wal-Mart (7.7 percent) (Cooke, 2005). Other early implementation issues include: wild fluctuations in tag reads; consumer privacy concerns (Sullivan, 2005a); environmental impact (Morrison, 2005); and security (Li *et al.*, 2006).

There is confusion concerning the actual state of RFID uptake. "The Bain 2005 management tool survey" of 960 global companies ranked 25 management tools on a scale of 1 (worst) to 5 (best). The survey found that RFID was last in usage with only 13 percent of respondents reporting the use of RFID and ranked 12th in satisfaction with an average score of 3.89. Yet, in cases where a tool had been implemented as part of a major organizational effort, RFID ranked first with an average score of 4.43 (Rigby and Bilodeau, 2005). Then in the Bain 2007 management tool survey, RFID was again last in usage with only 23 percent of respondents reporting its use and ranked 24th in satisfaction with an average score of 3.55. In cases where a tool had been implemented as part of a major organizational effort, RFID again ranked first with an average score of 4.34 (Rigby and Bilodeau, 2007).

Compounding the confusion concerning RFID is the lack of information on RFID implementations. Moore (2005) reported that RFID vendors and systems integrators have signed non-disclosure agreements, thereby preventing them from discussing these RFID implementations. In January, 2007 Wal-Mart had 600 mandated suppliers tagging cases and pallets (Swedberg, 2007a) being sent to five distribution centers and 1,000 stores (McWilliams, 2007). Yet, with all these suppliers deploying RFID, there is a lack of information concerning the quantitative results of those deployments. In our opinion, this wall of silence regarding empirical evidence of RFID has created a black hole around RFID. This wall of silence has had a duel effect; first, fueling speculation that RFID is a failing technology and second, allowing exaggerated estimates of benefits to go unverified.

In order to mitigate unrealistic expectations and false perceptions of RFID technology due to published hype, Hardgrave and Miller (2006) identified ten popular RFID myths (both positive and negative). For each myth discussed they presented the current reality of RFID. They concluded their paper by stating:

> Separating myth from reality should help provide rational expectations and perceptions so that organizations, consumers, and governments have a more realistic understanding of RFID (Hardgrave and Miller, 2006, p. 14).

Lee and Ozer (2007, p. 41) also reviewed the estimates of RFID benefits that were reported by numerous consulting companies and solution providers. Their conclusion states "there exists a credibility gap in all these reports, and in extreme cases, they amount to hypes".

From the above discussion, it is clear that there is considerable confusion concerning the benefits of RFID. In this paper we present the results of an extensive literature survey of practitioner focused articles and academic papers to identify empirical examples of RFID impact on supply chain performance. The remainder of our paper is organized as follows. First, we review the relevant literature on RFID. Next we present the business process framework we use to organize the empirical evidence of supply chain performance improvements due to RFID and we classify the evidence according to the framework. Then we propose a stage model explaining the effects of RFID on supply chain and five propositions for future research, followed by the discussion of the managerial and academic implications of our findings, and lastly we provide implementation advice for practitioners and suggestions for further research on RFID systems.

2. Literature review

The recent academic interest in RFID has generated a rapidly growing body of RFID and related literature. Therefore, in this section we review the RFID literature with a focus on those papers that are most relevant to the supply chain. We acknowledge the large number of papers that focus on health care applications of RFID, the ethics of deploying RFID, and RFID technology and security issues. See Chao *et al.* (2007) and Ngai *et al.* (2008) for historical literature reviews and analysis of RFID research. We classify the research literature of RFID in the supply chain into three areas: RFID overview (Table I), empirical studies (Table II) and analytical studies (Table III). The following sections provide a brief discussion of selected studies in each area and Tables I to III provide a complete list of studies and references.

Most early literature on RFID provides a general overview in this field. Topics include the RFID technology itself and its applications in the supply chain (Byfield, 1996), benefits (Kärkkäinen and Holmström, 2002), managerial guidelines (Angeles, 2005), and implementation challenges and strategies (Li and Visich, 2006) among others. A few papers focus on the use of RFID in either a specific industry or a specific country. For example, Davis and Jones (2004) made a case for the deployment of RFID

Overview study type	Emphasis
General overview	
Byfield (1996)	Current and future applications of RFID
Penttilä *et al.* (2004)	RFID technology and applications
Srivastava (2004)	RFID technology and applications
Spekman and Sweeney (2006)	RFID technology and applications
Reyes and Frazier (2007)	RFID technology and applications
Kärkkäinen and Holmström (2002)	Potential benefits in the supply chain
McFarlane and Sheffi (2003)	Improve logistics processes of shipping, transportation, receiving and in-facility operations
Lapide (2004)	Benefits of RFID for forecasting
Riemenschneider *et al.* (2007)	Business values of RFID in supply chain
Angeles (2005)	Managerial guidelines in implementation
Li and Visich (2006)	Advantages, supply chain impacts, implementation challenges, and strategies
Tajima (2007)	Identified 15 distinct benefit types; made four propositions on RFID & competitive advantage
Cannon *et al.* (2008)	Theory base to illustrate the benefits, complexities, and risks accompanying RFID adoption
Jansen and Krabs (1999)	RFID to control returnable containers
Visich *et al.* (2007)	Use of RFID in the closed-loop supply chain
Brewer and Sloan, 1999	Use of RFID as tracking technology in manufacturing and the supply chain
McFarlane *et al.* (2003)	Use of RFID for shop floor control
Twist (2005)	The impact of RFID on supply chain facilities
Specific industry	
Davis and Jones (2004)	The deployment of RFID in the military supply chain
Småros and Holmström (2000)	Use of RFID in the grocery industry
Prater *et al.* (2005)	Use of RFID in the grocery industry
Gessner *et al.* (2007)	Use of RFID in the grocery industry
Sellitto *et al.* (2007)	Information value associated with RFID in the retail supply chain
Specific country	
Jones *et al.* (2004)	Opportunities and implementation challenges of RFID for retailers in the United Kingdom
Scavarda *et al.* (2006)	Short case examples of RFID applications in Brazil

