European Journal of Information Systems (2009) 18, 592–614

www.palgrave-journals.com/ejis/

Understanding the value of integrated RFID systems: a case study from apparel retail

Frédéric Thiesse[1], Jasser Al-Kassab[1,2] and Elgar Fleisch[1,3]

[1]*Institute of Technology Management, University of St. Gallen, Switzerland;* [2]*SAP Research CEC St. Gallen, SAP (Switzerland) Inc., Switzerland;* [3]*Department of Management, Technology, and Economics, ETH Zurich, Switzerland*

Correspondence: Frédéric Thiesse, ITEM-HSG, University of St. Gallen, Dufourstrasse 40a, 9000 St. Gallen Switzerland.
Tel: +41 71 224 7243;
Fax: +41 71 224 7301;
E-mail: frederic.thiesse@unisg.ch

Abstract

This contribution is concerned with the business value of Radio Frequency Identification (RFID) technology in retail. We present a case study of an RFID project at Galeria Kaufhof, a subsidiary of Metro Group and one of the largest department store chains in Europe. The project encompasses a variety of RFID applications at the intersection of store logistics and customer service. The contribution that our study makes to the literature is threefold. First, we describe an innovative large-scale trial that goes beyond what was done in earlier projects in several respects. The most fundamental difference from previous trials is the full integration of RFID event data with point-of-sale (POS) and master data, which for the first time offers the retailer the opportunity to directly observe and analyse physical in-store processes. Second, the heterogeneity of RFID applications implemented by Kaufhof allows us to theorise about the effects that RFID may have on business processes from an IT value perspective. We develop a conceptual model to explain the different cause-and-effect chains between RFID investments and their impact on firm performance, the role of complementary and contextual factors, and the difficulty of assessing these impacts using objective performance measures. Third, we compare the case to a prior trial conducted by Kaufhof about 5 years earlier. The differences between the lessons that the company learned in the two projects illustrate the impact of technological advances and standardisation efforts in recent years on managerial perceptions of RFID business value, which allows for the derivation of a number of useful implications for practice.

European Journal of Information Systems (2009) **18,** 592–614.
doi:10.1057/ejis.2009.33; published online 27 October 2009

Keywords: RFID; retail industry; business value of IT; IT impacts; organisational capabilities

Introduction

Automatic identification technologies have become omnipresent in today's retail operations (Manthou & Vlachopoulo, 2001; Wyld, 2006). In particular, the introduction of barcodes and the UCC/EAN numbering system for consumer products more than 35 years ago fundamentally changed the industry and laid the foundation for several novel supply chain concepts, such as direct store delivery, continuous replenishment, and vendor-managed inventories (Nelson, 2001). Despite the initial cost concerns of grocery retailers, suppliers, and distributors in the 1970s, industry-wide acceptance was eventually achieved by setting the focus on a strong business case based on 'hard' and quantified benefits, which were likely to quickly result in a positive return on investment (Hicks, 1975; Pommer *et al.*, 1980; Brown, 1997; Haberman, 2001).

Received: 1 December 2008
Revised: 20 March 2009
2nd Revision: 11 June 2009
3rd Revision: 27 September 2009
Accepted: 30 September 2009

In contrast, the growing interest in the use of Radio Frequency Identification (RFID) on the part of the retail industry today has sparked an intense debate in academia and in practice regarding the benefits to be expected. Retail giants in the U.S. and Europe have made many efforts to convince suppliers, logistics service providers, and companies from other industries of the positive impact of RFID on supply chain performance. Presumably the most prominent and best-publicised example has been Metro Group's so-called 'Future Store Initiative', which encompasses various pilot implementations and a test lab open to the public. Some retailers such as Wal-Mart and Target have also decided to issue mandates that gave major suppliers deadlines after which retailers will refuse to accept non-RFID-tagged deliveries.

However, there is some indication that the initial enthusiasm about RFID has at least partly given way to a more disillusioned assessment (Lacy, 2005; The Economist, 2007). Often-voiced concerns regard issues including unclear benefits, prohibitive technology costs, and questions about cost-sharing among supply chain partners. Sceptics also point to the fact that there is little practical experience and research that substantiate the benefits of RFID as compared to existing solutions (Sheffi, 2004). Cachon (quoted by Wharton, 2005) notes that 'the hope and expectation among many people is that being able to track every unit of inventory in every location of the supply chain will somehow magically make inventory management go to the next level'. Woods (2004) even concludes that 'much of the enthusiasm for RFID tagging projects came from a fundamental misunderstanding of the state-of-the-art in data collection technologies'. Aside from economic considerations, an additional issue has emerged in that consumers perceive RFID as a risk to their personal privacy (Günther & Spiekermann, 2005; Thiesse, 2007). As a result, the overall adoption rate for RFID is still rather slow (Vijayaraman & Osyk, 2006; Brown & Bakhru, 2007; Lee & Shim, 2007; Leimeister *et al*., 2007; Edwards, 2008; Shih *et al*., 2008).

On the academic front, several publications have dealt with the application of RFID in organisations via empirical as well as analytical methods (Sellitto *et al*., 2007; Ngai *et al*., 2008b; Thiesse & Condea, 2009). The use cases described therein are located along the whole supply chain, from manufacturer to end consumer, with claimed benefits ranging from time and personnel cost savings and stock-out prevention to increased customer satisfaction and product safety. Where past investigations have been limited, however, is regarding a more theoretical perspective on the linkage between RFID investments, impacts on business processes, organisational capabilities and contextual factors, and firm performance in the RFID-specific value creation process. While many authors have discussed the outcomes that could potentially be achieved with the help of RFID, the efforts to explain and conceptualise these outcomes against the background of prior research on the business value of IT are sparse and scattered across IS, operations management, and other disciplines. In particular, the value of RFID data integration – in contrast to isolated operational efficiency gains, which have been considered in virtually any publication on RFID in the past years – is an area that is still under-researched.

We follow Thatcher & Pingry (2007), who argue that IT investments must be evaluated in their respective contexts, for example, the type of IT in which the firm invests or the market structure in which the firm competes. The context of our study is the use of RFID technology in the apparel retail industry. We report findings from the case study of a project at Galeria Kaufhof, a subsidiary of Metro Group and one of the largest department store chains in Europe. Kaufhof has been known for many years for its role as an early adopter of RFID in the supply chain due to a series of well-publicised feasibility tests conducted in 2003 (Loebbecke & Palmer, 2006a; Loebbecke, 2007a; Loebbecke & Huyskens, 2008). However, only recently has the company also started a large-scale trial to implement many of the RFID applications that have so far only been speculated about in one of its stores in Essen, Germany. While the majority of researchers in the field consider the use of RFID for the identification of logistical units such as containers and palettes along the supply chain, the case allows us to extend the research focus on the rather novel issue of item-level tracking from the distribution centre to the POS using a fine-meshed and integrated RFID data collection infrastructure. This study setting promises new insights into the value of RFID that go beyond the findings from prior studies. Based on our analysis, we discuss both theoretical propositions regarding the value of RFID and lessons learned from a practitioner's point of view.

The remainder of the article is organised as follows. The next section provides an overview of related works on the business value of IT in general and, specifically, the value of RFID in the retail industry. The third section describes our research methodology, and we continue with the case study of Kaufhof's item-level trial. The article closes with a discussion of research implications, managerial implications, and opportunities for further research.

Prior research on RFID value

Research on the business value of IT

The business value of IT is one of the classic issues in the IS field. The objective of this research stream is to develop a deeper understanding of the value of IT investments with regard to various performance measures including productivity, profitability, competitive advantage, cost reduction, and others (Bharadwaj *et al*., 1999; Devaraj & Kohli, 2003; Kohli & Hoadley, 2006). Early studies in the 1980s and the 1990s predominantly focused on the economy (Bender, 1986; Roach, 1987), industry (Bresnahan, 1986; Morrison & Berndt, 1990), or firm level (Weill, 1992; Loveman, 1994; Brynjolfsson & Hitt, 1996). The findings from this research are rather

inconclusive, with results ranging from negative to positive as well as neutral or bi-modal returns from IT (Mukhopadhyay *et al.*, 1995; Melville *et al.*, 2004; Thatcher & Pingry, 2007; Pare *et al.*, 2008).

In order to resolve these inconsistencies, several researchers have advocated a shift in the analytical focus to a more granular level and a refinement of the operationalisation of performance variables (Barua *et al.*, 1995; Ravichandran & Lertwongsatien, 2005). This 'process-oriented view' argues that more convincing evidence of IT business value is to be expected from investigations of IT impacts on individual business processes or inter-process linkages (Segars *et al.*, 1998; Tallon *et al.*, 2000; Li *et al.*, 2009). In their attempt to theorise the causal chain between IT impacts and IT expenditure as well as organisational performance, Soh & Markus (1995) develop a model that comprises an IT conversion process, an IT use process, and a competitive process. Studies that assess the relationship between the IT spending and process level outcomes have been conducted by Barua *et al.* (1995), Mukhopadhyay *et al.* (1995,1997), Shin (1997), Cotteleer & Bendoly (2006), Kohli & Hoadley (2006), and Radhakrishnan *et al.* (2008). The range of process variables used therein encompasses inventory levels, capacity utilisation, quality measures, and many others. A generalised framework of IT-induced effects on operational and management processes was proposed by Mooney *et al.* (1996).

Other researchers emphasise the importance of specific IT capabilities in realising the impacts desired from the so-called 'resource-based view' (RBV) from strategic management literature. According to the RBV, competitive advantage is obtained on the basis of corporate resources that are firm-specific, valuable, rare, imperfectly imitable, and not strategically substitutable by others (Barney, 1991). Grant (1991) additionally distinguishes between resources and capabilities. While from this perspective, IT is merely an undifferentiated resource, long-term competitive advantage is not created unless firms use such resources to create higher-order organisational capabilities (Mata *et al.*, 1995; Santhanam & Hartono, 2003; Wade & Hulland, 2004; Zhu, 2004; Rai *et al.*, 2006; Aral & Weill, 2007; Zhu *et al.*, 2009). Bharadwaj (2000) presents an empirical study to test the relationship between IT capabilities and firm performance by comparing the financial performance of IT leaders to those of other firms. Furthermore, some authors note that IT-related resources and capabilities can affect firm performance only when they are deployed in combination with other firm resources that enhance their value or effect (Ravichandran & Lertwongsatien, 2005). Investigations into the different types of IT resources and capabilities were presented by Wade & Hulland (2004) and Bhatt & Grover (2005). Ray *et al.* (2005) provide an empirical study of IT impacts on the customer service process that combines the process-oriented and the RBVs. A model that aims to integrate the various strands of research was proposed by Melville *et al.* (2004).

Research on the value of RFID in retail

The impact of RFID on supply chain performance has been discussed in a large number of white papers and articles in trade journals in recent years. Examples that specifically enumerate the benefits in retail stores are the reports by PwC Consulting (2002), Accenture (2003), A.T. Kearney (2004), and GCI (2005). Many of these first publications were prepared in the context of standardisation consortia such as the Auto-ID Center, an industry-sponsored project at MIT in the years 1999–2003; others were commissioned by industry organisations, for example, the Grocery Manufacturers of America (GMA). Although these sources might serve as a valuable foundation for understanding the industry's interest in RFID, the vast majority of such publications suffer from what Dutta *et al.* (2007) call a 'credibility gap' – that is, most of the existing estimates are not substantiated and are at best educated guesses.

