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# **Empirical Evidence of RFID Impacts on Supply Chain Performance**

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## **Abstract**

**Purpose** – A great deal of confusion exists in the literature concerning the benefits of radio frequency identification (RFID). The purpose of this paper is to investigate the actual benefits of 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. We classify the evidence by process (operational or managerial) and for each process by effect (automational, informational, and transformational).

**Findings** – The empirical evidence showed that the major effects from the implementation of RFID are automational effect on operational processes followed by informational effects on managerial processes. The RFID implementation has not reached transformational level on both operational and 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 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 frequency identification, RFID, Auto-ID, Supply chain, Empirical results, Business value

**Paper type** General review

## **1 Introduction**

Radio frequency identification (RFID) has received increased attentions from practitioners and academicians. Due to the mandates from Wal-Mart (O'Connor, 2005) and the United States (U.S.) Department of Defense (Collins, 2004a), January 2005 can be considered 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 U.S. 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); 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 began showing 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%). Other top concerns were cost (23.1%), no benefit to us (11.5%) and lack of support from Wal-Mart (7.7%) (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).

The benefits and issues related to RFID lead to confusion concerning the actual state of RFID. 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% of respondents reporting the use of RFID and ranked 12<sup>th</sup> 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% of respondents reporting and ranked 24<sup>th</sup> 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 5 distribution centers and 1000 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 dual effect, fueling speculation that RFID is a failing technology and 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 10 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” (p. 14). Lee and Ozer (2007) 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” (p. 41).

From the above discussion, it is clear 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 proposed 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 1), empirical studies (Table 2) and analytical studies (Table 3). The following sections provide a brief discussion of selected studies in each area and Table 1 to Table 3 provide a complete list of studies and references.

Most early literature in RFID provides a general overview in this field. Topics include 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 either RFID's use in a specific industry or a specific country. For example, Davis and Jones (2004) made a case for the

deployment of RFID 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 benefits of item-level tagging (Hou and Huang, 2006), and cash flow and risk (Ozelkan and Galambos, 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).

As can be seen, the existing literature appears to have a big 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 to effectively and efficiently use the organizations' resources to do the *work*.

Management processes are facilitated through improved availability and communication of information. Compared with bar-codes, 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 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 4 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 fifty-five examples of operational business value for RFID were identified as shown in Table 5. A significant majority of the evidence (forty-seven 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 5 because of the large number of empirical evidence examples for these two specific logistics processes. Table 5 shows that automational effects of RFID on operational process includes reduced cost, improved 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 U.S. dollars in inventory and has an annual inventory turnover of around 6. Increasing inventory turns from 6 to 12 at Wal-Mart could free up 12 to 14 billion dollars in cash (Corsten & Gruen, 2006). An analysis of out-of-stocks conducted by Corsten and Gruen (2003) found that that average out-of-stock rate in 40 cases was 8.3% and that 75% of the responsibility rested at the store level.

A six month study by Hardgrave *et al.* (2008b) of 4554 items in 24 Wal-Mart stores found that stock outs were reduced 26% at the twelve RFID-enabled stores. Stratification of the items by sales velocity (the number of units sold per day) showed reductions of 20% to 36% for those items with a sales velocity of 0.1 to 7 units a day and 62% for items with a sales velocity of 7 to 15 units per day. There was no impact on items with a sales velocity of greater than 15 units a day, but 90% 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% reduction in the test stores compared to the control stores. Hence, we report a 21% reduction in Table 6, not a 26% 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 3-month pilot study at a Staples Business Depot retail store in Toronto, Canada, bar-codes were replaced with RFID tags and pallet breakdowns went 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% 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% reduction in read time for each tagged dolly, a 15% reduction in shrinkage (Wilding and Delgado, 2004b), and a 15% reduction in lead time (Tierney, 2004). In this case RFID impacted three business value metrics: shipping, inventory control, and 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 2000 employees in data collection during filling at brewery,

delivery to customer, pickup from customer and return to brewery for a data base capable of tracking 32 million movements a year. Some of the reported benefits were a reduction in keg losses from 4% to 2%, 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 3 year period representing a savings 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 quantified 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. Especially 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 their 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 3 seconds at each workstation, generating a 6.5% 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% 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% 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 has fallen from 92,000 shipments to 11,000, and total inventory value in the supply chain was cut 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 6 lists fifteen examples of empirical evidence of informational effects of RFID on managerial processes. No automational and transformational effects were found for managerial processes.

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% greater sales than those that got them out late (Roberti, 2006). Another Proctor & Gamble pilot study for the new Fusion razor achieved a 92% product availability by day 3 of the launch, whereas the industry average is only 60% to 80% (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 Mi-Tu had a sales increase of 30% at 2 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 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 our quantified focus of the 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 the majority of RFID implementations has only first order impact on supply chain. This is 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 width and depth of RFID implementation across the supply chain, RFID will have the second order impact on the supply chain, which are not only informational effects on operational processes but also automational effects on managerial processes. The focus of this stage will be 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 chain. This is not surprising. Since RFID is still in an early stage of implementation, most organizations only implement RFID at a minimum level to meet the mandates from Wal-Mart and 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 (O'Connor, 2004). A 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.

**Proposition 1:** The effects of RFID on operational and managerial processes follow a stage model.

**Proposition 2:** For operational processes, RFID will first enable automational effects, followed by information effects and then transformational effects.

**Proposition 3:** For managerial processes, RFID will first enable informational effects, followed by automational effects and then transformational effects.

**Proposition 4:** For operational processes, RFID will facilitate transformational effects when the process is reengineered to significantly reduce production or supply chain cycle times.

**Proposition 5:** 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%. In many of 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 5 clearly represent processes that underwent significant change, where RFID was just part of the new design. Turkish sock manufacturer Gelal's 40% productivity improvement was also facilitated by the replacement of bar-coded cloth bags with RFID tagged plastic totes to move work-in-process (O'Connor, 2008a). The use of the just the totes should have facilitated the scanning process by providing a stable and consistent backing for the paper bar-code. 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 tremendous implications for practitioners and academicians. 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 of, 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. Academicians 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 analytics 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 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 Luehlhing, 2004).