Table I. Summary of RFID overview literature in supply chain management

in the military supply chain while Scavarda *et al.* (2006) presented short case examples of RFID applications in Brazil.

Empirical studies of RFID are dominated by case studies in big retailers or distributors such as UK retailer Sainsbury's (Kärkkäinen, 2003), Wal-Mart (Hardgrave *et al.*, 2008a; Hardgrave *et al.*, 2008b), and Metro Group (Loebbecke, 2007). Lai *et al.* (2005) and Brown and Russell (2007) discuss the issues relating to RFID adoption in China and South Africa respectively through interviews. Survey papers have mainly focused on the commitment to adopt RFID, and on the benefits and challenges of RFID implementations. One of the problems the exploratory surveys encountered was the low percentage of respondents who had actually implemented or were pilot testing RFID.

Recent literature includes a rapidly growing number of modeling papers in the areas of finance, inventory and manufacturing. Financial studies include the cost and

Table II. Summary of RFID empirical studies literature in supply chain management

Empirical study type	Emphasis
Case studies	
Kärkkäinen (2003)	Supply chain efficiency of short shelf life products at UK retailer Sainsbury's
Hardgrave *et al.* (2008a)	Impact of RFID on inventory accuracy through a field study of Wal-Mart stores
Hardgrave *et al.* (2008b)	RFID's impact on stockouts and the effect of sales velocity at Wal-Mart
Loebbecke (2007)	Clothing manufacturer to retail department store supply chain in Germany
Chow *et al.* (2006)	Forklift route optimization 4 of a GENCO Distribution System warehouse
Langer *et al.* (2007)	Impact of RFID on the outbound logistics operations for a GENCO return center
Delen *et al.* (2007)	Detailed illustration of a product moving through a distribution center to the retail shelf
Holmqvist and Stefansson (2006)	Volvo's supply chain flow
Ngai *et al.* (2007)	An RFID-based traceability system at a Hong Kong aircraft engineering company
Choy *et al.* (2007)	An RFID system to improve supply chain visibility for a medium sized 3PL
Kim *et al.* (2008)	RFID-based logistics system by Korean 3PL provider CJ-Global Logistics Service
Pålsson (2007)	Use of participant observation to describe a RFID implementation in a retail supply chain
Pålsson (2008)	Container tracking study of a large packaging company and its logistics providers
Interview	
Lai *et al.* (2005)	Adoption issues in China
Brown and Russell (2007)	Adoption issues in South Africa
Survey	
Bendoly *et al.* (2007)	RFID benefits and commitment to adopt
Whitaker *et al.* (2007)	Utilized two *InformationWeek* surveys to address both RFID adoption and business value
Vijayaraman and Osyk (2006)	The implementation of RFID in the warehouse industry
Reyes *et al.* (2007)	The extent of RFID adoption in industry
Angeles (2007)	Identify critical success factors
Godon and Visich (2007)	Perceptions on implementation challenges and benefits
Lin (2008)	Factors affecting RFID adoption by logistics providers in Taiwan
Angeles (2009)	Perceptions of the importance of absorptive capacity attributes related to RFID adoption

benefits of item-level tagging (Hou and Huang, 2006), and cash flow and risk (Ozelkan and Galambose, 2008). Inventory models are presented for vendor managed inventory (Szmerekovsky and Zhang, 2008), and the use of RFID tagged inventory to map supply networks (Bi and Lin, 2009). Manufacturing models include the use of RFID for mixed-model automotive assembly (Gaukler and Hausman, 2008), and for data collection, shop floor control and lot splitting (Hozak and Collier, 2008).

Analytical study type	Emphasis
Financial	
Adenso-Díaz and Gascón (1999)	Discounted payback analysis of the cash flows associated with the implementation of RFID
Hou and Huang (2006)	Cost/benefit modeling of item-level tagging in the Taiwanese printing industry
Ozelkan and Galambose (2008)	Financial modeling of various business scenarios and associated risk
Bottani and Rizzi (2008)	Cost/benefit analysis of pallet and case tagging in a three-echelon supply chain
Ustundag and Tanyas (2009)	Expected benefits and cost factors for an integrated three-echelon supply chain
Inventory	
Chande *et al.* (2005)	Modeled the monitoring and controlling of time-sensitive products through RFID
Heese (2007)	Inventory record inaccuracy modeling
Gaukler *et al.* (2007)	Item-level tagging modeling
Karaer and Lee (2007)	Modeling on information visibility and inventory decisions in reverse channel
Rekik *et al.* (2008)	Impact of RFID on reducing product misplacement errors at retail stores
de Kok *et al.* (2008)	Cost/benefit analysis of RFID to control for shrinkage due to theft
Wang *et al.* (2008a)	Modeling of a pull-based inventory replenishment system
Uckun *et al.* (2008)	Optimal investment in RFID to maximize profit by decreasing inventory inaccuracy
Szmerekovsky and Zhang (2008)	Inventory policy for item level tagging in a two-echelon, VMI system
Bi and Lin (2009)	Use of RFID to track inventory and map supply networks
Manufacturing	
Gaukler and Hausman (2008)	Use of RFID in mixed-model automotive assembly for process and quality savings
Hozak and Collier (2008)	Use of RFID for data collection, shop floor control and lot splitting