The growing interest in RFID technology is also reflected in a considerable number of related contributions in academic journals and conference proceedings (Ngai *et al.*, 2008b). Many of the first papers on RFID technology are general review articles that discuss the technological characteristics of RFID, applications to the retail supply chain, and implementation challenges. Often-cited examples are the works by Kärkkäinen & Holmström (2002), McFarlane & Sheffi (2003), Jones *et al.* (2004), Srivastava (2004), Angeles (2005), and Bose & Pal (2005). Various researchers also conducted surveys to measure managers' perceptions of RFID benefits (Koh *et al.*, 2006; Vijayaraman & Osyk, 2006; Brown & Russell, 2007; Moon & Ngai, 2008; Uhrich *et al.*, 2008). Other empirical studies have concentrated specifically on one or more cases of RFID implementation. Based on an RFID trial at Sainsbury's, Kärkkäinen (2003) discusses the technology's potential in the supply chain of short shelf-life products. Loebbecke & Palmer (2006a) and Loebbecke (2007a) investigate a 5-month trial by Kaufhof and Gerry Weber, a fashion goods manufacturer, and describe the observed operational benefits. Loebbecke (2007b) studies the use of RFID and other technologies in Metro's first Future Store. Wamba *et al.* (2008) provide a study of the benefits of the EPC Network – a network architecture for RFID data-sharing – in a beverage supply chain.

Only a few researchers so far have investigated the question of how to measure the impact of RFID on business processes. The case study by Delen *et al.* (2007) considers material handling processes in a distribution centre and a retail store. The authors identify a number of performance metrics that can be computed from RFID data and provide some real-world examples. Bottani & Rizzi (2008) examine a three-echelon FMCG supply chain. They assess the economical suitability of RFID for each player under different integration scenarios. Bendavid *et al.* (2007) attempt to track horizontal and vertical key performance indicators in order to assess the impacts of RFID on a five-layer supply chain. Based on

the same case example, Wamba & Bendavid (2008) use process simulations to analyse the impact of RFID on store inventory management. Veeramani *et al*. (2008) present a framework and a spreadsheet model for assessing the value of RFID implementation by tier-one suppliers to major retailers. Similarly, Luo *et al*. (2008) present a framework for RFID technology analysis including several different value metrics. Sellitto *et al*. (2007) identify information quality attributes associated with RFID along the supply chain; based on a review of the literature, they conclude that RFID adoption leads to enhanced organisational responsiveness through improved decision-making capabilities.

A comprehensive overview of RFID-induced supply chain visibility from an operations management perspective was given by Lee & Özer (2007). Other authors have focused their analytical research into RFID benefits specifically on the phenomenon of inventory inaccuracies that might be caused, for instance, by product misplacements or shrinkage. Works by Fleisch & Tellkamp (2005), de Kok *et al*. (2007), Heese (2007), Kök & Shang (2007), and Rekik *et al*. (2007, 2008) are examples of this research stream, which aims to quantify the potential for improvement that can be attained through the elimination of inaccuracies. Wong & McFarlane (2007) provide a qualitative analysis of the main determinants of suboptimal replenishment performance. The authors consider the structure of the traditional process and discuss opportunities for improvement using RFID, such as the automatic monitoring of stock levels and product movements as well as the automatic compilation of pick lists on mobile devices. Lee *et al*. (2004) and Thiesse *et al*. (2007) both use simulation models to investigate the effects of the redesign of the shelf replenishment process. Gaukler *et al*. (2007) examine the benefits of full replenishment efficiency in the case of shrinkage, misplacements, and other execution errors. Yao *et al*. (2007) and Szmerekovaky & Zhang (2008) specifically analyse the effect of RFID-based continuous review policies in a vendor-managed inventory system.

Research gap

As Kohli & Grover (2008) note using the example of RFID, IT – unlike other innovations – not only collects and processes but also generates information, which gives businesses the ability to incessantly assess and reinvent themselves. Loebbecke & Palmer (2006a) find that only 'few examples of creative uses of RFID data are available yet, but are sure to arise'. Sellitto *et al*. (2007) conjecture that RFID might foster the development of a firm's capability to interpret and utilise the information collected by the technology. A similar view is taken by Tajima (2007), who proposes that RFID may become a source of competitive advantage if companies understand how to utilise the captured data to develop new products and services. However, to quote Leonardi (2007), 'the role information plays in organisational change is often under-theorised and ITs are treated as if they were just technologies, receiving no special attention'. Despite the considerable number of related works, very few authors have so far empirically investigated the benefits of large RFID installations in productive use. In particular, an issue that has attracted little attention on the part of researchers is the value of RFID data integration. Moreover, we see a general shortcoming of prior works in the fact that these either provide no theoretical perspective on RFID value at all or operate using fuzzily defined terms and constructs that are not related to already existing theory in the area (see Table 1). The works by Whitaker *et al*. (2007), Tzeng *et al*. (2008), and Wamba *et al*. (2008) are the only RFID-related papers we are aware of that explicitly reference the IT value literature, with the second being the only one that derives any theoretical propositions. However, the study by Tzeng *et al*. (2008) is limited to the healthcare domain, and their results are not synthesised into a unified research model.

Case study methodology

The objective of our study is to extend our theoretical understanding of the different ways RFID creates business value, and to draw conclusions that support practitioners in their evaluation of the technology's business potential. Because the nature of our research can be described as explorative, we chose the case study method as a qualitative research approach (Eisenhardt, 1989; Yin, 2003; Pare, 2004). This method allows the researcher to investigate a contemporary phenomenon in its real-world context and provides a way of collecting, organising, and analysing data to obtain comprehensive, systematic, and in-depth information about the case. Case study research is especially useful for early, exploratory investigations in which the phenomenon is not yet completely understood and for which existing theory seems insufficient (Benbasat *et al*., 1987; Meredith, 1998). Our primary research question can be formulated as a *how* question, which is also typical and appropriate for qualitative case studies (Yin, 2003): How does RFID create business value in a retail environment?

Because of the early stage of RFID adoption and the small number of productive systems that can be regarded as representative, we employed a 'critical case sampling' strategy (Patton, 2002). Accordingly, we were looking for a case that is particularly information-rich and permits generalisation and maximum application to other cases. The Kaufhof project is suited to our needs because of the exceptional scope of the project with regard to the number of RFID-based functionalities, the integration of the technology with existing information systems, and the variety of affected business processes.

Our research question provides a well-defined focus for the study and permits us to specify the kind of data to be gathered. As is typical in case studies, data were collected using a mixture of techniques (Yin, 2003). In the context

Table 1 Overview of related works

Reference	*Industry context*	*Methodology*	*RFID value classification*
Loebbecke (2007a)	Retail	• Case study	—
Loebbecke (2007b)	Retail	• Case study	• Lead time reduction • Labour cost reduction • Enhanced data quality
Moon & Ngai (2008)	Retail	• Interviews	• Responsiveness • Relatedness • Refinement
Ngai *et al.* (2008a)	Retail	• Prototyping • Interviews	• Effectiveness • Efficiency • Innovation
Sellitto *et al.* (2007)	—	• Literature review	• Timeliness • Currency • Accuracy • Completeness
Tajima (2007)	—	• Literature review	• Increased supply chain efficiency • Increased innovation capability • Learning to adjust • Learning to transform
Tzeng *et al.* (2008)	Healthcare	• Case study	• Refinement of operational processes • Extension of business boundaries and scope
Uhrich *et al.* (2008)	Retail	• Interviews • Prototyping	• Cost saving • Increasing revenues per customer • Service quality
Wamba *et al.* (2008)	Retail	• Case study	• Strategy • Processes • Information flow • IT infrastructure • Human and physical resources
Whitaker *et al.* (2007)	—	• Survey • Regression analysis	—

of our study, data collection was conducted between September 2007 and May 2009 in the following ways.

Workshops: We attended six 2- to 4-h meetings where Kaufhof representatives from the IT and the logistics group were present whom Metro Group had chosen to be responsible for this specific project. Additional members that participated in some of the meetings came from the departments of controlling, marketing, and sales, as well as from Metro's internal IT service provider. During the meetings, field notes were taken, and we were also allowed to ask questions to bring greater clarity to our treatment of the topics discussed.

Interviews: As a complement to the workshops, we conducted semi-structured telephone interviews with different members of the project team. The issues discussed in these interviews mostly referred to the current project status, details of in-store processes, the functionality and internal structure of Kaufhof's information systems, and the team members' perceptions regarding RFID benefits. As with the workshops, the respondents' answers were independently documented by two of the authors and subsequently merged.

Site visits: We conducted four site visits to the Kaufhof store. The first one took place on the day of the official

opening of the trial in September 2007, with a guided tour for Metro's business partners and the press. The second and the third visits were conducted by Kaufhof for us in November 2007 and February 2008, respectively. These gave us the opportunity to observe the entire process chain of a department store, from goods receipt to the POS, and to discuss various technological issues. The purpose of the fourth visit in May 2008 was to observe Kaufhof's trial with RFID as an instrument for inventory-taking.

Project documentation: Furthermore, Kaufhof supplied us with several project-related documents. These included the specifications of the RFID infrastructure, process flowcharts, survey data, presentations, floor layout plans, and other graphical material.

RFID data: Another source for our study was the company's RFID repository encompassing the complete data gathered by the infrastructure over one year. The repository includes more than 13 million RFID events, each characterised by a transponder ID, a reader ID, an event type, and a timestamp. Furthermore, we had access to the corresponding master data and sales data from the same time period. This allowed us to conduct a variety of analyses in addition to using the reports generated by Kaufhof itself. The primary purpose was to verify the information collected from the interviews and documentation and to gain further insights into the usefulness of RFID data for department store management.

The heterogeneity of our sources gave us the opportunity for data triangulation, which is necessary to check and establish validity in qualitative studies. Specifically, the availability of the original RFID data set proved highly important in avoiding subjective influences in the research process, a common disadvantage of studies based on just participant observation.

Galeria Kaufhof's Essen RFID project

Company background

Kaufhof Warenhaus AG is a subsidiary of Metro Group, the fifth largest retailer worldwide (Deloitte, 2008), which operates 126 department stores in Germany, 113 of them under the brand name 'Galeria Kaufhof', and 15 in Belgium. As one of Europe's leading department store chains, Galeria Kaufhof is visited by more than two million customers each day and has a total sales floor of 1.5 million square metres. The company employs about 25,000 people and generated €3.6 billion in sales in 2007 (Kaufhof, 2009). Its assortment primarily consists of international brands of middle to upper price level.

Kaufhof's RFID activities date back to 2003, when it started a collaboration with the fashion merchandise manufacturer Gerry Weber (Loebbecke & Palmer, 2006a; Loebbecke, 2007a). The main objective of this first project was to examine to what extent RFID can contribute to the acceleration and simplification of supply chain operations under real-world conditions (Metro, 2005). For this purpose, logistical units and items were equipped with RFID transponders by Gerry Weber's logistical service provider upon shipment to the Kaufhof DC. Both partners conducted a series of feasibility tests along the supply chain using dock door readers, smart shelves, mobile readers for inventory-taking, and an RFID-enabled check-out. The objective of the trial was to assess achievable read rates and time-savings due to automatic object identification, and to investigate the technology's suitability for replacing conventional Electronic Article Surveillance (EAS) systems. The idea of utilising RFID to realise novel customer applications and to change in-store processes was also considered by the project team, but these scenarios remained in the abstract and were not part of the trial itself. Similarly, the integration of RFID data sources was not implemented besides simple LAN connections and the fact that one RFID reader was plugged into the barcode scanner interface of a POS terminal. As a result, the subsequent quantitative business case analysis concentrated on time and labour cost savings due to process automation at various points in the supply chain. The use of RFID for EAS purposes proved impractical at that time because of the limited reading distances. However, Kaufhof's overall evaluation of the business potential offered by RFID, including the many qualitative results gathered by the project team, was nevertheless very positive.