## References

- Adenso-Díaz, B. and F. Gascón (1999) 'A payback model for radio frequency in warehousing,' *International Journal of Physical Distribution & Logistics*, Vol. 29, No. 10, pp. 631-645.
- Angeles, R. (2005), "RFID technologies: Supply-chain applications and implementation issues", *Information Systems Management*, Vol. 22, No. 1, pp 51-65.
- Angeles, R. (2007) 'Empirical study on the critical success factors for RFID implementation and their relationships with expected deployment outcomes,' *Proceedings of the 38<sup>th</sup> Annual Meeting of the Decision Sciences Institute*, pp. 1631-1636.
- Angeles, R. (2009) 'Perceptions of the importance of absorptive capacity attributes as they relate to radio frequency identification implementation by firms anticipating radio frequency identification use,' *International Journal of Management and Enterprise Development*, Vol. 6, No. 1, pp. 88-117).
- Anonymous (2002a) 'Part 5: Warehousing efficiencies,' *RFID Journal*, October 14, <http://www.rfidjournal.com/article/articleprint/200/-1/5/>, accessed October 19, 2005.
- Anonymous (2002b) 'Part 6: Improving logistics,' *RFID Journal*, November 18, <http://www.rfidjournal.com/article/articleprint/201/-1/5/>, accessed October 19, 2005.
- Anonymous (2003) 'RFID speeds P&G plant throughput,' *RFID Journal*, February 3, <http://www.rfidjournal.com/article/articleprint/291/-1/1/>, accessed March 2, 2005.
- Anonymous (2007a) 'RFID reconciles CPG and retailer relationships,' *Chain Store Age*, Vol. 83, No. 9, p. 6A.
- Anonymous (2007b) 'Best Buy's best-cost, customer-centric supply chain,' *Chain Store Age*, Vol. 83, No. 9, p. 4A.
- Bacheldor, B. (2006) 'Toshiba laptop plant raises productivity,' *RFID Journal*, November 13, <http://www.rfidjournal.com/article/articleprint/2817/-1/1/>, accessed November 14, 2006.
- Bacheldor, B. (2007) 'RFID covers Durakon's assembly operations,' *RFID Journal*, January 22, <http://www.rfidjournal.com/article/articleprint/2987/-1/1/>, accessed January 25, 2007.
- Bendoly, E., A. Citurs and B. Konsynski (2007) 'Internal infrastructural impacts on RFID perceptions and commitment: Knowledge, operational procedures, and information processing standards,' *Decision Sciences*, Vol. 38, No. 3, pp. 423-449.
- Bi, H.H. and D.K.J. Lin (2009) 'RFID-enabled discovery of supply networks,' *IEEE Transactions on Engineering Management*, Vol. 56, No. 1, pp. 129-141.
- Blanchard, D. (2004) 'RFID at the gates,' *Logistics Today*, Vol. 45, No. 9, pp. 1, 16.

Bottani, E. and A. Rizzi (2008) 'Economical assessment of the impact of RFID technology and EPC system on the fast-moving consumer goods supply chain,' *International Journal of Production Economics*, Vol. 112, No. 2, pp. 548-569.

Brewer, A. and Sloan, N. (1999) 'Intelligent tracking in manufacturing', *Journal of Intelligent Manufacturing*, Vol. 10, Nos. 3-4, pp. 245-250.

Brown, I. and J. Russell (2007) 'Radio frequency identification technology: An exploratory study on adoption in the South African retail sector,' *International Journal of Information Management*, Vol. 27, No. 4, pp. 250-265.

Burnell, J. (2005) 'Real world RFID,' *Realtime*, Vol. 8, No. 1, pp. 26-29.

Byfield, I. (1996) 'Developments in RFID', *Sensor Review*, Vol. 16, No. 4, pp. 4-5.

Cannon, A., P.M. Reyes, G. Frazier and E. Prater (2008) 'RFID in the contemporary supply chain: multiple perspectives on its benefits and risks,' *International Journal of Operations & Production Management*, Vol. 28, No. 5, pp. 433-454.

Chande, A., S. Dhekane, N. Hemachandra and N. Rangaraj (2005) 'Perishable inventory management and dynamic pricing using RFID technology,' *Sadhana*, Vol. 30, Parts 2 & 3, pp. 445-462.

Chao, C.C., J.M. Yang and W.Y. Jen (2007) "Determining technology trends and forecasts of RFID by a historical review and bibliometric analysis from 1991 to 2005" *Technovation*, Vol. 27, No. 5, pp 268-279.

Chappell, L., D. Durdan, G. Gilbert, L. Ginsburg, J. Smith and J. Tobolski (2002) 'Auto-ID on delivery: The value of auto-ID technology in the retail supply chain', *MIT Auto-ID Center*, November 1, pp.1-26.

Chappell, L., L. Ginsburg, P. Schmidt, J. Smith and J. Tobolski (2003) 'Auto-ID on the line: The value of auto-ID technology in manufacturing', *MIT Auto-ID Center*, February 1, pp.1-30.

Chow, H.K.H., K.L. Choy, W.B. Lee and Lau, K.C. (2006) 'Design of a RFID case-based resource management system for warehouse operations', *Expert Systems with Applications*, Vol. 30, No. 4, pp. 561-576.

Choy, K.L., S.C.K. So, J.J. Liu, H. Lau, S.K. Kwok (2007) 'Improving logistics visibility in a supply chain: an integrated approach with radio frequency technology,' *International Journal of Integrated Supply Management*, Vol. 3, No. 2, pp. 135-155.

Collins, J. (2004a), 'DOD updates RFID policy,' *RFID Journal*, April 1, <http://www.rfidjournal.com/article/articleprint/856/-1/1/>, accessed July 13, 2004.