Table III. Summary of RFID analytical studies literature in supply chain management

As can be seen, the literature appears to have a substantial void in providing an extensive review of the existing empirical evidence of RFID in the supply chain. Our research attempts to fill this void, and as a result our hope is to provide practitioners and researchers with a better understanding of how RFID can be used to create value in the supply chain.

3. Empirical evidence of RFID

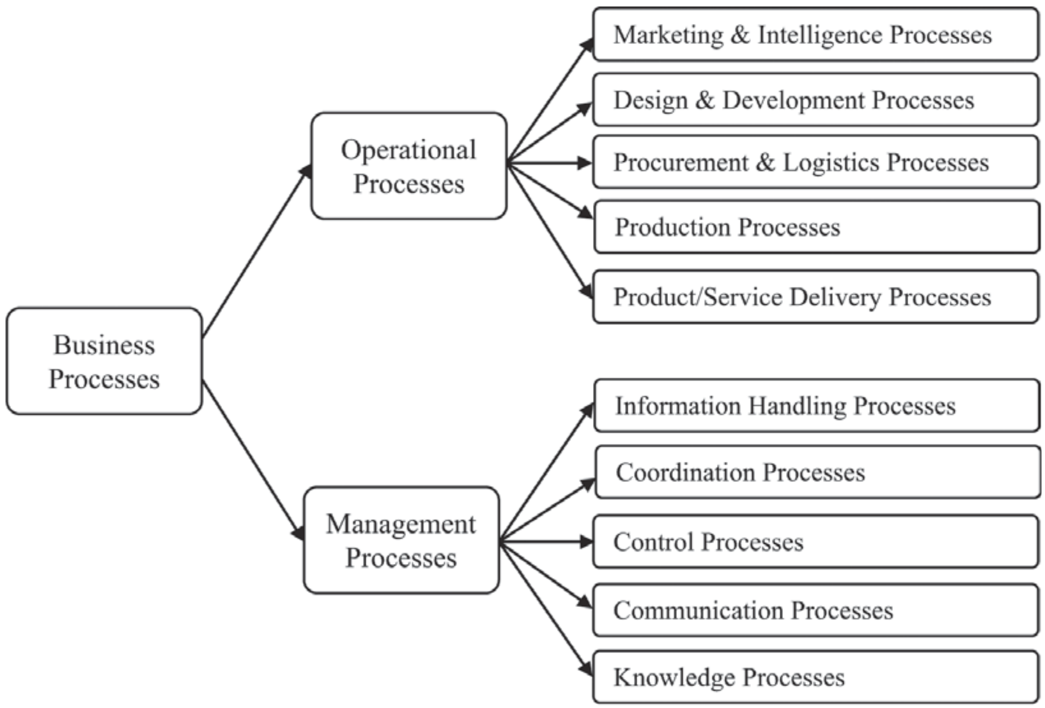
In our review of the empirical evidence of RFID in the supply chain we report only on those metrics that are based on actual results reported from a pilot study or an actual implementation. We purposely do not include: estimated benefits or benefits that have been masked to protect confidentiality (Langer *et al.*, 2007); results from unidentified companies (unless the results are significant); results that are difficult to separate due to phased implementations of information management systems and RFID (Choy *et al.*, 2007); and aggregated evidence from multi-year implementations across all of a company's facilities (Chappell *et al.*, 2002; Chappell *et al.*, 2003, Pålsson, 2008).

Several frameworks have been suggested to conceptualize the business value of RFID in the supply chain. Riemenschneider *et al.* (2007) proposed a RFID assimilation model that occurs in three waves: technology deployment, data understanding, and business value creation. Tajima (2007) presented several models where RFID deployment leads to competitive advantage. Based on the process-focused nature of the empirical evidence we have identified, we use the business process oriented framework proposed by Mooney *et al.* (1996) to organize our data. Cotteleer and Bendoly (2006) adopted the framework to investigate the immediate and on-going operational benefits from enterprise resource planning (ERP) implementations. In a different ERP implementation study, Karimi *et al.* (2007) used the framework to develop a business process outcomes construct. This construct measured the improvements ERP made in the efficiency, effectiveness and flexibility of processes impacted by the ERP system. Wang *et al.* (2008b) applied the framework to identify the effects of information technology (IT) on operational and managerial processes, and compared the degree of impact between firms that outsourced IT and those who kept IT in-house. In the following two sub-sections we first present the framework, define the processes, and discuss the three effects. We then define the business value metrics and categorize the empirical evidence in the framework.