This experience motivated Kaufhof to join the consortium of 'Building Radio Frequency Identification Solutions for the Global Environment' (BRIDGE), an R&D project funded by the European Commission in 2006. The company's main interest in BRIDGE was to implement RFID in its own processes, to speed up RFID adoption in the textile sector, and to share its experiences with industry organisations and standardisation bodies. As part of the project, Kaufhof implemented an RFID infrastructure in the menswear department on the third floor of its store in Essen, Germany, with a total of 2000 square metres in September 2007. Its main partner in this trial was Gardeur AG, one of the leading German manufacturers of brand garments, who operates a shop-in-shop in the Galeria Kaufhof store. The differences in terms of infrastructure and applications between the two trials conducted in 2003 and 2007/08, respectively, are highlighted in Table 2.

Project objectives

During the opening of the trial, various executives of Metro and Kaufhof were present and sketched out their ideas regarding the project's objectives. Metro Group's Chief Information Officer stated that:

> By using RFID with our Galeria Kaufhof sales brand, we are giving customers a totally new kind of shopping experience and are considerably improving customer service.

Table 2 Profiles of the Kaufhof RFID trials in 2003 and 2007/2008

		2003 (5 months)	*2007/08 (15 months)*
Technology and standards	Frequency Band	HF	Near-Field UHF
	Air interface	Philips I-Code (ISO 15693)	EPC Gen 2
	Numbering scheme	SSCC, EAN + Gerry Weber ID	EPC (SSCC, SGTIN)
Hardware/Software components	No. of stationary readers	<10	64 (incl. 208 antennae)
	No. of mobile devices	2	10
	No. of transponders	~5′000	~150′000
	Central RFID data repository	No	Yes
	Integration with Kaufhof IS	No	Yes
Reader locations	DC Goods Receipt	Yes (logistical unit)	No
	DC Goods Issue	Yes (logistical unit)	Yes (item and logistical unit)
	Store Goods Receipt	Yes (logistical unit)	Yes (item and logistical unit)
	Backroom storage	No	Yes (item)
	Transit backroom/sales floor	No	Yes (item)
	Fitting rooms	No	Yes (item)
	Smart shelves	Yes (item)	Yes (item)
	Magic mirror	No	Yes (item)
	Check-out	Yes (category)	Yes (item)
	Elevators	No	Yes (item)
	Exits	No	Yes (item)
	Escalators	Yes (item)	Yes (item)
	Mobile devices	Yes (item)	Yes (item)
Customer applications	Shelf displays	No	Yes
	Magic mirror	No	Yes
	Fitting room displays	No	Yes
	Mobile sales advisory	No	Yes

Similarly, the CEO of Galeria Kaufhof described his company's intentions as being possible to pursue through the implementation of RFID as follows:

> Here in Essen, we will be able to do a live test of to what extent our staff can be freed from non-value-adding activities and, thus, gain additional time for direct customer service. Moreover, we intend to learn more about our customers' experiences with the new technology via surveys and studies. That is to say, we would like to test whether the advantages that we can expect from RFID on the item level are also feasible in practice.

An executive from Metro's IT innovation unit added another aspect by focussing on operational benefits related to inventory management and in-store logistical processes:

> With this pilot, we demonstrate how a department store fully equipped with RFID on the item level can work. The business benefit to us as retailers is that an end-to-end RFID infrastructure at the item level can fill the data void that exists between products being received and products being sold. We can now also see products in those steps in our process chain that so far haven't been illuminated by the inventory management system.

Despite these predefined goals, the actualisation of the project had the character of an 'innovation-based implementation' (Peppard & Ward, 2005). As such, its objective was not primarily to solve a single, clearly identified business problem but, rather, to focus on the capabilities of the technology first and then to consider ways to exploit the resulting opportunities. For this purpose, a workshop with members from different organisational units was organised. The initial objectives that all participants agreed on at the beginning were increased stock availability, the identification of new revenue sources, the optimisation of existing processes and the creation of new ones, and the design of additional management reports. During the course of the workshop, the potential of RFID was discussed from three perspectives, as depicted in Table 3. Ideas regarding how the value of RFID in addressing these issues could be investigated were collected and roughly specified by the workshop participants. Subsequently, these ideas were grouped into three categories and refined as follows: (a) continuous analyses of RFID event data, (b) field experiments, and (c) surveys of customers and employees.

Infrastructure and supported processes

From a technological point of view, the trial is the first worldwide that makes use of so-called 'near-field UHF' (Nikitin *et al.*, 2007) transponders, which combine high read rates for tags in the HF frequency band with the low cost of standardised UHF tags. On the sales floor,

Table 3 Drivers and expected benefits of the Kaufhof project

Level	*Drivers*	*Expected benefits*
Strategy	• Industry characteristics (e.g., wide product assortment, short product life cycles, high seasonality) • Vertically integrated competitors (e.g., Zara) • Increasingly complex customer behaviour	• Reduction of cost pressure • Better understanding of customer processes • Faster response to demand changes
Operations	• Efficiency gains in store logistics (e.g., commissioning, storage, product display, replenishment) • Customer service improvement (e.g., sales advisory, POS services, returns)	• Reduced capital commitment • Enhanced visibility of inventories and physical processes • Reduction of non-value-adding activities
Technology	• Bulk identification • Robustness • No line-of-sight restriction • Substitution of EAS systems	• Time and cost savings • Increased data quality

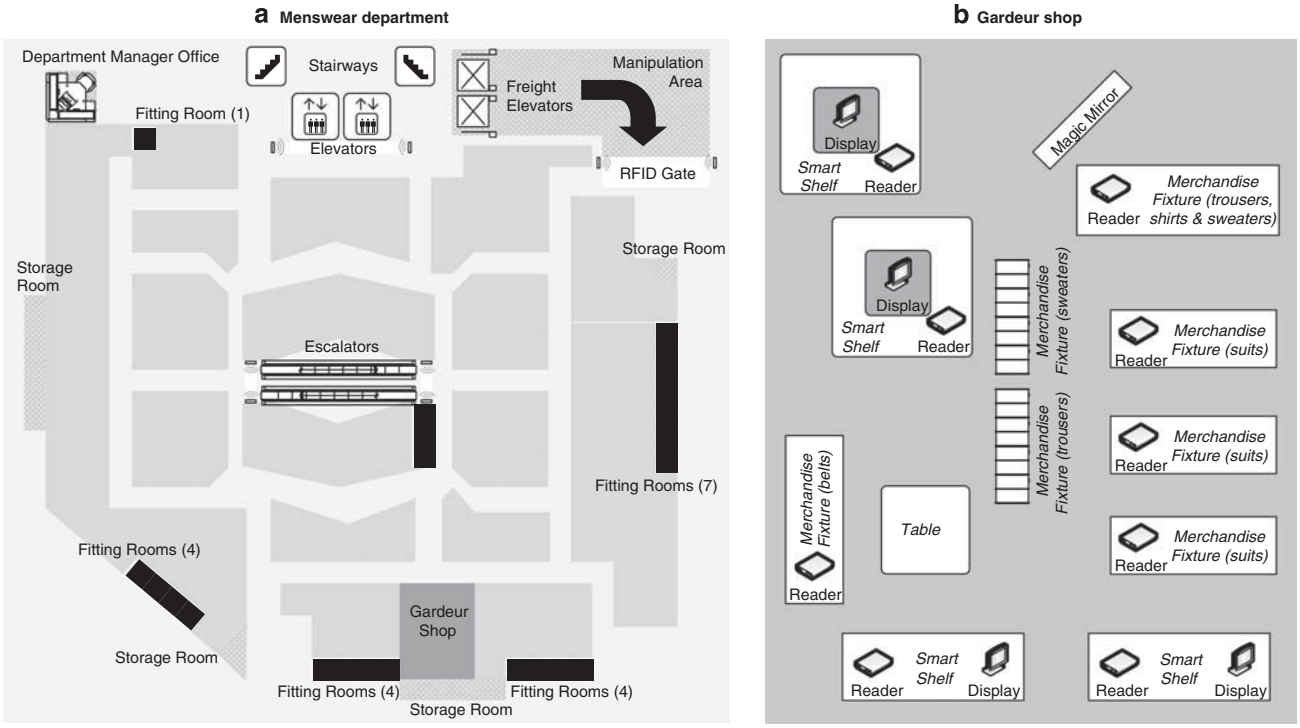

Figure 1 Floor layout at Galeria Kaufhof in Essen.

approximately 30,000 individual RFID-equipped apparel items are constantly available. These are seamlessly tracked at the item level on their way from the DC to the POS. Furthermore, about 500 merchandise fixtures are likewise tagged. In the menswear department, RFID readers are installed at the escalators and elevators, on the gateways between the sales floor and the backroom, at the entry to the backroom storage area, on several shelves, and in all 20 fitting rooms. In total, the infrastructure includes 64 RFID readers and 208 antennas. Some RFID readers are additionally equipped with photo-electric barriers and motion detectors in order to determine the direction of the flow of goods. A schematic overview of the installation is given in Figure 1.

All products to be sold in the Essen menswear department are shipped via the regional DC in the nearby city of Neuss, where passive RFID tags are attached on the clothing. With every movement of products

captured by the readers, RFID events are generated and stored in the company's 'EPC Information Service (EPCIS)' (EPCglobal, 2007), a repository for the collection and sharing of RFID data. The system is installed in parallel to the existing merchandise information system, which has been developed and improved over the last 15–20 years, and supports store management and sales floor processes. Every item arriving at the Essen store is identified at the dock door, compared with the corresponding EDI message on the delivery, and added to the virtual store inventory. Readers at the entries, exits, and checkout counters of the menswear department allow Kaufhof to distinguish between backroom and sales floor inventory. An extension of the merchandise IS was developed that detects products that are not available on the shelf even though they are in stock. This information, in principle, enables the fully automatic triggering of replenishments.

On top of these systems, four applications were specifically designed for customer service:

- *Smart shelves*: Shelves in the Gardeur shop are equipped with RFID readers and screens. The latter show the current availability of items on these particular shelves. Thus, customers looking for a specific item do not need to check the entire shelf to know which sizes and colours are available.
- *Magic mirror*: A large mirror with a built-in screen on the sales floor offers product information. Customers who approach this so-called 'Magic Mirror' with a tagged item receive information about materials, care instructions, available sizes, and colours.
- *Smart monitor*: RFID readers behind the walls recognise the product codes of clothing that is brought into the fitting rooms. A screen inside each fitting room at the Gardeur shop displays additional information on the product and other available sizes and colours. Furthermore, depending on the set of detected items, the system makes recommendations regarding alternative or complementary products.
- *Mobile devices*: In the case of customers looking for an item in a different size or colour, handheld mobile devices ('MDE') can be used to scan the item's RFID tag. Store employees can send a query to the RFID system regarding the availability and location of other items in the same category on the sales floor or in the backroom. Furthermore, MDE devices are also used for goods receipt and inventory-taking to accelerate the process beyond what is possible when manually counting each item using a mobile barcode reader.