- Collins, J. (2004b) 'Golf car maker scores with RFID,' *RFID Journal*, March 22, <http://www.rfidjournal.com/article/articleprint/839/-1/1/>, accessed March 2, 2005.
- Collins, J. (2005) 'Hampton Unlocks ROI from RFID,' *RFID Journal*, April 11, <http://www.rfidjournal.com/article/articleprint/1489/-1/1/>, accessed November 2, 2005.
- Collins, J. (2006a) 'RFID implementation is an art,' *RFID Journal*, June 14, <http://www.rfidjournal.com/article/articleprint/2427/-1/1/>, accessed July 13, 2006.
- Collins, J. (2006b) 'P&G finds RFID 'sweet spot',' *RFID Journal*, May 3, <http://www.rfidjournal.com/article/articleprint/2312/-1/1/>, accessed May 18, 2006.
- Collins, J. (2006c) 'DOD quantifies payback from RFID',' *RFID Journal*, May 3, <http://www.rfidjournal.com/article/articleprint/2313/-1/1/>, accessed May 18, 2006.
- Corsten, D. and T. Gruen (2006) 'Wal-Mart: living up to new expectations', *ECR Journal*, Vol. 6, No. 1, pp. 9-18.
- Corsten, D. and T. Gruen (2003) 'Desperately seeking shelf availability: An examination of the extent, the causes, and the efforts to address retail out of stocks', *International Journal of Retail & Distribution Management*, Vol. 31, No. 11/12, pp. 605-617.
- Cooke, J.A. (2005), 'Slow but Steady,' *Logistics Management*, February, pp. 31-34.
- Cotteleer, M.J. and E. Bendoly (2006) 'Order Lead-Time Improvement Following Enterprise Information Technology Implementation: An Empirical Study,' *MIS Quarterly*, Vol. 30, No. 3, pp. 643-660.
- Davis, H.C. and S.R. Jones (2004) 'RFID technology: Is the capability a boon or burden for DoD?', *Air Force Journal of Logistics*, Vol. 28, No. 4, pp. 14-25.
- Davis, H.E. and M.S. Luehlfinfing (2004) 'Radio frequency Identification: The Wave of the Future,' *Journal of Accountancy*, Vol. 198, No. 5, pp. 43-49.
- Deffree, S. (2005) 'Philips rolls out RFID in its semi supply chain,' *Electronic News* (North America), March 7.
- Delen, D., B. Hardgrave and R. Sharda (2007) 'RFID for better supply-chain management through enhanced information visibility', *Production and Operations Management*, Vol. 16, No. 5, pp. 613-624.
- FDA (2004) 'Combating counterfeit drugs: A report of the Food and Drug Administration,' *U.S. Department of Health and Human Services, Food and Drug Administration*, Rockville, Maryland, February.



- Gaudin, S. (2008) 'Retailer looks to RFID to boost sales,' *Computerworld*, Vol. 42, No. 17, p. 12.
- Gaukler, G.M. and W.H. Hausman (2008) 'RFID in mixed-model automotive assembly operations: Process and quality cost savings,' *IIE Transactions*, Vol. 40, No. 11, pp. 1083-1096.
- Gaukler, G., R. Seifert and W. Hausman (2007) 'Item level RFID in the retail supply chain', *Production and Operations Management*, Vol. 16, No. 1, pp. 65-76.
- Gessner, G.H., L. Volonino and L.A. Fish (2007) "One-up, one-back ERM in the food supply chain," *Information Systems Management*, Vol. 24, No. 3, pp. 213-222.
- Godon, D., J.K. Visich and S. Li, (2007) 'An exploratory study of RFID implementation benefits and challenges in the supply chain,' *Proceedings of the 38<sup>th</sup> Annual Meeting of the Decision Sciences Institute*, Phoenix, AZ, pp. 5261-5266.
- Hardgrave, B., J. Aloysius, S. Goyal and J. Spencer (2008a) 'Does RFID improve inventory accuracy? A preliminary analysis,' Information Technology Research Institute, Sam M. Walton College of Business, University of Arkansas, working paper ITRI-WP107-0311. Available at <http://www.itri.uark.edu>.
- Hardgrave, B., S. Langford, M. Waller, and R. Miller (2008b) "Measuring the impact of RFID on out of stocks at Wal-Mart," *MIS Quarterly Executive*, Vol. 7, No. 4, pp. 181-192.
- Hardgrave, B. and R. Miller (2006) 'The myths and realities of RFID', *International Journal of Global Logistics & Supply Chain Management*, Vol. 1, No. 1, pp. 1-16.
- Heese, H. (2007) 'Inventory Record Accuracy, Double Marginalization and RFID adoption', *Production and Operations Management*, Vol. 16, No. 5, pp. 542-553.
- Holmqvist, M. and G. Stefansson (2006) "'Smart Goods' and mobile RFID: A case with innovation from Volvo,' *Journal of Business Logistics*, Vol. 27, No. 2, pp. 251-272.
- Hou, J.-L. and C.-H. Huang (2006) "Quantitative performance evaluation of RFID applications in the supply chain of the printing industry," *Industrial Management + Data Systems*, Vol. 106, Nos. 1-2, pp. 96-120.
- Hozak, K. and D.A. Collier (2008) "RFID as an enabler of improved manufacturing performance," *Decision Sciences Journal*, Vol. 39, No. 4, pp. 859-881.
- Hudson, K. (2007) 'Best Buy foresees using RFID to track inventory,' *Wall Street Journal* (Eastern Edition), April 4.
- Jansen, R. and A. Krabs (1999) 'Automatic identification in packing-radio frequency identification in multi-way system', *Packing Technology and Science*, Vol. 12, pp.229-234.

- Jones, P., C. Clarke-Hill, P. Shears, D. Comfort and D. Hillier (2004) 'Radio frequency identification in the UK: Opportunities and challenges,' *International Journal of Retail & Distribution Management*, Vol. 32, No. 3, pp.164-171.
- Karaer, O. and H. Lee (2007) 'Managing the reverse channel with RFID-enabled negative demand information', *Production and Operations Management*, Vol. 16, No. 5, pp. 625-645.
- Karimi, J., T.M. Somers and A. Bhattacharjee (2007) 'The Impact of ERP Implementation on Business Process Outcomes: A Factor-Based Study,' *Journal of Management Information Systems*, Vol. 24, No. 1, pp. 101-134.
- Kärkkäinen, M. (2003) 'Increasing efficiency in the supply chain for short shelf life goods using RFID tagging,' *International Journal of Retail & Distribution Management*, Vol. 31, No. 10, pp. 529-536.
- Kärkkäinen, M. and J. Holmström (2002) 'Wireless product identification: enabler for handling efficiency, customization and information sharing', *Supply Chain Management: An International Journal*, Vol. 7, No. 4, pp. 242-252.
- Katz, J. (2006) 'Reaching for ROI on RFID,' *Industry Week*, February, p. 29.
- Kim, C., K. Yang and J. Kim (2008) 'A strategy for third-party logistics systems: A case analysis using the blue ocean strategy,' *Omega*, Vol. 36, No. 4, pp. 522-534.
- Kok, A.G. de, K.H. van Donselaar and T. van Woensel (2008) 'A break-even analysis of RFID technology for inventory sensitive to shrinkage,' *International Journal of Production Economics*, Vol. 112, No. 2, pp. 521-531.
- Lai, F., J. Hutchinson and G. Zhang (2005) 'Radio frequency identification (RFID) in China: opportunities and challenges,' *International Journal of Retail & Distribution Management*, Vol. 33, Nos. 11/12, pp. 905-916.
- Langer, N., C. Forman, S. Kekre and A. Scheller-Wolf (2007) 'Assessing the impact of RFID on return center logistics,' *Interfaces*, Vol. 37, No. 6, pp. 501-514.
- Lapide, L. (2004) 'RFID: What's in it for the forecaster?', *The Journal of Business Forecasting*, Vol. 23, No. 2, pp. 16-19.
- Lee, H. and O. Ozer (2007) 'Unlocking the value of RFID', *Production and Operations Management*, Vol. 16, No. 1, pp. 40-64.
- Li, S. and J.K. Visich (2006) 'Radio frequency identification: Supply chain impact and implementation challenges,' *International Journal of Integrated Supply Management*, Vol. 2, No. 4, pp. 407-424.