3.1 The business process oriented framework

The business process oriented framework presented by Mooney *et al.* (1996) was originally developed to facilitate the assessment of the business value of information technology. Figure 1 shows the typology of processes introduced by Mooney *et al.* (1996) and our discussion of the typology follows from their work. Operational processes are those activities that are required to complete the work of the firm. In other words, the execution of tasks by the firms' functional business areas that make up the firms' value chain. Operational processes are affected by various forms of technology that can improve the efficiency of the value creating work. Management processes are those activities associated with administration, allocation, monitoring and control, which effectively and efficiently use the organizations' resources to do the work. Management processes are facilitated through improved availability and communication of information. Compared with barcodes, the use of RFID tags can improve efficiency and provide higher levels of information availability in identifying, processing and tracking goods as they move through the supply chain. Since RFID is an information and communication technology that is being utilized in a variety of business applications and processes, we adapt this framework for the empirical evidence from the implementation of RFID in the supply chain.

Mooney *et al.* (1996) proposed three linked effects on operational and management processes for value creation through information technology. In addition, for each business process – effect combination they defined several potential process level business value metrics. First, automational effects relate to the value derived from making the process more efficient. Operational process metrics include labor cost reductions, improved reliability and efficiency, and reduced throughput and inventory costs. Management process metrics include reduced administrative expense, better control of processes, easier reporting, and routinization. Second, informational effects



Source: Mooney *et al.* (1996)

Figure 1. Typology of business processes

are due to the ability of the technology to gather, store, process and distribute information. Improved utilization, quality and responsiveness, reduced waste, and greater operational flexibility were proposed as operational process metrics. Management process metrics include improved effectiveness, decision quality, resource usage and empowerment, and higher levels of creativity. Third, transformational effects refer to the ability of the technology to create process innovation and transformation. Reengineered operational process metrics include product and service innovation and enhancement, reduced cycle times, and high-level customer relationships. Management processes metrics include improved competitive flexibility and capability, and redesigned organizational form. See Table IV for a summary of the business value metrics for the processes and effects.

We next report on our classification of the empirical evidence using the above-discussed framework. In our classification we focus on efficiency to identify operational processes and on effective decision making for managerial processes, and we use the business value metrics for each process/effect as a guideline in organizing the data.

3.2 Operational processes empirical evidence

A total of 55 examples of operational business value for RFID were identified as shown in Table V. A significant majority of the evidence (47 examples) were categorized as automational, while five were identified as informational and only three as transformational. For automational effects, we added the sub-categories of shipping efficiency and receiving efficiency to Table V because of the large number of empirical evidence examples for these two specific logistics processes. Table V shows that automational effects of RFID on operational processes includes reduced cost, improved

Table IV.
Business value metrics

	Automational	Informational	Transformational
Operational (Focus on efficiency)	Labor cost Reliability Efficiency Inventory costs Throughput	Utilization Quality Responsiveness Waste Operational flexibility	Product and service innovation Cycle times Customer relationships
Management (Focus on effective decision making)	Administrative expense Control Reporting Routinization	Effectiveness Decision quality Resource usage Empowerment Creativity	Competitive flexibility Competitive capability Organizational form

Source: Mooney *et al.* (1996)

shipping and receiving efficiency, improved inventory control, reduced inventory cost and reduced throughput time.

One of the major automational effects was in the area of inventory control where the use of RFID can lead to a complete elimination of manual shelf inspections and automatic triggering of shelf replenishment based on recorded product movement, which then reduced stockouts. We have previously noted that reducing inventory and out-of-stock merchandise were two objectives of Wal-Mart's RFID initiative (Seideman, 2003). Wal-Mart holds approximately 20 billion US dollars in inventory and has an annual inventory turnover of around six. Increasing inventory turns from six to 12 at Wal-Mart could free up 12 to 14 billion dollars in cash (Corsten and Gruen, 2006). An analysis of out-of-stocks conducted by Corsten and Gruen (2003) found that the average out-of-stock rate in 40 cases was 8.3 percent and that 75 percent of the responsibility rested at the store level.

A six-month study by Hardgrave *et al.* (2008b) of 4,554 items in 24 Wal-Mart stores found that stock outs were reduced by 26 percent at the 12 RFID-enabled stores. Stratification of the items by sales velocity (the number of units sold per day) showed reductions of 20 percent to 36 percent for those items with a sales velocity of 0.1 to 7 units a day and 62 percent for items with a sales velocity of seven to 15 units per day. There was no impact on items with a sales velocity of greater than 15 units a day, but 90 percent of the items in the study had a sales velocity of 3 or less. However, during the course of this study, stockouts also declined at the control stores, with the net effect being a 21 percent reduction in the test stores compared to the control stores. Hence, we report a 21 percent reduction in Table V, not a 26 percent reduction. According to Hardgrave *et al.* (2008b), Wal-Mart had other ongoing initiatives unrelated to RFID technology which helped the control stores reduce stockouts. They also postulate that the Hawthorne Effect, the recognition that workers could be motivated by attention from management (Reid and Sanders, 2005), could have influenced employee behavior at the control stores.