All four applications run on a web application server that retrieves RFID data from the EPCIS server as well as the corresponding master data and inventory information from the merchandise IS. Moreover, product-related digital content (e.g., product images and descriptions), as needed for recommender functionality, is provided by the supplier. A summary of the entire infrastructure, data flows between back-end systems, and supported business processes is given in Figure 2.

Data analyses and experiments

The continuous collection of data by the RFID infrastructure has allowed Kaufhof to conduct several analyses of in-store processes that go beyond what is already being done with the help of barcode-based sales and inventory data. Analyses of RFID raw data stored in the EPCIS repository alone do not provide much business value but help the company to monitor the performance of their data collection infrastructure and the quality of the data generated. However, for the technology to be usable for process-related analyses, the raw data have to undergo a sequence of processing steps. On the one hand, filtering mechanisms are used in order to derive aggregated and cleansed information on business events in the store. On the other hand, these events are enriched by master and POS data, which provide the corresponding business context. The following data sets are generated that way (see Figure 3):

- *Trace histories*: An RFID trace history describes a product's lifecycle over time, starting from the labelling point in the DC and ending at checkout on the sales floor. In order to generate trace histories, read events associated with a tag ID are first aggregated by reader location, sorted by their corresponding time stamps, and then transformed into a linked list. Trace histories are necessary for analyses in the area of process execution and inventory management.
- *Smart shelf inventories*: Inventory data are generated from smart shelf reads that allow for tracking inventory changes over time. Besides the detection of 'out of shelf' situations, these data allow for the identification of misplaced merchandise.
- *Try-ons*: For the generation of try-on data, the fitting room reads are first aggregated over time and then filtered in order to remove items carried by passing customers or employees, as well as items from nearby merchandise fixtures. Try-ons allow for the analysis of fitting room utilisation, and of complements and substitutes that are tried on together.
- *Merchandise performance*: In order to investigate the correlation between sales, try-ons, and inventory levels on the sales floor, the previously described try-on events are combined with POS data and the inventory level at the time of the try-on. The attribution of fitting room visits to a purchase poses a challenge because the RFID installation does not allow for the identification of customers. The resulting data allow for various analyses of the attractiveness and performance of individual items or entire categories.

An exemplary analysis using these aggregated data is depicted in Figure 4. The figure provides an overview of the sales floor, subdivided into shop-in-shops for different article groups and brands. Just like sales items on

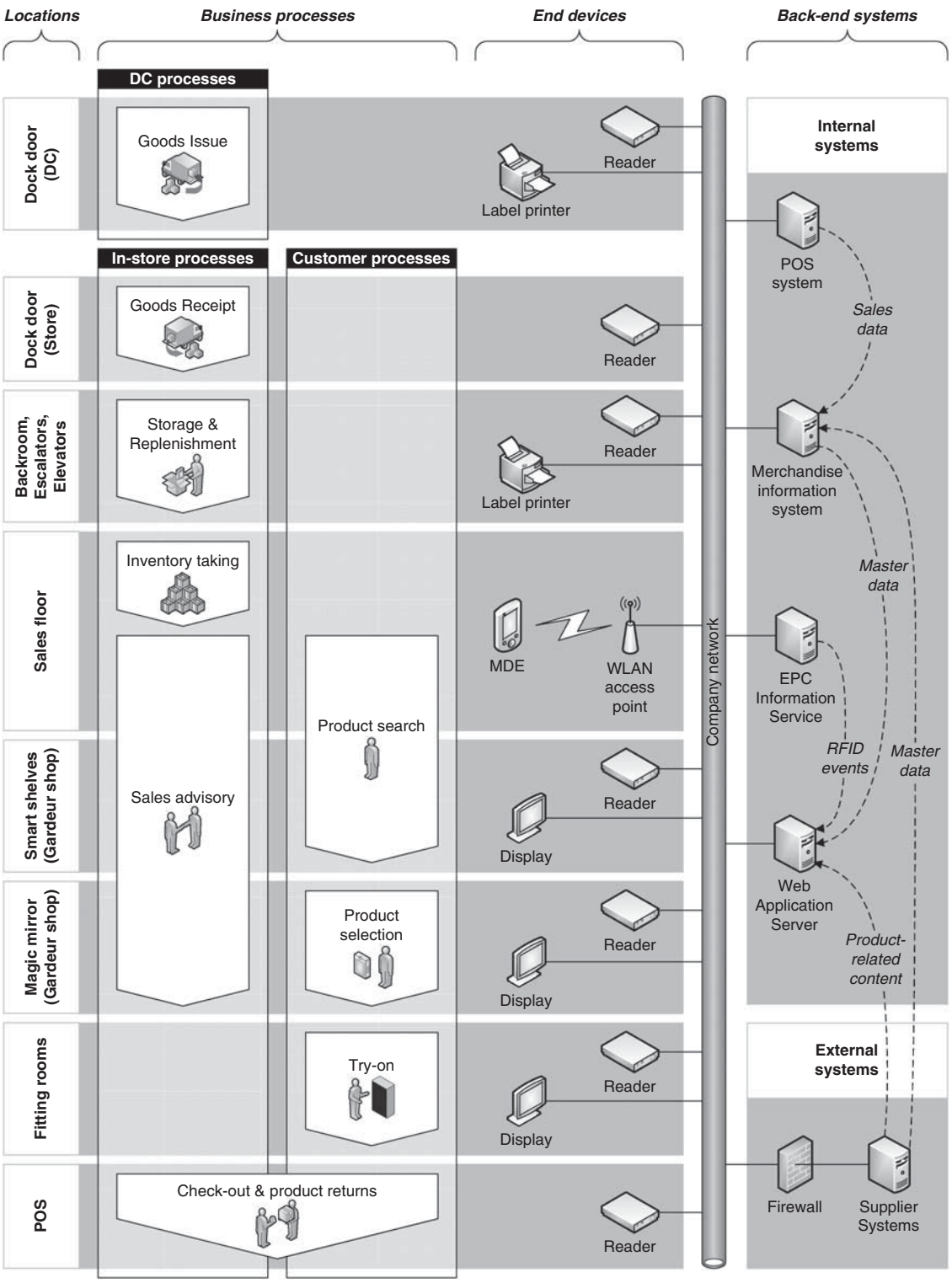

Figure 2 Technological infrastructure and supported business processes.

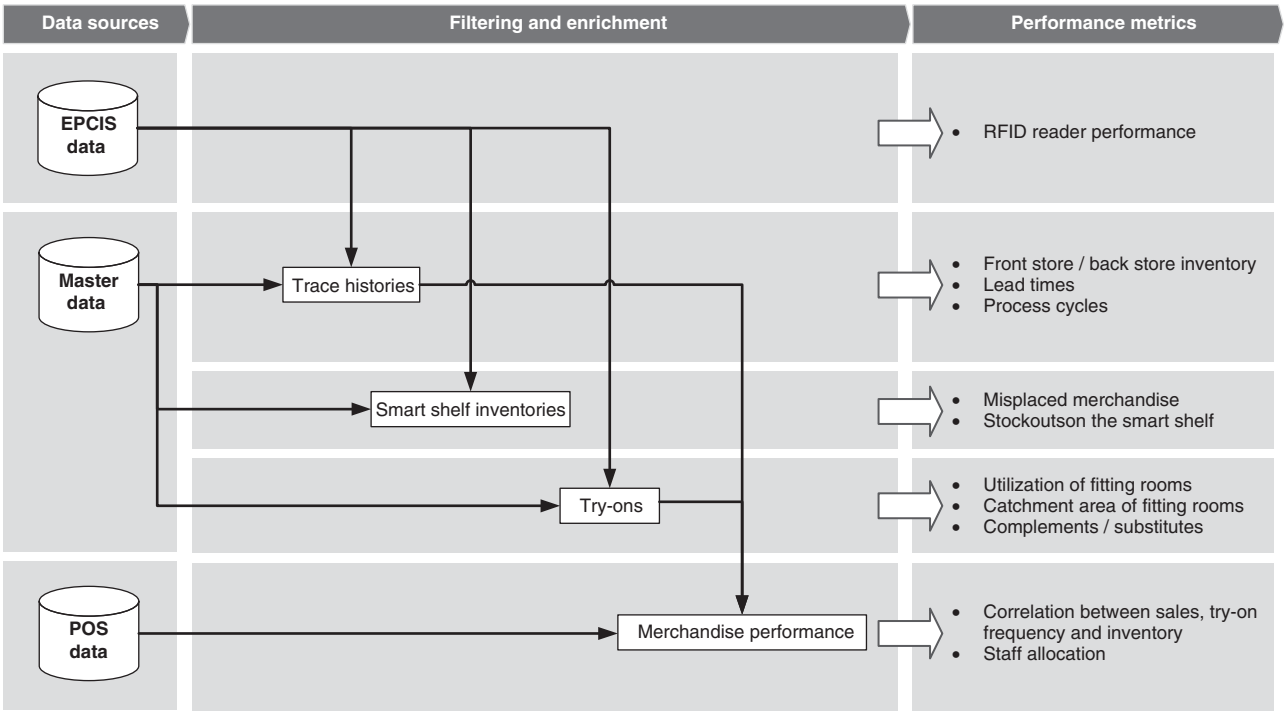

Figure 3 Overview of RFID data analyses and performance metrics.

the sales floor, each merchandise fixture and shop have a unique identifier. Each item is assigned to a merchandise fixture, and each fixture is assigned to its shop. Together with the information on the previously described try-on events, this information can be used in order to visualise the 'catchment areas' of fitting rooms. In the example in Figure 4, grey shading indicates the number of products that were taken to one of the fitting rooms in the lower right corner. The graphical visualisation helps the retailer to optimise his sales floor layout and the positioning of the fitting rooms, and gives indications about movement patterns of customers. The results can also be used to optimise product placements on the sales floor (e.g., complementary articles) or to influence customer shopping paths.

From the combination of try-on and sales data, additional opportunities arise to analyse merchandise performance within product categories. The example given in Figure 5 depicts the number of try-ons for a given category during the opening hours of one day, the number of sales events, and the ratio of the two values (represented as bars). The data indicate that the ratio of try-ons and sales events changes significantly over time. In this case, the retailer could not profit proportionally from the rush of interested visitors trying on articles in the early evening times. The comparison of the try-on/sales ratio at 3 pm with that at 5 pm shows that an increase in try-ons by more than 100% does not translate into a corresponding sales increase. A conceivable explanation might be that insufficient staff is present on the sales floor during these hours, resulting in lost sales, especially for articles that require extensive customer counselling, such as suits.

In addition to employing process analyses, Kaufhof made use of RFID to collect data from various experiments on the sales floor. For example, inventory levels and product presentation were periodically changed over several weeks according to a predefined scheme to investigate the impact that these factors have on try-ons and sales. In these cases, RFID was not a facilitating technology but was rather a sophisticated measurement instrument.

Evaluation and experiences

Because of the sheer size of the infrastructure alone, implementing and operating an RFID system like the one in Essen posed a new challenge to Metro and Kaufhof despite their extensive experience with the technology gathered in recent years. Some configuration efforts were necessary in the first weeks to optimise the quality of the collected data. After these issues were properly addressed, Kaufhof's evaluation of reliability and performance throughout the entire 15 months of the trial was very positive. RFID read rates at different reader locations were virtually 100%, which was partly due the physical characteristics of textiles, but also due to the use of novel near-field UHF technology and other state-of-the-art equipment. The only case of insufficient read rates was observed at the checkout counter, which could be attributed to the fact that RFID was installed in parallel to conventional barcode readers with staff at the POS having to activate the RFID reader device manually.