- Li, S., J.K. Visich, B.M. Khumawala and C. Zhang (2006) 'Radio frequency identification technology: Applications, technical challenges and strategies,' *Sensor Review*, Vol. 26, No. 3, pp.193-202.
- Lin, C.Y. (2008) "Factors affecting the adoption of radio frequency identification technology by logistics services providers: an empirical study," *International Journal of Management*, Vol. 25, No. 3, pp. 488-499.
- Langer, N., C. Forman, S. Kekre and A. Scheller-Wolf (2007) 'Assessing the impact of RFID on return center logistics,' *Interfaces*, Vol. 37, No. 6, pp. 501-514.
- Loebbecke, C. (2007) 'Piloting RFID along the supply chain: A case analysis,' *Electronic Markets*, Vol. 17, No. 1, pp. 29-37.
- McFarlane, D., Sarma, S., Chirn, J.L., Wong, C.Y. and Ashton, K. (2003) 'Auto ID systems and intelligent manufacturing control', *Engineering Applications of Artificial Intelligence*, Vol. 16, No. 4, pp. 365-376.
- McFarlane, D. and Sheffi, Y. (2003) 'The impact of automatic identification on supply chain operations', *The International Journal of Logistics Management*, Vol. 14, No. 1, pp. 1-17.
- McWilliams, G. (2007) 'Wal-Mart's radio-tracked inventory hits static,' *Wall Street Journal*, February 15, pp. B1, B6.
- Moeeni, F. (2006) 'From light frequency identification (LFID) to radio frequency identification (RFID) in the supply chain,' *Decision Line*, Vol. 37, No. 3, pp. 8-13.
- Mooney, J.G., V. Gurbaxani and K.L. Kraemer (1996) 'A process oriented framework for assessing the business value of information technology,' *The DATA BASE for Advances in Information Systems*, Vol. 27, No. 2, pp. 68-81.
- Moore, B. (2005) 'The Wal-Mart mandate: compliance and beyond,' *Material Handling Management*, September, pp. 16-19.
- Morrison, J. (2005) 'Sudden impact: RFID and the environment,' *RFID Journal*, Vol. 2, No. 5, pp. 8-13.
- Ngai, E., T. Cheng, K.-H. Lai, P. Chai, Y. Choi and R. Sin (2007) 'Development of an RFID-based traceability system: Experiences and lessons learned from an aircraft engineering company', *Production and Operations Management*, Vol. 16, No. 5, pp. 554-568.
- Ngai, E.W.T., K. Moon, F. Riggins and C. Yi (2008) 'RFID research: An academic literature review (1995-2005) and future research directions,' *International Journal of Production Economics*, Vol. 112, No. 2, pp. 510-520.

- O'Connor, M. C. (2005) 'Suppliers meet mandate frugally,' *RFID Journal*, January 3, <http://www.rfidjournal.com/article/articleview/1308/1/1/>, accessed March 22, 2005.
- O'Connor, M.C. (2006a) 'Media providers entertain RFID's potential,' *RFID Journal*, June 23, <http://www.rfidjournal.com/article/articleprint/2450/-1/1/>, accessed July 13, 2006.
- O'Connor, M.C. (2006b) 'Staples Business Depot sees big benefits from RFID test,' *RFID Journal*, September 27, <http://www.rfidjournal.com/article/articleprint/2684/-1/1/>, accessed September 29, 2006.
- O'Connor, M.C. (2006c) 'Clothing maker says RFID significantly improves production,' *RFID Journal*, August 21, <http://www.rfidjournal.com/article/articleprint/2684/-1/1/>, accessed August 23, 2006.
- O'Connor, M.C. (2007a) 'Wal-Mart Canada making RFID progress,' *RFID Journal*, November 27, <http://www.rfidjournal.com/article/articleprint/3766/-1/1/>, accessed November 30, 2007.
- O'Connor, M.C. (2007b) 'Falabella plans second item-level RFID pilot,' *RFID Journal*, August 27, <http://www.rfidjournal.com/article/articleprint/3585/-1/1/>, accessed September 4, 2007.
- O'Connor, M.C. (2007c) 'Staples Business Depot sees positive results from active tag test,' *RFID Journal*, August 27, <http://www.rfidjournal.com/article/articleprint/3695/-1/1/>, accessed October 26, 2007.
- O'Connor, M.C. (2007d) 'Dollar Store sees dollar signs in RFID,' *RFID Journal*, November 29, <http://www.rfidjournal.com/article/articleprint/3771/-1/1/>, accessed December 7, 2007.
- O'Connor, M.C. (2007e) 'Cami expands its RFID deployment,' *RFID Journal*, November 28, <http://www.rfidjournal.com/article/articleprint/3767/-1/1/>, accessed December 3, 2007.
- O'Connor, M.C. (2007f) 'Western Digital uses RFID seals to streamline customs,' *RFID Journal*, April 20, <http://www.rfidjournal.com/article/articleprint/3767/-1/1/>, accessed May 16, 2007.
- O'Connor, M.C. (2007g) 'Lemmi fashion changes frequency,' *RFID Journal*, August 21, <http://www.rfidjournal.com/article/articleprint/3571/-1/1/>, accessed August 24, 2007.
- O'Connor, M.C. (2008a) 'Sock-maker running faster with RFID directed production,' *RFID Journal*, June 6, <http://www.rfidjournal.com/article/articleprint/4119/-1/1/>, accessed June 11, 2008.
- O'Connor, M.C. (2008b) 'RiteCare says RFID helps cure its warehouse woes,' *RFID Journal*, December 9, <http://www.rfidjournal.com/article/articleprint/4503/-1/1/>, accessed December 10, 2008.