In addition, some of these automational gains are impressive and are due to the ability of RFID to automatically count the goods on a pallet and reconcile the amount with the invoice. For example, during a three-month pilot study at a Staples Business Depot retail store in Toronto, Canada, barcodes were replaced with RFID tags and

Automational	
Labor cost	Warehouse labor reduction of 14 percent (Burnell, 2005) Elimination of two-yard administration positions (*RFID Journal*, 2002b) Production employees reduced from 20 to 12 with no change in production volume (O'Connor, 2008a) Production labor cost reduced 17 percent (Violino, 2005) Customs processing labor cost for containers reduced by 25 percent (O'Connor, 2007f) Reduced labor by up to 60 hours to count inventory (O'Connor, 2008c)
Efficiency	Retail shelf inventory replenishment three times faster (Sullivan, 2005b) Warehouse handling time reduced by 50 percent (Deffree, 2005) Time for double transaction at yard (drop-off and pick-up) reduced by 66 percent (Blanchard, 2004) Yard gate efficiency improved 75 percent (O'Connor, 2007e) Yard gate personnel productivity improved 50 percent (Blanchard, 2004)
Shipping efficiency	Time to process an order for shipment reduced from 45 minutes to six minutes; or reduced to 20 seconds compared with 80 seconds to 20 minutes for a bar code system; or reduced by 80 percent (Shister, 2005; O'Connor, 2007d; Katz, 2006; Bacheldor, 2006) Pallet build speed reduced from 90 to 11 seconds (Shister, 2005) Average time to load a truck reduced from 50 to 20 minutes; truck loading 40 percent faster than handheld barcode system (Swedberg, 2007d; *RFID Journal*, 2003) Read time for reusable assets (dolly and 25 trays) reduced by 83 percent (Wilding and Delgado, 2004b) Time to check quantity and mix of goods at distribution center reduced 68 percent (Wessel, 2008a)
Receiving efficiency	Pallet breakdown decreased from 17.75 minutes to 2.7 minutes at retail store (O'Connor, 2006b) Arrival inspection time reduced 10 percent to 50 percent (Holmqvist and Stefansson, 2006) Check in and truck unload time reduced 15 to 20 minutes (Burnell, 2005) Order verification time reduced from 20 seconds to five seconds (Katz, 2006) Productivity increase for goods receipt of 57 percent (Bacheldor, 2006) Time needed to compare deliveries with orders reduced 80 percent (Wessel, 2007) Time to process a delivered pallet at DC reduced from 5.36 to 2.65 minutes a 51 percent reduction (O'Connor, 2006b) Time to check quantity and mix of goods at grocery store reduced 80 percent (Wessel, 2008a) Time required to receive apparel at a distribution center reduced by 70 percent (Wessel, 2008b)
Inventory control	Retail store stock-outs reduced by 11 percent; 21 percent; 25 percent; 26 percent; or 50 percent (Burnell, 2005; Hardgrave *et al.*, 2008b; O'Connor, 2007b; O'Connor, 2007c; Webster and Wal-Mart's, 2008) Warehouse inventory count accuracy increase from 96 percent to 99 percent (*RFID Journal*, 2002a) Retail store reduction in understated perpetual inventory of 13 percent (Hardgrave *et al.*, 2008a) Reduction in phantom inventory of 50 percent (*Chain Store Age*, 2007a) Time reduction of 80 percent to count inventory (Roberti, 2007)

(*continued*)

Table V. Dimensions of RFID operational business value

	Inventory count accuracy of 98.4 percent; or 99.6 percent (Collins, 2006a; O'Connor, 2007b)
	Retail store customer service level improved from an average of 85 percent to 99 percent (Gaudin, 2008)
	Retail store inventory accuracy of > 99 percent (O'Connor, 2008c)
Inventory cost	Lost goods reduction of 18 percent (Burnell, 2005)
	Shrinkage reduced by 15 percent (Wilding and Delgado, 2004b)
	Reduced perishable product loss by 10 percent (Swedberg, 2007f)
	Safety stock reduction of 30 percent (Wessel, 2008a)
	Warehouse inventory reduced by 50 percent; or 17 percent (O'Connor, 2008b; Roberti, 2008)
Throughput	Reusable container lead time reduced 15 percent (Tierney, 2004)
	Daily yard throughput increased 38 percent during peak season (Blanchard, 2004)
	Production lead time reduced 27 percent (O'Connor, 2006c)
	Production capacity increased 6.5 percent, (Collins, 2004b)
	Supply chain inbound and outbound through-put time reduced by 50 percent (Deffree, 2005)
	Number of goods processed at warehouse doubled and sometimes tripled (O'Connor, 2007g g)
	Accuracy of pallets shipped to customers increased from 92 percent to 97 percent (Chow *et al.*, 2006)
	Container locating reduced from 4 to 12 hours to immediately (Schor, 2006)
	Product locating accuracy of 99.9 percent (Swedberg, 2007b)
Informational	
Utilization	Reusable container loss reduced from 4 percent to 2 percent (Wilding and Delgado, 2004a)
	Reusable container purchasing cost reduced by 4 million pounds per year (Wilding and Delgado, 2004a)
Responsiveness	Rush order processing time reduced from six hours to three and sometimes two hours (O'Connor, 2007g)
	Supply chain response time reduced from seven to five days (Swedberg, 2007e)
Waste	Packaging errors eliminated (Bacheldor, 2007)
Transformational	
Process redesign	Production cycle time reduced from 88 to 46 minutes (Collins, 2004b)
	Parts replenishment process redesign freed up 50 percent more floor space to the manufacturing line which along with efficiency improvements from RFID to boost production from 175,000 units annually to 275,000 (57 percent capacity increase) without expanding the facility and with a reduced workforce (O'Connor, 2007e)
	Military supply chain average delivery time reduced from 28 to 16 days, supply backlog reduced from 92,000 shipments to 11,000, inventory reduced from US$127 million to $70 (Collins, 2006c)

Table V.

pallet breakdowns reduced from 17.75 minutes to 2.7 minutes. Pallets sent to stores carried a large number of different products (O'Connor, 2006b).