Figure 4 Catchment areas of fitting room clusters (Example).

Against the background of these results and low transponder prices, the idea of using RFID as a substitute for existing EAS systems was regarded as technologically feasible. This application area was even regarded as a major driver of any positive ROI calculation. However, it was also evident that before any large-scale roll-outs could realistically be planned, supply chain partners would have to agree on appropriate standards. One of Metro's IT project managers noted that:

> There are standardisation activities on an industry level to recommend the use of standard near-field UHF transponders without additional modifications for EAS. If we had such an RFID-based EAS solution, we would automatically have about half of the business case done as well. This, however, presumes that all suppliers adopt the technology.

The high level of detection accuracy also allowed Kaufhof to test the applicability of RFID for inventory management on the item level for the entire department. On the one hand, readers between the backroom area and the sales floor were used to monitor products moving between the two areas in order to calculate estimates of sales floor inventory, which was not possible with the existing inventory management system. These estimates were then validated using manual inspections and POS data. The data indicate that backroom monitoring poses a cost-efficient alternative to inventory monitoring using smart shelves if precise information on item locations is not required. Smart shelf readers, again, were used to analyse the frequency and duration of product misplacements. The results of both tests helped the retailer to develop a better understanding of the performance of in-store processes; they also showed that RFID provides the necessary data quality for process transformation, such that necessary tasks on the sales floor are automatically triggered by real-time information.

With regard to the use of mobile devices, the 2007/2008 trial was the first time that Kaufhof tested the

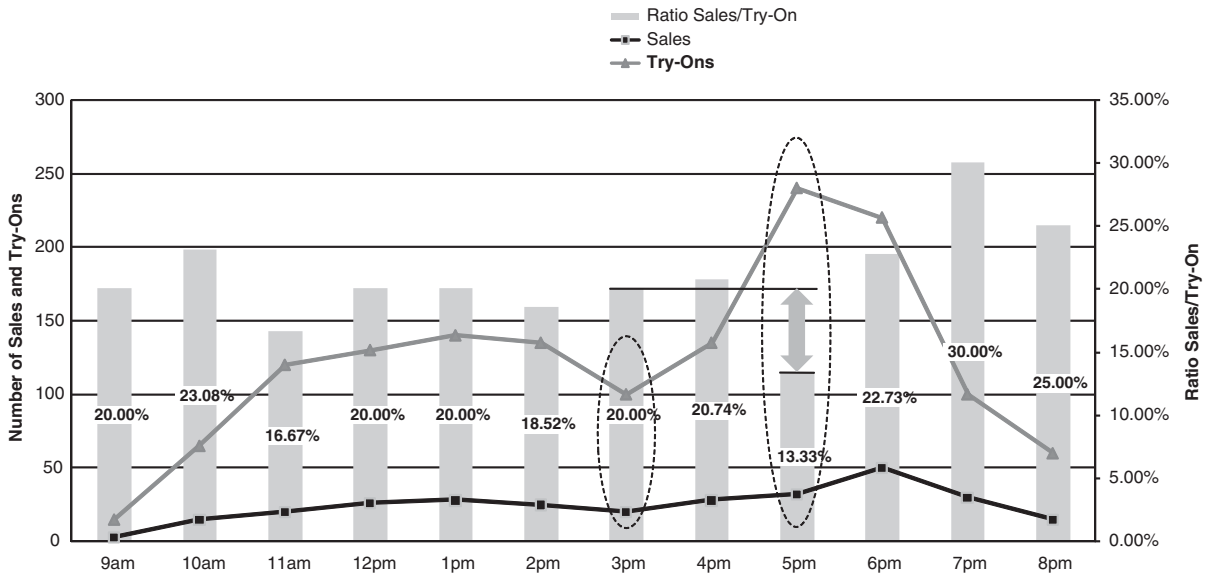

Figure 5 Analysis of sales/try-on ratios over time (Example).

performance of RFID in inventory-taking for an entire assortment. For this purpose, all items in the menswear department were recorded twice by barcode and RFID, respectively. The results indicated time-savings of more than 87% on average by the use RFID. The least improvements were observed for slackly hanging textiles. However, the advantages of RFID became evident the more items were hanging on a particular merchandise fixture. Items that had to be taken from the fixture and items that required employees to additionally enter size information also clearly showed the benefits of RFID. An additional advantage of RFID was seen in the fact that item-level identification prevents multiple reads of the same EAN code, which poses a potential source of inventory inaccuracies. However, with regard to the future use of RFID in inventory-taking, one of Kaufhof's IT executives noted:

> In its current form, RFID-based inventory taking seems not yet ready for productive usage. This is not owing to the technology itself. We have seen that RFID significantly accelerates the entire process in our trials, despite read rates slightly differing for different assortments. However, in order for the technology to be allowed to replace the traditional process, we would have to get an audit certificate. The associated costs might be substantial and perhaps render this application unfeasible from an economical perspective at this point in time.

By testing bulk identification at goods receipt and inventory-taking, it was possible to show that RFID allows for significant time-savings here as compared to the barcode as well. In contrast, the benefits of RFID at the POS were verifiable but nevertheless evaluated as negligible due to the small number of items per purchase.

In order to evaluate customer attitudes toward RFID-based applications, Kaufhof conducted a survey among 250 customers (50% women, 50% younger than 40 years) in May 2008. The three stationary applications (i.e., smart shelves, magic mirror, and smart displays) were to a large extent evaluated positively by customers, with smart shelves displaying the best ratings. Fifty-six per cent of all respondents regarded these items as constituting a great improvement in their shopping experience. Smart displays were equally successful, with 49% recording very positive answers. It was the detailed information on product availability that was particularly appreciated. Customers were also asked if they had perceived any negative aspects of either application. This question was answered in the negative by 83 and 79% of the respondents, respectively. In the contrast, the magic mirror was seen as an improvement by only 33%. As some of the comments indicated, this can be attributed to the limited usefulness of the information displayed and the position of the display in the mirror area. Privacy issues were not considered in the survey, but Kaufhof informed their customers about the presence of RFID readers and prepared their employees to answer specific questions. Perhaps as a result, only three privacy-related customer complaints were observed during the whole trial period.

Kaufhof also conducted interviews with sales staff-members who were asked to report on their experiences with RFID. The respondents appreciated most of all the use of the mobile devices for inventory-taking and the search functionality, which allows them to easily locate items on the sales floor. The interviews clearly showed that the employees' attitude towards RFID rose and fell with the observability of its benefits in the completion of everyday processes. Moreover, a number of

suggestions for improvement were gathered – for example, regarding the available search criteria.

The trial results that attracted the most interest came from the examination of large amounts of RFID data and the managerial implications thereof. The previously described analyses provided a number of new insights into store logistics and customer processes, for example, the differences between try-ons and sales across categories, the flow of goods through the store, the utilisation of fitting rooms, the frequency of execution errors, and others. The director of Metro's IT unit emphasised the value of the data for supply chain coordination and marketing:

> In the case of applications in the textile domain, the vertical integration of the value chain is crucial. The more store brands a retailer distributes, the more quickly the advantages of RFID can be realised. Another decisive factor will be the fact that modern UHF transponders can be used for both logistics and EAS solutions. […] The increase in precise information – be it about inventory levels or product properties – offers many novel possibilities. […] As soon as such an infrastructure is in place, the marketing people in charge will hardly be willing to miss the opportunities that will arise.

On the other hand, it became clear that RFID data would not always lead to unambiguous findings and that the phase of interpreting and drawing conclusions from RFID data would require more time. A major issue with the processing of collected data was the quality of master data to which RFID codes refer. For some products, only category-level information was available; for others, suppliers were using only one common EAN code for all available sizes.

Another issue arose from the discussion regarding the value of management-related information. The need to continuously analyse and aggregate data collected by the RFID infrastructure as well as field experiments and surveys into various reports was intuitively affirmed by members of the project team. However, a general answer regarding how to structure and quantify the impacts of such information on performance could not be provided. This was partly attributed to the lack of appropriate performance metrics. The performance of category managers, for instance, is not reflected by any specific process metric but is rather measured by the turnover generated within the respective product category. A Kaufhof IT executive stated the following:

> Quantifying the value of such marketing-related information from RFID systems is difficult. However, this is not characteristic of RFID. We have often found in the past that MIS projects are significantly harder to justify quantitatively than operational systems.

A critical constraint on some types of analyses was seen in German privacy and labour legislation. A Kaufhof representative provided the following example of staff performance measurements:

> The analysis of items lying in the fitting rooms is a sensitive issue. This information could principally be associated with individual sales employees. Our work council would have to agree on that explicitly. To avoid any confusion among our staff, we excluded such applications from our project right from the outset.

Another important lesson of the project was that some of the results would not instantaneously be transferable to other stores. Because of the small size of backroom storage areas in Essen, for instance, the project team realised that the potential for improving replenishment processes was inevitably limited. This, nevertheless, is not necessarily the case for other, larger branches that keep substantial amounts of backroom inventory. The same holds for the elimination of search time due to the small size of the sales floor compared to that of other stores.

Discussion

Research implications

As our case description has shown, the Kaufhof trial demonstrates a number of ways in which RFID may create business value in a retail environment. From a research perspective, the richness of the trial thus opens up the opportunity to analyse the characteristics of different RFID impact types within one case. For this purpose, it is necessary to abstract from single pieces of empirical evidence and develop a representation of the economical rationale behind the Kaufhof trial on a conceptual level. In the following, this is done by formulating theoretical propositions (P1–9) regarding the causal linkage between RFID and firm performance. In addition, as we point out by the end of the subsection, this conceptual view also allows for conclusions to be drawn regarding the profile of RFID value, the transferability of observed impacts, and the challenges to their quantification.

In order to structure our findings from the case, we make use of two complementary frameworks known from the IT value literature. On a macro level, we draw upon the framework by Melville *et al*. (2004), which encompasses internal and external factors on three different levels: (a) the focal firm, (b) the competitive environment, and (c) the firm's macro-environment (i.e., country characteristics). Within the focal firm, the framework describes IT value generation as an interplay of IT and other organisational resources that influence the performance of business processes and, as a result, that of organisational performance as a whole. To categorise the different effects of RFID on business processes on a micro-level, we use the IT impact framework by Mooney *et al*. (1996). Based on Davenport's (1993) classification of operational processes (i.e., a firm's value chain) and management processes (i.e., information processing, control, coordination, and communication), the model posits that IT creates business value along three dimensions and leads to automational, informational, and transformational

Table 4 RFID impacts on business processes of a department store

Process type	*Impact type*	*RFID applications*	*Performance metrics*
Operational	Automational	• Goods Issue and Receipt • Inventory-taking • Checkout • Returns management	• Time • Personnel costs • Detection rate
	Informational	• Smart shelves • Magic mirror • Smart monitor • MDE	• Customer satisfaction/loyalty • Personnel costs • Revenue
	Transformational	• Shelf replenishment • Misplacement prevention	• Personnel costs • Capital commitment • Inventory service level • Revenue • Customer satisfaction/loyalty
Management	Informational	• Process management • Category management • Store layout design • Purchasing/reordering • HR planning	• Revenue • Profitability • Customer satisfaction/loyalty

effects. The starting point for our analysis is the classification of observed impacts and the corresponding metrics that were considered by Kaufhof for quantification, as given in Table 4.