- O'Connor, M.C. (2008c) 'American Apparel expands RFID to additional stores,' *RFID Journal*, December 12, <http://www.rfidjournal.com/article/articleprint/4510/-1/1/>, accessed January 7, 2009.
- Ozelkan, E. and A. Galambos (2008) 'When does RFID make business sense for managing supply chains?,' *International Journal of Information Systems and Supply Chain Management*, Vol. 1, No. 1, pp. 15-47.
- Pålsson, H.(2007) "Participant observation in logistics research: Experiences from an RFID implementation study," *International Journal of Physical Distribution & Logistics Management*, Vol. 37, No. 2, pp. 148-163.
- Pålsson, H. (2008) "Using RFID technology captured data to control material flows," *Proceedings of the POMS 9<sup>th</sup> Annual Conference*, La Jolla, CA, May.
- Penttilä, K.M., D.W. Engels and M.A. Kivikoski (2004) 'Radio frequency identification systems in supply chain management', *International Journal of Robotics and Automation*, Vol. 19, No. 3, pp. 143-151.
- Prater, E., G. Frazier and P.M. Reyes (2005) 'Future impacts of RFID on e-supply chains in grocery retailing,' *Supply Chain Management: An International Journal*, Vol. 10, No. 2, pp. 134-142.
- Reid, R.D. and N.R. Sanders (2005) *Operations Management An Integrated Approach*, Wiley, Hoboken, NJ.
- Rekik, Y., E. Sahin and Y. Dallery (2008) 'Analysis of the impact of the RFID technology on reducing product misplacement errors at retail stores,' *International Journal of Production Economics*, Vol. 112, No. 1, pp. 264-278.
- Reyes, P.M. and G. Frazier (2007) 'Radio frequency identification: past, present and future business applications', *International Journal of Integrated Supply Management*, Vol. 3, No. 2, pp. 125-134.
- Reyes, P.M., G. Frazier, E. Prater and A. Cannon (2007) 'RFID: the state of the union between promise and practice', *International Journal of Integrated Supply Management*, Vol. 3, No. 2, pp. 192-206.
- Riemenschneider, C., B. Hardgrave and D. Armstrong (2007) "Is there a business case for RFID," Information Technology Research Institute, Sam M. Walton College of Business, University of Arkansas, working paper ITRI-WP091-0507. Available at <http://www.itri.uark.edu>.
- Rigby, D. and B. Bilodeau (2005) 'The Bain 2005 management tool survey,' *Strategy & Leadership*, Vol. 33, No. 4, pp. 4-12.

Rigby, D. and B. Bilodeau (2007) 'Bain's global 2007 management tools and trends survey,' *Strategy & Leadership*, Vol. 35, No. 5, pp. 9-16.

Roberti, M. (2005a) 'The serendipity effect,' *RFID Journal*, October 31, <http://www.rfidjournal.com/article/articleprint/1960/-1/128/>, accessed November 2, 2005.

Roberti, M. (2006) 'P&G adopts EPC advantaged strategy,' *RFID Journal*, January 24, <http://www.rfidjournal.com/article/articleprint/2103/-1/128/>, accessed February 2, 2006.

Roberti, M. (2007) 'RFID heats up in Latin America,' *RFID Journal*, May 28, <http://www.rfidjournal.com/article/articleprint/3344/-1/2/>, accessed June 11, 2007.

Roberti, M. (2008) 'HP optimizes RFID system at printer plant,' *RFID Journal*, October 28, <http://www.rfidjournal.com/article/articleprint/4204/-1/2/>, accessed October 31, 2008.

Scavarda, A.J., L.F. Scavarda, V. Kraemer, S.R.I. Pires and C.N. Filho (2006) 'RFID applied to logistics: The Brazilian Experience', *Proceedings of the 17<sup>th</sup> Annual Meeting of the Production and Operations Management Society*.

Schor, M. (2006) 'What drives supply chain innovation?,' *World Trade*, Vol. 19. No. 12, pp. 70-72.

Seideman, T. (2003), 'The race for RFID,' *Journal of Commerce*, December 1, p. 1.

Sellitto, C., B. Stephen and P. Hawking (2007) 'Information quality attributes associated with RFID-derived benefits in the retail supply chain,' *International Journal of Retail & Distribution Management*, Vol. 35, No. 1, pp. 69-87.

Shister, N. (2005) 'RFID: Taking stock of the Wal-Mart Pilot,' *World Trade*, Vol. 18. No. 8, pp. 38-42.

Småros, J., and J. Holmström (2000) 'Reaching the consumer through e-grocery VMI,' *International Journal of Retail and Distribution Management*, Vol. 28, No. 2, pp. 55- 61.

Spekman, R. and P. Sweeney (2006) 'RFID: From concept to implementation,' *International Journal of Physical Distribution & Logistics Management*, Vol. 36, No. 10, pp. 736-754.

Srivastava, B. (2004) 'Radio frequency ID technology: The next revolution in SCM', *Business Horizons*, Vol. 47, No. 6, pp. 60-68.

Sullivan, L. (2005a) 'The little chip that couldn't (yet),' *Information Week*, October 10, pp. 34-40.

Sullivan, L. (2005b) 'Wal-Mart brings the RFID proof,' *Information Week*, October 17, p. 22.