Another automational example comes from the food division of London-based retailer Marks & Spencer. They deployed RFID tags to track 3.5 million reusable plastic trays contained in plastic dollies (Jones *et al.*, 2004). Annual throughput of plastic trays is approximately 85 million and 70 percent of the product line is perishable. Marks & Spencer implemented a pilot study that replaced bar codes with RFID tags when they had to replace non-standard containers with European-sized containers. The reported benefits included an 83 percent reduction in read time for each tagged dolly, a 15 percent reduction in shrinkage (Wilding and Delgado, 2004b), and a 15 percent reduction in lead time (Tierney, 2004). In this case RFID impacted three business value metrics:

(1) shipping;

(2) inventory control; and

(3) throughput.

The evidence of informational effects from RFID is rather limited compared to that of automational effects. Scottish Courage, one of the largest brewers in the UK, tagged 1.9 million kegs with low frequency, read/write tags and equipped 26 depots and 600 vehicles for tracking. Implementation required training 2,000 employees in data collection during filling at brewery, delivery to customer, pickup from customer and return to brewery for a database capable of tracking 32 million movements a year. Some of the reported benefits were a reduction in keg losses from 4 percent to 2 percent, the identification and elimination of "unofficial supply chains", and a reduction in distribution overheads due to fewer distribution errors. In addition, no new containers were needed to be purchased over a three-year period representing a saving of 4 million pounds/year (Wilding and Delgado, 2004a). A possible reason for the lack of evidence of RFID impact on informational effects on operational processes could be our focus on quantifiable results. For example, information on inventory availability in the backroom can be used to trigger a stock replenishment process such that stockouts are prevented and inventory turnover is increased. While the automational effects of that information can be quantified, the benefit of the informational impact is difficult to quantify. This is especially the case since the inventory information could also be used to locate the inventory, verify inventory accuracy and cost the inventory.

Transformational effects of RFID are mainly generated by operational process redesign. Club Car, a manufacturer of golf and utility vehicles in Augusta, Georgia, redesigned its manufacturing facility and process with an RFID system. The new production line is capable of mixed-model production of over 100 customization options and production time was reduced from 88 to 46 minutes. Tagged skids are controlled by the Manufacturing Execution System at each of the 46 workstations and RFID saved three seconds at each workstation, generating a 6.5 percent increase in capacity (Collins, 2004b). Another example is an RFID-based parts replenishment system at the Cami Automotive plant in Ingersoll, Ontario. This system allows workers to press a button to activate an RFID tag requesting a replenishment order which is sent to an RFID equipped forklift operator. The new system freed up 50 percent more floor space along the manufacturing line which, along with efficiency improvements from RFID, boosted production from 175,000 units annually to 275,000. This 57 percent capacity increase was accomplished without expanding the facility and with a reduced workforce (O'Connor, 2007e). In addition, the United States Marines implemented RFID for their supply chain to Iraq. The impact was to reduce average delivery times from 28 to 16 days, supply backlog from 92,000 shipments to 11,000, and total inventory value in the supply chain from $127 million to $70 million (Collins, 2006c).

In sum, it can be seen that the major effect of RFID implementation on operational processes is primarily automational. Empirical evidence of RFID on informational and transformational effects on operational processes is very limited.

3.3 Managerial processes empirical evidence

Table VI lists 15 examples of empirical evidence of informational effects of RFID on managerial processes. No automational and transformational effects were found for managerial processes.

Automational	–
Informational	
Effective sales	Sales increase of 12 percent in retail apparel store – only denim apparel items tagged (Wilding and Delgado, 2004b)
	Sales increase of 15 percent in retail apparel store – individual garments tagged (O'Connor, 2008c)
	Unit sales increases of 14 percent; 14.1 percent; and 41.1 percent (O'Connor, 2006a; *Chain Store Age*, 2007b; Hudson, 2007)
	Sales dollar increases of 14 percent; 18.7 percent; and 30 percent (Hudson, 2007; *Chain Store Age*, 2007b; Swedberg, 2007c)
Effective retail promotions coordination	Promotion product availability of 92 percent by day three of the promotion launch (Collins, 2006b)
	Sales increase for stores that moved the display to the location before the promotion began: 48 percent; 61 percent; or 140 percent (Roberti, 2005; Roberti, 2006; Chain Store Age, 2007a)
Invoice reconciliation	Discrepancies reduced from 80 percent to 0 percent (Collins, 2005)
	Container shipment records accuracy increase from 70 percent to 100 percent (O'Connor, 2007f)
Decision quality	Reduction in manual inventory orders of 10 percent or 42 percent (Sullivan, 2005b; O'Connor, 2007a)
	Reusable container cycle time reduced from 47 days 40 days – enables postponement (*RFID Journal*, 2002b)
	Annual procurement cost reduced 11 percent (Violino, 2005)
	Stock turnaround increase from 5.5 to 6 (O'Connor, 2007d)
Resource usage	Yard parking spaces required reduced up to 40-60 at any given time (Blanchard, 2004)
	Reduced required tractors from 120 to 67 in one year (*RFID Journal*, 2002b)
Production control	Production planning accuracy improved 29 percent (O'Connor, 2006c)
Transformational	–