P1. Automational effects on operational processes: The first type of RFID impact that we observed is caused by automational effects, which come into play in situations in which data are already being captured. An example is the receiving process, in which employees scan a delivery's 'Serial Shipping Container Code (SSCC)' to confirm that they have carried out certain tasks as well as the barcodes of individual items to check for completeness. Here, the benefits of RFID can be explained by process automation – that is, the process is accelerated but not structurally changed. RFID may also lead to small gains in data quality, but this is not the primary focus of the application.

P2. Informational effects on operational processes: In contrast, informational effects occur if RFID leads to improvements related to at least one aspect of data quality, which in turn will lead to an increase in value. With the existing data-capturing technology, such improvements would have been too costly to implement to be economically feasible. Customer service provides an example of an arena in which store employees have access to more detailed information on the exact location and the characteristics of individual items, which not only reduces search times but also improves service quality. Informational effects are not caused by RFID alone but rather are fostered by additional tools that build upon the corresponding data collection infrastructure. The implementation of these tools requires various IT capabilities, which are simultaneously extended by the possibilities opened up by RFID.

P3. Transformational effects on operational processes: Third, we observed transformational effects, that is, an increase in value resulting from the technology and a simultaneous change in the process, which makes use of the increase in data quality in a different and more effective way. An example is the shelf replenishment process. With barcode technology, it is very costly to separate backroom inventory from sales floor inventory. RFID allows Kaufhof to record the movement of products between backroom and sales floor to continuously control shelf inventory levels by reading the RFID tags on the item level at low marginal cost. This can lead to a complete elimination of manual reviews and their replacement with system-triggered shelf replenishments, hence yielding increased product availability and higher sales. The success of process transformation, however, depends on a company's process capability – that is, its capacity to effectively design, implement, and manage business processes. At the same time, RFID extends these capabilities by enabling new processes that were not feasible before.

P4. Informational effects on management processes: The implementation of RFID in the firm may help an organisation to extend its information capabilities, which in turn has an influence on the performance of management processes via informational effects. The Kaufhof case suggests that the effect of RFID with regard to management processes can be mainly classified as informational. On the one hand, RFID provides detailed information on the reality of store process execution, which can be used for continuous process improvement. On the other hand, the data collection infrastructure serves as a tool used to better understand aspects of customer behaviour and perceptions of changes in a

store's assortment, product presentation, or floor layout. Thus, RFID may become a novel data source for management processes like category management, store layout design, and HR processes (e.g., staff planning). However, complementary information capabilities are required to translate RFID impacts on the level of management processes into value.

P5. Information capabilities: The development of an information capability enables learning feedback loops and thus contributes to the enhancement of other organisational capabilities. A special characteristic of an information capability is that it is not independent of other organisational capabilities but rather fosters them. In the Kaufhof example, RFID not only serves as an information feed that supports business processes but also allows for the verification of correct process execution. Thus, a learning feedback loop is created that allows a company to continuously observe and improve its process capabilities. The same holds for RFID-based information offerings to consumers, where RFID serves as both information source and instrument for investigating the impact of information on consumer behaviour. The company may accordingly enhance its IT capabilities if these data are used to improve the design of IT artefacts.

P6. Substitutional effects: The substitution of one technology by RFID in the firm may also lead to changes that have an immediate and process-independent impact on value metrics. In the Kaufhof case, it is the planned substitution of proprietary EAS systems, with reusable tags moving in a closed loop between manufacturer and retailer, that is expected to lead to substantial cost savings. These substitutional effects are not captured by the process-focussed framework because they do not relate to single processes or activities but rather have to do with the RFID infrastructure as a whole. Notwithstanding some supporting activities that would be eliminated as well, such as the collection of tags at the POS and their transport back to the suppliers, Kaufhof's core processes would remain untouched.

P7. RFID capabilities: The impact of RFID investments is moderated by a distinct RFID capability, which is different from other IT capabilities. The deployment of an RFID infrastructure from the design stage to productive use requires specific skills and knowledge of RFID technology. Metro Group operates its own internal IT service unit that has gained extensive experience with RFID in recent years. Throughout the realisation of its system in Essen, Kaufhof was nevertheless supported by four different providers of hardware, software, and consulting services. This indicates that the success of RFID implementation projects depends on the presence of an RFID-related capability that is not necessarily congruent with other IT capabilities that already exist, even within IT-intensive organisations.

P8. Contextual factors: Our case example provides evidence of the role of influence factors external to the firm that determine the outcome of an RFID project. The first factor (i.e., trading partner resources) refers to a supplier's ability and willingness to provide high-quality data on RFID tagged goods, as well as the capacity to process data generated by the RFID system that is made available by the retailer. In the Kaufhof case, for example, the value of data on try-ons and sales is limited by a supplier's ability to quickly respond to sudden changes in customer demand. The second factor (i.e., industry characteristics) refers to characteristics such as the structure of the supply chain, the number of product variants, and the intensity of competition. One motivation for Kaufhof to consider the tagging of individual sales items was the large number of variations in terms of colours and sizes. This is in contrast to the standard in grocery retail, where products are far less heterogeneous and, accordingly, case-level tagging seems more appropriate. The third factor (i.e., country characteristics) includes aspects like privacy and labour legislation, demographics, and cultural issues, which may have an impact on the design of an RFID system and its acceptance by customers.

P9. Intermediate outcomes: The previously described RFID impacts are reflected in a variety of outcomes that are, in different ways, linked to firm performance. On the one hand, the cost-saving effects of technology substitution are evident. In the case of operational processes, these can also usually be quantified quite easily through the associated time and cost savings, increases in service level, increased capital commitment, and other elements. This holds not only for automational effects but also for transformational and informational effects, though the exact size of the effect might be harder to determine in advance. On the other hand, the Kaufhof case suggests that RFID-based improvements in management process performance become manifest in another way. The tasks related to store layout design, category management, or marketing, for instance, represent unstructured, knowledge-intensive, and individual-bound activities whose performance is hardly directly observable. Informational effects on management processes are therefore only reflected in their indirect influences on operational processes or firm performance as a whole. As a consequence, the construction of the corresponding cause-and-effect chain is not a trivial task and is heavily influenced by subjective perceptions of RFID benefits.

In total, the nine propositions add up to a conceptual model of RFID value as depicted in Figure 6 that contributes to our understanding of RFID business value in three respects. First, the model provides a profile of the different ways RFID technology may create value in an organisation. That is, it explains which impact types can be expected from the use of RFID and which cannot. The discussion around the use of RFID for the prevention of stock-outs, which can be found in several articles in trade journals and academic journals alike, poses an example of why such categorisation is necessary and non-trivial. A logical flaw that is often present in these publications is caused by confusion regarding stock-outs

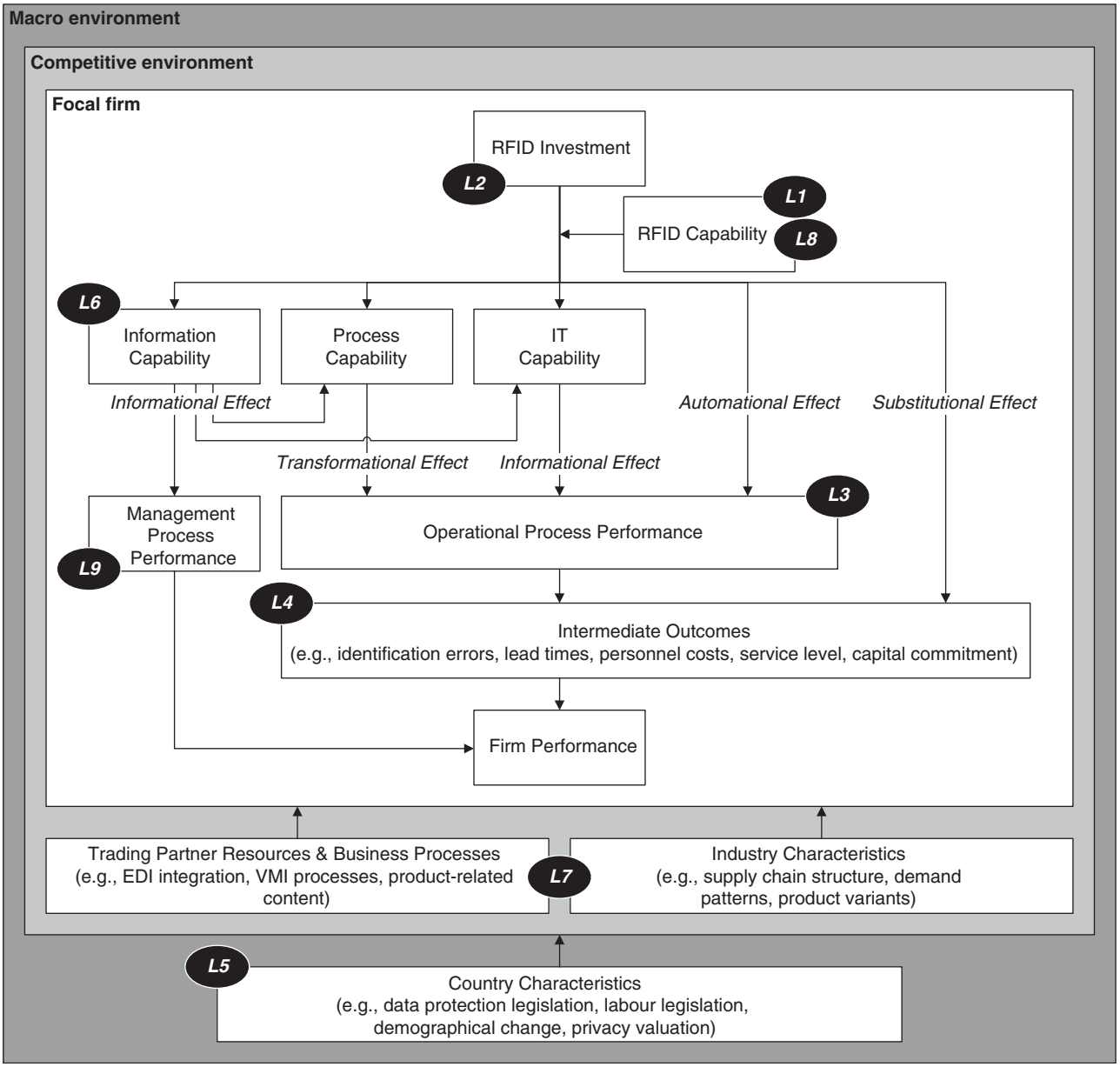

Figure 6 Conceptual model of RFID business value (black circles link model elements to practical lessons learned from the trial; cf. subsection on managerial implications).

on the store level and 'out of shelf' situations on the sales floor. While the latter issue can be addressed by RFID through the transformation of shelf replenishment processes, the first is a sign of suboptimal reordering practices on the store management level more than an indication of a lack of inventory visibility. In fact, as proposed by our model, the necessary management process automation cannot be achieved by RFID but instead requires the introduction of automatic reordering systems.