- Swedberg, C. (2007a) 'Movie, music suppliers opt for simple RFID compliance,' *RFID Journal*, January 23, <http://www.rfidjournal.com/article/articleprint/2989/-1/1/>, accessed January 25, 2007.
- Swedberg, C. (2007b) 'Wal-Mart embraces RFID's green potential,' *RFID Journal*, May 1, <http://www.rfidjournal.com/article/articleprint/3284/-1/1/>, accessed October 29, 2007.
- Swedberg, C. (2007c) 'Hong Kong shoppers use RFID-enabled mirror to see what they want,' *RFID Journal*, September 4, <http://www.rfidjournal.com/article/articleprint/3284/-1/1/>, accessed September 14, 2007.
- Swedberg, C. (2007d) 'Daisy Brand deems RFID a success,' *RFID Journal*, January 10, <http://www.rfidjournal.com/article/articleprint/2958/-1/1/>, accessed January 12, 2007.
- Swedberg, C. (2007e) 'Throttleman adopts item-level tagging,' *RFID Journal*, August 24, <http://www.rfidjournal.com/article/articleprint/3580/-1/1/>, accessed August 25, 2007.
- Swedberg, C. (2007f) 'Schuitema ponders future of fresh-chain pilot,' *RFID Journal*, December 10, <http://www.rfidjournal.com/article/articleprint/3793/-1/1/>, accessed December 14, 2007.
- Szmerekovsky, J.G. and J. Zhang (2008) "Coordination and adoption of item-level RFID with vendor managed inventory," *International Journal of Production Economics*, Vol. 114, No. 1, pp. 388-398.
- Tajima, M. (2007) 'Strategic value of RFID in supply chain management,' *Journal of Purchasing & Supply Management*, Vol. 13, No. 4, pp. 261-273.
- Tierney, S. (2004) 'Towards a new supply chain future,' *Supply Chain Europe*, Vol. 13, No. 8, p. 56.
- Twist, D.C. (2005) 'The impact of radio frequency identification on supply chain facilities,' *Journal of Facilities Management*, Vol. 3, No. 3, pp.226-239.
- Uckun, C., F. Karaesman and S. Savas (2008) "Investment in improved inventory accuracy in a decentralized supply chain," *International Journal of Production Economics*, Vol. 113, No. 2, pp. 546-566.
- Ustundag, A. and M. Tanyas (2009) "The impacts of radio frequency identification (RFID) technology on supply chain costs," *Transportation Research Part E*, Vol. 45, No. 1, pp. 29-38.
- Vijayaraman, B. and B. Osyk (2006) 'An empirical study of RFID implementation in the warehousing industry', *The International Journal of Logistics Management*, Vol. 17, No. 1, pp. 6-20.
- Violino, B. (2005) 'Motorcycle maker powers up with RFID,' *RFID Journal*, October 10, <http://www.rfidjournal.com/article/articleprint/3107/-1/1/>, accessed March 7, 2007

Visich, J.K., S. Li and B.M. Khumawala, (2007) 'Enhancing product recovery value in closed-loop supply chains with RFID,' *Journal of Managerial Issues*, Vol. 19, No. 3, pp. 436-452.

Wang, S.-J., S.-F. Liu and W.L. Wang (2008a) 'The simulated impact of RFID-enabled supply chain on pull-based inventory replenishment in TFT-LCD industry,' *International Journal of Production Economics*, Vol. 112, No. 2, pp. 570-586.

Wang, L., K.L. Gwebu, J. Wang and D.X. Zhu (2008b) 'The Aftermath of Information technology Outsourcing: An Empirical Study of Firm Performance Following Outsourcing Decisions,' *Journal of Information Systems*, Vol. 22, No. 1, pp. 125-159.

Webster, J. S. (2008) 'Wal-Mart's RFID revolution a tough sell,' *Network World*, Vol. 25, No. 36, pp. 34-36.

Weil, M. (2004) 'RFID confusion and possibility,' *APICS - The Performance Advantage*, February, pp. 50-54.

Wessel, R. (2007) 'Anticipating ROI, Rewe expands its RFID deployment,' *RFID Journal*, March 1, <http://www.rfidjournal.com/article/articleprint/1905/-1/1/>, accessed October 17, 2007.

Wessel, R. (2008a) 'Italian retail pilot quantifies RFID's many benefits,' *RFID Journal*, October 27, <http://www.rfidjournal.com/article/articleprint/4418/-1/1/>, accessed October 31, 2008.

Wessel, R. (2008b) 'Indian conglomerate ITC focuses on RFID expansion,' *RFID Journal*, November 14, <http://www.rfidjournal.com/article/articleprint/4449/-1/1/>, accessed November 19, 2008.

Whitaker, J., S. Mithas and M. Krishnan (2007) 'A field study of RFID deployment and return expectations', *Production and Operations Management*, Vol. 16, No. 5, pp. 599-612.

Wilding, R. and T. Delgado (2004a) 'RFID demystified: Supply-chain applications,' *Logistics and Transport Focus*, May, pp. 42-48.

Wilding, R. and T. Delgado (2004b) 'RFID demystified: company case studies,' *Logistics and Transport Focus*, June, pp. 32-42.



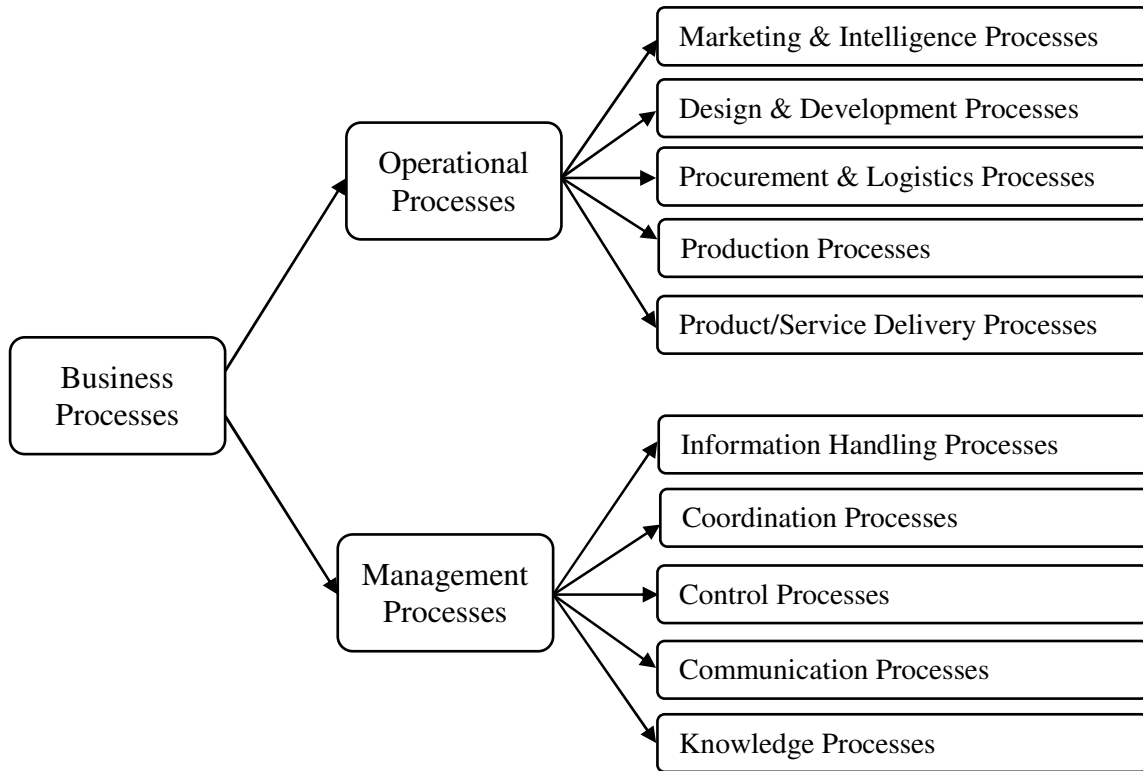


Figure 1 Typology of Business Processes (Mooney, *et al.*, 1996)