Table VI. Dimensions of RFID managerial business value

The empirical evidence of informational effects of RFID on managerial processes indicates that RFID can increase sales, improve retail promotions coordination, improve reconciliation, improve decision making effectiveness and quality, improve resource usage, and improve production control. A Proctor & Gamble pilot study to track the Braun CruZer electric shaver for a Father's Day promotion found that stores that put the display out on time had 61 percent greater sales than those that got them out late (Roberti, 2006). Another Proctor & Gamble pilot study for the new Fusion razor achieved a 92 percent product availability by day three of the launch, whereas the industry average is only 60 percent to 80 percent (Collins, 2006b). In the apparel industry, RFID-enabled mirrors have been used to enhance the shopping experience and to increase sales. Upscale Hong Kong fashion label and retailer had a sales increase of 30 percent at two stores using an RFID-enabled mirror in the dressing room. The system reads the garment and visually recommends mix-and-match items, which provides the customer with more choices and hence more sales opportunities (Swedberg, 2007c).

No single example of automational and transformational effects of RFID on managerial processes was found in this study. This may be explained partially by the early stage of RFID implementation and the quantified focus of our study. Compared to the effects of RFID on operational processes, its impacts on managerial processes are very limited.

3.4 Discussion of findings and propositions

Our analysis shows that the major effects from the implementation of RFID are automational effects on operational processes and informational effects on managerial processes. The finding is consistent with the three-stage model suggested by Mooney *et al.* (1996) regarding the impact of IT on business value. According to Mooney *et al.* (1996), first order effects of IT on operational processes are automational, resulting primarily from the automation of certain operational processes; and the first order effects of IT on managerial processes are informational primarily through the availability of better information for control, coordination, and decision-making. As a consequence of process automation and innovation, the information content of operational processes increases, thus generating the second order effect (informational effects) of IT on operational processes. At the same time, process innovations reduce the amount of information processing and automate certain aspects of management processes, thus creating second order effects (automational effects) on managerial processes. In other words, the second order effects of IT are the extension of the automational effects of IT to managerial processes and the extension of informational effects to operational processes. In addition, a third order transformational effect of IT is originated from the new capabilities and new ways of doing business.

If we apply the above model to the impact of RFID on the supply chain, a three-stage model can be proposed. The first order impact of RFID on supply chain is associated with automational effects on operational processes by reducing labor, automating inventory count and control, and reducing throughput time, and is also associated with informational effects on managerial processes through the availability of better information for production control, decision making, and coordination and resource usage. In this stage, RFID is mainly implemented at a certain entity (retail store, warehouse/distribution center and manufacturing) in a supply chain. RFID is used to automate certain operational processes, such as inventory count, product locating, and goods shipping and receiving. At the same time, the implementation of RFID will have informational effects on managerial processes since it generates real-time information for better management. This argument is verified by our empirical evidence indicating that the majority of RFID implementations has only first order impact on the supply chain. This is probably due to an early stage of RFID adoption by organizations.

With the automation of operational processes, the availability of rich information for managerial processes, and the increased breadth and depth of RFID implementation across the supply chain, RFID will have the second order impact on the supply chain. This involves not only informational effects on operational processes but also automational effects on managerial processes. The focus of this stage will be the better understanding and utilization of information generated from RFID systems. By analyzing and utilizing such information, organizations will be able to improve resource utilization, increase operational flexibility and responsiveness, and improve quality (informational effects on operational processes). In addition, the accumulation, analysis and utilization of information from managerial processes will enable the automation/routinization of certain managerial processes, such as ordering, inventory replenishment and forecasting. Only limited empirical evidence was found in this study to support the second order impact of RFID on supply chains. This is not surprising. Since RFID is still at an early stage of implementation, most organizations only implement RFID at a minimum level to meet the mandates from, e.g. Wal-Mart and the Department of Defense and only a few organizations are able to fully utilize the information generated from RFID systems. In fact, the effective use of the massive data captured by RFID systems and the incorporation of RFID technology throughout the whole supply chain has been cited as a major issue in RFID implementation. Venture Development Corp. surveyed 100 Chief Technology Officers and found that data management and monitoring has been rated as one of most important issues in the implementation of RFID systems. More than half of the surveyed individuals expressed concern with the quality and synchronization of the data generated by RFID devices. Field research conducted by Wal-Mart, the Auto-ID Center and key suppliers at Wal-Mart's pilot distribution center in Oklahoma for tagging of cases resulted in the generation of 30 times more data as products were tracked through the supply chain (Wilding and Delgado, 2004b).

The third order effects of RFID will be transformational, driven by process innovation and supply chain redesign to achieve competitive advantage. In this stage, the implementation of RFID systems will revolutionize supply chain dynamics by significantly increasing supply chain transparency through the dissemination of large amounts of accurate, real-time data. This data can be used to enhance decision making throughout the supply chain to increase supply chain efficiency by reducing lead times and inventory levels, while minimizing stockouts, overstocks and shrinkage. These improvements should lead to higher levels of customer satisfaction, sales and profits, and sustainable competitive advantage.