Secondly, the model allows one to draw conclusions regarding the transferability of observed impacts from one organisation to another. This aspect refers to the role of complementary organisational capabilities, which by definition are significantly harder to copy or to substitute for than any technological infrastructure. As a consequence, RFID impacts that heavily depend on the presence of such capabilities might not be realisable to the same extent in two different companies. On the one hand, a substitutional effect (e.g., the use of RFID for anti-theft purposes) obviously poses an example of a class of RFID benefits that is not substantially influenced by firm-specific capabilities. The expected benefits would accordingly depend only on the size of the respective

installations. On the other hand, informational effects on the management level depend on an organisation's or – even worse – an individual's capacity to interpret RFID-generated information and draw the right conclusions from it. Benefits might diverge significantly because the same information that proves extremely valuable to one organisation may be worthless to another.

A third aspect that is closely related to the second refers to the question of to what extent the impact of RFID investments can be measured by objective performance metrics. Simply put, it can be said that measurements are more reliable when the corresponding metric more closely relates to a single activity or cost factor. Automational effects in the form of time-savings observed in the goods receipt process, for instance, can easily be translated into potential for cost reductions. Quantifying the impact of process transformation on the shelf replenishment process, for example, is already harder because several other factors, such as seasonal influences, changing assortments, and promotional campaigns, have to be taken into account. As proposed by our model, the impact on management process performance, again, poses the greatest challenge in terms of quantification because the only applicable metrics today are highly aggregated financial and non-financial measures on the firm level – for example, revenue and customer satisfaction. From a research perspective, this issue is perhaps the most important aspect of our case with regard to opportunities for further research because it directly points to one of the fundamental and largely unresolved questions in the IT value literature: how can organisations generate value from information?

Managerial implications

Beyond the academic perspective, the Kaufhof case also provides a number of lessons relevant to management practice. On the one hand, these include familiar factors that have often been cited in traditional IS development, such as top management support, training, etc., which also apply to RFID implementation. On the other hand, some lessons are distinctive and deserve more detailed consideration (cf. Figure 6). In order to highlight the novelty of these implications with regard to prior studies, we contrast our findings with those from the earlier trial conducted by Kaufhof in 2003. Loebbecke (2007a), following a concept first suggested in Loebbecke & Palmer (2006b), discusses the results of the 2003 trial in terms of the so-called '5 P's of RFID': physics, price, processes, performance, and privacy. In this subsection, we highlight to what extent the 2007/2008 trial changed or extended the company's view of RFID using the five categories. In a second step, we propose to complement these categories using what we call the '4 I's of integrated RFID': integration, interpretation, interoperability, and involvement. These four additional categories allow us to discuss further practical implications that can be drawn specifically from our study of a fully integrated system.

L1. Physics: While the fundamental physical laws of RF communications have not changed, of course, recent technological advances nevertheless offer solutions to some of the related issues that user companies have faced in the past. As Kaufhof noticed in the 2007/2008 trial, the problem of insufficient read rates still requires some configuration efforts, but read rates of virtually 100% are possible by now even at chokepoints such in the transition between backroom and sales floor, with large amounts of tags passing through the RF field simultaneously and differing angles between transponders and antennae. Another noteworthy difference from the 2003 trial refers to the extended read range, which now allows for using RFID as an alternative to existing anti-theft systems. This achievement is a consequence of Kaufhof's decision in favour of another frequency band. Considering the usage of HF technology for item-level tagging and UHF technology for logistical units, Loebbecke (2007a) finds that 'no single frequency fully suits the needs for both the distribution centre applications and item-level in-store usage of RFID'. As we have seen in the 2007/2008 trial, this statement no longer holds with the introduction of near-field UHF transponders, which combine conventional UHF microchips with a novel antenna design, thus allowing for larger reading distances while achieving the high detection rates seen with HF technology.

L2. Price: According to Loebbecke (2007a), per unit prices for disposable transponders in 2003 were €0.30 and €0.50 including anti-theft functionality. Owing to the decrease in price in recent years, the cost for near-field UHF transponder inlays, which can be integrated into existing barcode labels attached to the merchandise, reached a low of about €0.07 in 2007. Despite this substantial drop in price level, transponder costs are still the dominant factor in ROI calculations regarding supply-chain-wide RFID implementation (i.e., in contrast to use of closed-loop systems). However, according to Kaufhof's view, current transponder prices have decreased enough to make RFID-based EAS solutions economically feasible, particularly under the precondition that anti-theft functionality resides in the software and not on the tag. Although these systems alone do not constitute the one and only 'killer application' that justifies the replacement of existing technology, they might, on the long run, become the hoped-for driver of widespread diffusion of item-level RFID in the industry that other applications can build upon.

L3. Processes: In their first trial in 2003, 'Kaufhof only tested basic functions and potential service offerings' (Loebbecke & Palmer, 2006a). The focus of the project was verifying the performance of state-of-the-art technology rather than changing store processes. This was not done until the 2007/2008 trial, when the company really implemented RFID-based processes. The comparison of barcode-based and RFID-based inventory-taking, for example, provided insight into the factors that eventually determine the size of operational improvements, for

example, product type, position of the RFID label, and merchandise fixture, among others. On the one hand, it was shown that RFID can accelerate the process significantly for the whole assortment because employees do not have to take clothes from the shelves anymore in order to look for barcode labels. On the other hand, it became evident that additional activities would be necessary in order to ensure that all items are equipped with transponders to prevent them from remaining undetected. Furthermore, the 2007/2008 trial was the first time that Kaufhof implemented RFID-based mobile applications to support their sales staff. In particular, all search-related functionalities provided by these devices were highly appreciated and led to a reduction in non-value-adding activities. RFID was thus used not only used as a cost-saving but also as a service-enhancing technology. Third, Kaufhof examined how to utilise RFID as a measurement instrument that generates more detailed information on in-store processes. The lesson that the company learned was that the reality of process execution in retail is often not entirely known unless an automatic data collection technology provides the necessary data. RFID may serve as a tool to detect existing inefficiencies and to continuously control the effectiveness of countermeasures.

L4. Performance: The benefits of RFID were assessed in the 2003 trial using three indicators: lead times, labour cost reduction, and data quality (Loebbecke, 2007a). In the 2007/2008 trial, the same metrics were applied to examine the size of automational effects on operational processes. However, RFID was also used to generate several novel performance measures for operational processes, such as misplacement frequency and on-shelf service level, as well as detailed product histories for single items and whole categories. In addition, it was shown that the combination of RFID and POS data can be used not only to monitor but also to control activities on the sales floor – for example, by triggering shelf replenishments. In contrast, the Kaufhof case simultaneously highlights the difficulty of measuring performance changes due to informational effects. The performance of category management, store layout design, or marketing, for example, depends on a variety of factors including individual decision-making capabilities. The impact of RFID on these tasks is only indirectly observable through the improvement of operational processes or firm-level metrics. Similarly, the exact influence of consumer applications on the sales floor in terms of customer loyalty and purchase frequency might only be reflected in non-financial indicators. Hence, companies planning to use RFID for such purposes must be aware of the difficulties involved in expressing the full benefits of RFID in cash terms.

L5. Privacy: At the time of the 2003 trial, privacy risks and the actions of pressure groups had just become a major issue in the U.S. and Europe. The fear among many observers was that retailers might link customer information to products for profiling or tracking even after purchase. A number of boycott campaigns on the Internet, protests against individual trials, and negative press reports affected Metro and other companies worldwide. In 2003, transponders were routinely cut off at the checkout counter in order to address the potential privacy concerns of Kaufhof customers. In 2007/2008, Kaufhof decided to inform customers proactively by indicating the presence of readers with the help of highly visible adhesive labels, logos and instructions printed on transponder labels, as well as with freely available information brochures. Transponders were only removed from the products on request to allow for the identification of returned items. The company nevertheless experienced virtually no negative reactions during the whole trial period. Whether this is a consequence of their open communications policy or the consumers' perception of RFID benefits cannot be ascertained for certain at this point in time. Another conceivable explanation could be that the privacy debate in recent years, despite its presentation in the media, never really resonated with the broader public. However, the implementation of integrated RFID systems might trigger a second wave of anti-RFID activities and re-intensify the discussion around privacy risks.

L6. Integration: Beyond the optimisation of operational processes, our case illustrates the benefit of RFID as an integrated data collection infrastructure whose whole exceeds the sum exceeds of its parts. The conclusions that might be drawn from such data have often been presumed – for example, by Loebbecke (2007a), who illustrates the idea using the following fictitious example of an intelligent clothes rack: 'If a customer put a blouse back on the clothes rack after five seconds, she might not like the material. If five minutes went by, it is likely that the customer tried on the article'. However, the trial conducted in 2007/2008 was the first time that a retailer really explored the opportunities involved with the use of the technology. As our case study has shown, the data quality and level of detail provided by RFID allow for the generation of a plethora of different analyses of product histories, in-store logistics, customer behaviour, and merchandise performance, among others. Some support and refine what has already been determined from existing data, whereas others point to new and previously unobserved phenomena. Furthermore, the same data can be used to implement novel consumer applications and to support sales processes, such as the search for products that meet specific criteria. In light of the manifold possibilities regarding how to make use of the gathered information, a future challenge for retailers will eventually be to develop capabilities that allow them to turn these options into competitive advantage.

L7. Interpretation: Another lesson from the Kaufhof project is that RFID data in themselves provide little value if they are not integrated with other operational systems to link tag IDs to product information and business events. The output generated by RFID reading devices should not be mistaken for meaningful business information;

it requires further filtering and enrichment before any interpretation makes sense. Regarding the use of the enriched data, Loebbecke & Palmer (2006a) speculate that 'finer granularity allows individual retail outlets to not only know they have red shirts in stock, but the sizes as well'. However, the 2007/2008 trial has shown that despite the high granularity made possible by item-level tagging, its value does not exceed that of the barcode if the corresponding master data in existing information systems do not include the same level of detail. As we have seen in the data provided by Kaufhof, some suppliers, for instance, do not use different EAN codes for different sizes of products. In addition, no standardised colour codes are in place in the industry so far. The master data linked to EPC events included more than 900 codes, representing variants such as 'deep blue', 'midnight blue', and 'navy', as well as vague terms such as 'mud'. Hence, insights regarding the colour and size of products in stock as mentioned are only partially feasible. Improving master data quality will be a complex issue for retailers as long as their own procurement managers and suppliers do not see the benefits. This issue might change with the collaborative use of RFID data throughout the supply chain and the growing popularity of master data pools like SINFOS in Germany, but there is still a long way to go before these practices are established in the industry.

L8. Interoperability: In 2003, no relevant RFID standards aside from the ISO 15693 air interface standard were available (Loebbecke & Huyskens, 2008). In particular, there were no interface standards for the implementation of systems that integrate all hardware components into one data repository and with other systems. The lack of common numbering schemes for RFID-equipped items rendered the management of an entire store assortment on the item level nearly impossible. As a result, the 2003 trial was limited to products from only one supplier. Even today, RFID is still far from being a plug-and-play technology and requires substantial efforts with regard to configuration and adaptation to a company's requirements, as is necessary to achieve the desired level of performance and quality of data. However, it was not least of all the rise of the family of standards around the Electronic Product Code (EPC) that actually enabled the creation of Kaufhof's infrastructure. On the one hand, standards increase the interoperability of single components. As a result, the need to possess extensive RFID knowledge to effectively cope with issues like RF interferences becomes less critical. On the other hand, standards lead to interoperable systems in and between organisations, which may lead to additional benefits in the future. Therefore, even companies that intend to start with isolated RFID artefacts should pursue an infrastructure-centred approach based on widely accepted industry standards.