**Table 1. Summary of RFID Overview Literature in Supply Chain Management**

<b>Overview Study Type</b>	<b>Emphasis</b>
<i>General Overview</i>	
Byfield (1996)	Current and future applications of RFID.
Penttilä <i>et al.</i> (2004)	RFID technology and applications.
Srivastava (2004)	RFID technology and applications.
Spekman & Sweeney (2006)	RFID technology and applications.
Reyes & Frazier (2007)	RFID technology and applications.
Kärkkäinen & Holmström (2002)	Potential benefits in the supply chain.
McFarlane & Sheffi (2003)	Improve logistics processes of shipping, transportation, receiving and in-facility operations.
Lapide (2004)	Benefits of RFID for forecasting.
Riemenschneider <i>et al.</i> (2007)	Business values of RFID in supply chain.
Angeles (2005)	Managerial guidelines in implementation.
Li & Visich (2006)	Advantages, supply chain impacts, implementation challenges, and strategies.
Tajima (2007)	Identified 15 distinct benefit types; made 4 propositions on RFID & competitive advantage.
Cannon <i>et al.</i> (2008)	Theory base to illustrate the benefits, complexities, and risks accompanying RFID adoption.
Jansen & Krabs (1999)	RFID to control returnable containers.
Visich <i>et al.</i> (2007)	Use of RFID in the closed-loop supply chain.
Brewer <i>et al.</i> , 1999	Use of RFID as tracking technology in manufacturing and the supply chain.
McFarlane <i>et al.</i> (2003)	Use of RFID for shop floor control.
Twist (2005)	The impact of RFID on supply chain facilities.
<i>Specific Industry</i>	
Davis & Jones (2004)	The deployment of RFID in the military supply chain.
Småros & Holmström (2000)	Use of RFID in the grocery industry.
Prater <i>et al.</i> (2005)	Use of RFID in the grocery industry.
Gessner <i>et al.</i> (2007)	Use of RFID in the grocery industry.
Sellitto <i>et al.</i> (2007)	Information value associated with RFID in the retail supply chain.
<i>Specific Country</i>	
Jones <i>et al.</i> (2004)	Opportunities and implementation challenges of RFID for retailers in the United Kingdom.
Scavarda <i>et al.</i> (2006).	Short case examples of RFID applications in Brazil.

**Table 2. Summary of RFID Empirical Studies Literature in Supply Chain Management**

Empirical Study Type	Emphasis
<i>Case Studies</i>	
Kärkkäinen (2003)	Supply chain efficiency of short shelf life products at UK retailer Sainsbury's.
Hardgrave <i>et al.</i> (2008a)	Impact of RFID on inventory accuracy through a field study of Wal-Mart stores.
Hardgrave <i>et al.</i> (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 <i>et al.</i> (2006)	Forklift route optimization 4 of a GENCO Distribution System warehouse.
Langer <i>et al.</i> (2007)	Impact of RFID on the outbound logistics operations for a GENCO return center.
Delen <i>et al.</i> (2007)	Detailed illustration of a product moving through a distribution center to the retail shelf.
Holmqvist & Stefansson (2006)	Volvo's supply chain flow.
Ngai <i>et al.</i> (2007)	An RFID-based traceability system at a Hong Kong aircraft engineering company.
Choy <i>et al.</i> (2007)	An RFID system to improve supply chain visibility for a medium sized 3PL.
Kim <i>et al.</i> (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.
<i>Interview</i>	
Lai <i>et al.</i> (2005)	Adoption issues in China.
Brown & Russell (2007)	Adoption issues in South Africa.
<i>Survey</i>	
Bendoly <i>et al.</i> (2007)	RFID benefits and commitment to adopt.
Whitaker <i>et al.</i> (2007)	Utilized two <i>InformationWeek</i> surveys to address both RFID adoption and business value.
Vijayaraman & Osyk (2006)	The implementation of RFID in the warehouse industry.
Reyes <i>et al.</i> (2007)	The extent of RFID adoption in industry.
Angeles (2007)	Identify critical success factors.
Godon <i>et al.</i> (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.

**Table 3. Summary of RFID Analytical Studies Literature in Supply Chain Management**

Analytical Study Type	Emphasis
<i>Financial</i>	
Adenso-Díaz & 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 & Galambos (2008)	Financial modeling of various business scenarios and associated risk.
Bottani & Rizzi (2008)	Cost/benefit analysis of pallet and case tagging in a three-echelon supply chain.
Ustundag & Tanyas (2009)	Expected benefits and cost factors for an integrated three-echelon supply chain
<i>Inventory</i>	
Chande <i>et al.</i> (2005)	Modeled the monitoring and controlling of time-sensitive products through RFID.
Heese (2007)	Inventory record inaccuracy modeling.
Gaukler <i>et al.</i> (2007)	Item-level tagging modeling.
Karaer & Lee (2007)	Modeling on information visibility and inventory decisions in reverse channel.
Rekik <i>et al.</i> (2008)	Impact of RFID on reducing product misplacement errors at retail stores.
Kok <i>et al.</i> (2008)	Cost/benefit analysis of RFID to control for shrinkage due to theft.
Wang <i>et al.</i> (2008a)	Modeling of a pull-based inventory replenishment system.
Uckun <i>et al.</i> (2008)	Optimal investment in RFID to maximize profit by decreasing inventory inaccuracy.
Szmerekovsky & 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.
<i>Manufacturing</i>	
Gaukler & Hausman (2008)	Use of RFID in mixed-model automotive assembly for process and quality savings.
Hozak & Collier (2008)	Use of RFID for data collection, shop floor control and lot splitting.