Based on the above discussions, we make the following propositions regarding RFID technology in the supply chain. Future research could test or modify these propositions.

P1. The effects of RFID on operational and managerial processes follow a stage model.

P2. For operational processes, RFID will first enable automational effects, followed by informational effects and then transformational effects.

P3. For managerial processes, RFID will first enable informational effects, followed by automational effects and then transformational effects.

P4. For operational processes, RFID will facilitate transformational effects when the process is reengineered to significantly reduce production or supply chain cycle times.

P5. For managerial processes, RFID will facilitate transformational effects when the process is reengineered to significantly improve competitive capability.

A significant majority of the empirical evidence comes from pilot studies, and few firms have implemented end-to-end RFID applications in their internal operations or in their extended supply chain. Moreover, none of the examples from the literature (academic and practitioner) are supported by a detailed cost/benefit analysis. For example, in the Hardgrave *et al.* (2008b) study, the cost of deploying RFID to count the inventory versus the cost of hiring additional employees to count the inventory is not explored. However, they do report the potential sales gains for Wal-Mart and for their suppliers if stockouts can be reduced by 21 percent. In many published reports the examples of empirical evidence are presented with very little information on the implementation. Details are lacking and rigid scientific methods are not employed. The only exceptions that we are aware of are the Hardgrave *et al.* (2008a, 2008b) studies on perpetual inventory accuracy and on stockouts. Another issue with the evidence is the controlled nature of the pilot studies that focused on narrow applications. No evidence is presented on how the RFID implementation impacted other processes. For example, if you speed up only the receiving process with RFID, you have now made the put-away process a bottleneck. If the facility does not have enough room to store the off-loaded material on the receiving dock, then the gains from RFID are reduced or even negated.

In many cases, the gains are not due solely to RFID technology. As noted in the Introduction, the two Bain management tool surveys (Rigby and Bilodeau, 2005, 2007) found that RFID ranked first in satisfaction when it was implemented as part of a major organizational effort. The three transformational effect examples in Table V clearly represent processes that underwent significant change, where RFID was just part of the new design. Turkish sock manufacturer Gelal's 40 percent productivity improvement was also facilitated by the replacement of barcoded cloth bags with RFID tagged plastic totes to move work-in-process (O'Connor, 2008a). The use of just the totes should have facilitated the scanning process by providing a stable and consistent backing for the paper barcode. In discussing the implementation of RFID at American Apparel, RFID technology director Zander Livingston stated:

> A big part of the project was organizing the store in the first place, and that alone helps you increase sales (O'Connor, 2008c).

Hence, organizing for RFID helps you see other problems that need to be fixed in order to maximize the benefits from the RFID implementation.

4. Research implications and conclusions

This research has implications for practitioners and academics. The empirical evidence presented shows the impact of RFID expressed as quantitative values, not just as estimates or in vague and unclear statements such as "improved inventory visibility" or "sped up the receiving process". Significant benefits have been reported for a variety of processes and performance measures. In addition, we have classified the empirical evidence into operational and managerial processes, and the effect: automational, informational, and transformational. As far as we are aware, this is the first attempt to collect and organize the reported empirical evidence on RFID deployment. The proposed stage model provides a systematic way of examining the benefits of RFID on the supply chain.

For managers, the empirical evidence presented can help them identify implementation areas where RFID can have the greatest impact. The data can be used to build the business case for RFID and therefore better estimate ROI and the payback period. Academics can use the data as modeling parameters for manufacturing, logistics, supply-chain and retail studies. However, it must be said that the implementation of RFID is still at the early stage and the majority of deploying companies have not yet fully obtained the estimated benefits reported in the literature.

Moeeni (2006) noted that Moore's law favors RFID as the costs associated with implementing RFID systems have continuously declined while performance has improved. Moeeni also stated that according to Metcalfe's law, as more organizations deploy RFID the business value of RFID should increase. We agree with these assessments and our research has shown there is a business case to be made for RFID. However, it is up to each individual business to implement RFID in order to improve process efficiency and through business analysis to identify revenue-enhancing opportunities in the market.

For completeness it is important to point out some of the limitations of our research. First, the empirical evidence cited in this paper was collected from secondary sources and therefore not directly observed by the authors. This leads to the second limitation, which is the lack of consistency in performance measure definitions. A third limitation of this research is its focus on quantifiable data and the measurement of informational effects on operational business value, as discussed in Section 3.2. In addition, we do not distinguish between pilot studies and full implementations of RFID. As noted in Section 3.3 by Hardgrave *et al.* (2008b) a Hawthorne Effect could have impacted the results, especially the pilot study data. Finally, all articles reviewed were those written in English only. Given the significant level of RFID interest in Europe, Asia and Latin America we are sure to have missed empirical evidence possibly published in other languages.

Future study can test the stage model and associated propositions proposed in this study through a survey methodology. Future research should also focus on scientifically rigorous case studies that investigate and report in detail the impact of RFID on multiple processes across the organization and the supply chain, including cross-functional applications such as between operations and marketing. In addition, research should investigate how RFID can be used by accountants to help meet Sarbanes-Oxley audit requirements for actual inventory costs as it moves through the supply chain as well as the accuracy of physical inventory at points in the supply chain (Davis and Luehlfing, 2004).

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Further reading

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