**Table 4 Business Value Metrics (from Mooney *et al.*, 1996)**

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

**Table 5. Dimensions of RFID Operational Business Value**

<b>Automational</b>	
<i>Labor Cost</i>	Warehouse labor reduction of 14% (Burnell, 2005).
	Elimination of 2 yard administration positions (Anonymous, 2002b).
	Production employees reduced from 20 to 12 with no change in production volume (O'Connor, 2008a)
	Production labor cost reduced 17% (Violino, 2005).
	Customs processing labor cost for containers reduced by 25% (O'Connor, 2007f).
	Reduced labor by up to 60 hours to count inventory (O'Connor, 2008c).
<i>Efficiency</i>	Retail shelf inventory replenishment 3 times faster (Sullivan, 2005b).
	Warehouse handling time reduced by 50% (Deffree, 2005).
	Time for double transaction at yard (drop-off & pick-up) reduced by 66% (Blanchard, 2004).
	Yard gate efficiency improved 75% (O'Connor, 2007e).
	Yard gate personnel productivity improved 50% (Blanchard, 2004).
<i>Shipping Efficiency</i>	Time to process an order for shipment reduced from 45 minutes to 6 minutes; or reduced to 20 seconds compared with 80 seconds to 20 minutes for a bar code system; or reduced by 80% (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% faster than handheld barcode system (Swedberg, 2007d; Anonymous 2003).
	Read time for reusable assets (dolly & 25 trays) reduced by 83% (Wilding & Delgado, 2004b).
	Time to check quantity and mix of goods at distribution center reduced 68% (Wessel, 2008a).
<i>Receiving Efficiency</i>	Pallet breakdown decreased from 17.75 minutes to 2.7 minutes at retail store (O'Connor, 2006b).
	Arrival inspection time reduced 10% to 50% (Holmqvist & Stefansson, 2006).
	Check in and truck unload time reduced 15 to 20 minutes (Burnell, 2005).
	Order verification time reduced from 20 seconds to 5 seconds (Katz, 2006).
	Productivity increase for goods receipt of 57% (Bacheldor, 2006).
	Time needed to compare deliveries with orders reduced 80% (Wessel, 2007).
	Time to process a delivered pallet at DC reduced from 5.36 to 2.65 minutes a 51% reduction (O'Connor, 2006b).
	Time to check quantity and mix of goods at grocery store reduced 80% (Wessel, 2008a).
	Time required to receive apparel at a distribution center reduced by 70% (Wessel, 2008b).
<i>Inventory Control</i>	Retail store stock-outs reduced by 11%; 21%; 25%; 26%; or 50% (Burnell, 2005; Hardgrave <i>et al.</i> , 2008b; O'Connor, 2007b; O'Connor, 2007c; Webster, 2008).
	Warehouse inventory count accuracy increase from 96% to 99% (Anonymous, 2002a).
	Retail store reduction in understated perpetual inventory of 13% (Hardgrave <i>et al.</i> , 2008a).
	Reduction in phantom inventory of 50% (Anonymous, 2007a).
	Time reduction of 80% to count inventory (Roberti, 2007).
	Inventory count accuracy of 98.4%; or 99.6% (Collins, 2006a; O'Connor, 2007b).

	Retail store customer service level improved from an average of 85% to 99% (Gaudin, 2008).
	Retail store inventory accuracy of > 99% (O'Connor, 2008c).
<i>Inventory Cost</i>	Lost goods reduction of 18% (Burnell, 2005).
	Shrinkage reduced by 15% (Wilding & Delgado, 2004b).
	Reduced perishable product loss by 10% (Swedberg, 2007f).
	Safety stock reduction of 30% (Wessel, 2008a).
	Warehouse inventory reduced by 50%; or 17% (O'Connor, 2008b; Roberti, 2008).
<i>Throughput</i>	Reusable container lead time reduced 15% (Tierney, 2004).
	Daily yard throughput increased 38% during peak season (Blanchard, 2004).
	Production lead time reduced 27% (O'Connor, 2006c).
	Production capacity increased 6.5%, (Collins, 2004b).
	Supply chain inbound and outbound through-put time reduced by 50% (Deffree, 2005).
	Number of goods processed at warehouse doubled and sometimes tripled (O'Connor, 2007g).
	Accuracy of pallets shipped to customers increased from 92% to 97% (Chow <i>et al.</i> , 2006).
	Container locating reduced from 4 to 12 hours to immediately (Schor, 2006).
	Product locating accuracy of 99.9% (Swedberg, 2007b).
<b>Informational</b>	
<i>Utilization</i>	Reusable container loss reduced from 4% to 2% (Wilding & Delgado, 2004a).
	Reusable container purchasing cost reduced by 4 million pounds per year (Wilding & Delgado, 2004a).
<i>Responsiveness</i>	Rush order processing time reduced from 6 hours to 3 and sometimes 2 hours (O'Connor, 2007g).
	Supply chain response time reduced from 7 to 5 days (Swedberg, 2007e).
<i>Waste</i>	Packaging errors eliminated (Bacheldor, 2007).
<b>Transformational</b>	
<i>Process Redesign</i>	Production cycle time reduced from 88 to 46 minutes (Collins, 2004b).
	Parts replenishment process redesign freed up 50% 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% 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 6. Dimensions of RFID Managerial Business Value**

<b>Automational</b>	
<b>Informational</b>	
<i>Effective Sales</i>	Sales increase of 12% in retail apparel store – only denim apparel items tagged (Wilding and Delgado, 2004b).
	Sales increase of 15% in retail apparel store – individual garments tagged (O’Connor, 2008c).
	Unit sales increases of 14%; 14.1%; and 41.1% (O’Connor, 2006a; Anonymous, 2007b; Hudson, 2007).
	Sales dollar increases of 14%; 18.7%; and 30% (Hudson, 2007; Anonymous, 2007b; Swedberg, 2007c).
<i>Effective Retail Promotions Coordination</i>	Promotion product availability of 92% by day 3 of the promotion launch (Collins, 2006b).
	Sales increase for stores that moved the display to the location before the promotion began: 48%; 61%; or 140% (Roberti, 2005a; Roberti, 2006; Anonymous, 2007a).
<i>Invoice Reconciliation</i>	Discrepancies reduced from 80% to 0% (Collins, 2005).
	Container shipment records accuracy increase from 70% to 100% (O’Connor, 2007f).
<i>Decision Quality</i>	Reduction in manual inventory orders of 10% or 42% (Sullivan, 2005b; O’Connor, 2007a).
	Reusable container cycle time reduced from 47 days 40 days - enables postponement (Anonymous, 2002b).
	Annual procurement cost reduced 11% (Violino, 2005).
	Stock turnaround increase from 5.5 to 6 (O’Connor, 2007d).
<i>Resource Usage</i>	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 (Anonymous, 2002b).
<i>Production Control</i>	Production planning accuracy improved 29% (O’Connor, 2006c).
<b>Transformational</b>	