L9. Involvement: The Kaufhof case also demonstrates the necessity of involving members of different organisational units as well as suppliers in the project. In their survey of employees, for instance, Kaufhof gathered a number of valuable suggestions for improving the functionality of mobile devices. An interesting statement made by one employee, for example, was that mobile applications perhaps should not be used in front of the customer because the dependency on an electronic device could be regarded as a sign of incompetence. Applications should therefore be designed together with prospective users to achieve a good fit with their individual needs. Similarly, companies should be aware that the mere availability of data does not imply easy interpretation from a business perspective. It is therefore crucial to cultivate a project team that includes other individuals besides technology experts. Moreover, the Kaufhof project shows the need for tight collaboration between retailers and suppliers with regard to RFID event data, master data, and other product-related digital content. During our visits, for instance, we were able to observe some smart displays giving recommendations regarding Gardeur products that were not available at the Essen store. This indicates that the content provided by the supplier was insufficiently adapted to the physical assortment at the particular store. Not least, the desirable level of cooperation with suppliers presumes that the retailer is willing to share data, too.

Summary and outlook

This article presented a study of a large-scale RFID trial that goes beyond what has been done in earlier projects in several respects, including the technologies and standards used, the applications implemented, and the level of integration with other systems. It is this aspect of data integration and usage that distinguishes our study from prior cases in retail. The richness of the case (i.e., the heterogeneity of the RFID applications and supported processes) allowed us to compare the different cause-and-effect chains between RFID investments and their impact on firm performance. Based on two existing frameworks from the IT value literature, we developed a conceptual model that reflects the economical rationale behind the trial and allowed us to discuss the observed RFID impacts, the difficulty in assessing their value using objective performance measures, and the role of complementary and contextual factors. Furthermore, the special role of the company under consideration as one of the first protagonists of the RFID movement allowed us to compare this trial to an earlier project conducted about 5 years ago. We compared the lessons learned from our case to those documented in the two prior works. The results illustrate the impact of technological advances and standardisation efforts in recent years on managerial perceptions of RFID business value and allow for the derivation of a number of useful implications for practice.

Starting from this contribution, we see opportunities for further research in various directions. While the main advantage of case research lies in the production of in-depth examinations of socio-economic phenomena,

the external generalisability of the findings is limited for the very same reason. We considered a project of an early adopter that already possesses extensive experience with RFID and that is affiliated with one specific industry. Objectives and conditions in other companies might differ significantly and result in diverging evaluations of the technology. Low demand rates, high-value items, a wide product variety, and a strong need for customer service, for example, are among the typical characteristics of apparel retail and drove the tagging of products on the item level in the Kaufhof case. In contrast, these factors hardly apply, for example, to grocery retail, which accordingly seems more suited to case-level RFID. With all this in mind, it seems that the validity of our research would benefit from insights obtained from additional cases that confirm, extend or disprove our conclusions.

A second opportunity lies in longitudinal studies of the competitive advantage that might be drawn from RFID data. Although our collected data span more than a year, we were unable to fully examine the long-term impacts of RFID implementation. 'Soft' impacts, such an increase in customer satisfaction, were highlighted via surveys; however, the extent to which these will also be reflected in higher transaction frequencies, increased revenues, and an overall increase in profitability in the coming years remains to be seen. For this purpose, it will be necessary to conduct quantitative studies using larger samples at a later stage in the RFID adoption process. These would also provide further insight into the importance of organisational capabilities to the value creation process and the development of competitive advantage.

Finally, we encourage further research on sophisticated models and tools that support the decision-maker in the design of RFID systems and processes. A number of spreadsheet-based planning tools for RFID projects were developed by academia and various industries in recent years. However, more advanced analytical and simulation models will be needed to fully capture the complexity of the transformational effects. Another promising opportunity for research lies in the area of filtering, analysis, and visualisation techniques for large amounts of RFID event data.

Acknowledgements

We thank the project team members from Kaufhof Warenhaus AG, MGI METRO Group Information Technology GmbH and IBM Deutschland GmbH for their support in the preparation of this paper.

References

ACCENTURE (2003) *Auto-ID in the Box: The Value of Auto-ID Technology in Retail Stores*. Auto-ID Center, MIT, Cambridge, MA.

ANGELES R (2005) RFID technologies: applications and implementation issues. *Information Systems Management* **22(1)**, 51–65.

ARAL S and WEILL P (2007) IT assets, organizational capabilities, and firm performance: how resource allocations and organizational differences explain performance variation. *Organization Science* **18(5)**, 763–780.

BARNEY JB (1991) Firm resources and sustained competitive advantage. *Journal of Management* **17(1)**, 99–120.

BARUA A, KRIEBEL C and MUKHOPADHYAY T (1995) Information technology and business value: an analytic and empirical investigation. *Information Systems Research* **6(1)**, 3–23.

BENBASAT I, GOLDSTEIN DK and MEAD M (1987) The case research strategy in studies of information systems. *MIS Quarterly* **11(3)**, 369–387.

BENDAVID Y, LEFEBVRE E, LEFEBVRE LA and WAMBA SF (2007) B-to-B e-commerce: assessing the impacts of RFID technology in a five layer supply chain. 40th Hawaii International Conference on System Sciences, Waikoloa, HI.

BENDER DH (1986) Financial impact of information processing. *Journal of Management Information Systems* **3(2)**, 22–32.

BHARADWAJ A (2000) A resource-based perspective on information capability and firm performance: an empirical investigation. *MIS Quarterly* **24(1)**, 169–196.

BHARADWAJ AS, BHARADWAJ SG and KONSYNSKI BR (1999) Information technology effects on firm performance as measured by tobin's q. *Management Science* **45(7)**, 1008–1024.

BHATT GD and GROVER V (2005) Types of information technology capabilities and their role in competitive advantage: an empirical study. *Journal of Management Information Systems* **22(2)**, 253–277.

BOSE I and PAL R (2005) Auto-ID: managing anything, anywhere, anytime in the supply chain. *Communications of the ACM* **48(8)**, 100–106.

BOTTANI E and RIZZI A (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* **112(2)**, 548–569.

BRESNAHAN TF (1986) Measuring the spillovers from technical advance: mainframe computers in financial services. *The American Economic Review* **76(4)**, S. 742–S. 755.

BROWN A and BAKHRU A (2007) Information systems innovation research and the case of RFID. In *Organizational Dynamics of Technology-based Innovation: Diversifying the Research Agenda* (MCMASTER T, WASTELL D, FERNELEY E and DEGROSS JI, Eds), pp 363–376, Springer, Heidelberg.

BROWN I and RUSSELL J (2007) Radio frequency identification technology: an exploratory study on adoption in the South African retail sector. *International Journal of Information Management* **27(4)**, 250–265.

BROWN SA (1997) *Revolution at the Checkout Counter*. Harvard Business Review Press, Cambridge, MA.

BRYNJOLFSSON E and HITT L (1996) Paradox lost? firm-level evidence on the returns to information systems spending. *Management Science* **42(4)**, 541–558.

COTTELEER MJ and BENDOLY E (2006) Order lead-time improvement following enterprise information technology implementation: an empirical study. *MIS Quarterly* **30(3)**, 643–660.

DAVENPORT TH (1993) *Process Innovation: Reengineering Work through Information Technology*. Harvard Business School Press, Cambridge.

DE KOK AG, VAN DONSELAAR KH and VAN WOENSEL T (2007) A break-even analysis of RFID technology for inventory sensitive to shrinkage. *International Journal of Production Economics* **112(2)**, 521–531.

DELEN D, HARDGRAVE BC and SHARDA R (2007) RFID for better supply-chain management through enhanced information visibility. *Production and Operations Management* **16(5)**, 613–624.

DELOITTE (2008) 2008 Global powers of retailing, deloitte touche tohmatsu LLC. [WWW document] http://www.deloitte.com/dtt/cda/doc/content/dtt_globalpowersretailing.pdf (accessed 29 October 2008).

DEVARAJ S and KOHLI R (2003) Performance impacts of information technology: is actual usage the missing link? *Management Science* **49(3)**, 273–289.

DUTTA A, LEE HL and WHANG S (2007) RFID and operations management: technology, value, and incentives. *Production and Operations Management* **16(5)**, 646–655.

EDWARDS J (2008) EPC's tipping point. *RFID Journal* **5(5)**, 11–17.

EISENHARDT KM (1989) Building theories from case study research. *Academy of Management Review* **14(4),** 532–550.

EPCGLOBAL (2007) EPC Information Services (EPCIS) Version 1.0.1 specification. EPCglobal, Inc. [WWW document] http://www.epcglobalinc.org/standards/epcis/epcis_1_0_1-standard-20070921.pdf (accessed 29 October 2008).

FLEISCH E and TELLKAMP C (2005) Inventory inaccuracy and supply chain performance: a simulation study of a retail supply chain. *International Journal of Production Economics* **95(3),** 373–385.

GAUKLER G, SEIFERT RW and HAUSMAN WH (2007) Item-level RFID in the retail supply chain. *Production and Operations Management* **16(1),** 65–76.

GCI (2005) *EPC: A Shared Vision for Transforming Business Processes. Global Commerce Initiative*. GCI Cologne, Germany.

GRANT RM (1991) The resource based theory of competitive advantage. *California Management Review* **33(3),** 114–135.

GÜNTHER O and SPIEKERMANN S (2005) RFID and the perception of control: the consumer's view. *Communications of the ACM* **48(9),** 73–76.

HABERMAN AL (2001) 17 billion reasons to say thanks. In *Twenty-Five Years Behind Bars* (HABERMAN AL, Ed), pp 113–151, Harvard University Press, Cambridge, MA.

HEESE HS (2007) Inventory record inaccuracy, double marginalization, and RFID adoption. *Production and Operations Management* **16(5),** 542–553.

HICKS LE (1975) *The Universal Product Code*. AMACOM, New York, NY.

JONES P, CLARKE-HILL C, SHEARS P, COMFORT D and HILLIER D (2004) Radio frequency identification in the UK: opportunities and challenges. *International Journal of Retail & Distribution Management* **32(3),** 164–171.

KÄRKKÄINEN M (2003) Increasing efficiency in the supply chain fort short shelf life goods using RFID tagging. *International Journal of Retail & Distribution Management* **31(10),** 329–336.

KÄRKKÄINEN M and HOLMSTRÖM J (2002) Wireless product identification: enabler for handling efficiency, customisation and information sharing. *Supply Chain Management: An International Journal* **7(4),** 242–252.

KAUFHOF (2009) Kurzportrait. Kaufhof Warenhaus AG, Cologne [WWW document] http://www.galeria-kaufhof.de/sales/coco/co_unternehmen_011_kurzportrait.asp?FLEXID=0 (accessed 10 March 2009).

A.T KEARNEY (2004) *RFID/EPC: Managing the Transition (2004–2007)*. A.T. Kearney, Inc., Chicago, IL.

KOH CE, KIM HJ and KIM EY (2006) The impact of RFID in retail industry: issues and critical success factors. *Journal of Shopping Center Research* **13(1),** 101–117.

KOHLI R and GROVER V (2008) Business value of IT: an essay on expanding research directions to keep up with the times. *Journal of the Association for Information Systems* **9(1),** 23–39.

KOHLI R and HOADLEY E (2006) Towards developing a framework for measuring organizational impact of IT-enabled BPR: case studies of three firms. *The Data Base for Advances in Information Systems* **37(1),** 40–58.

KÖK AG and SHANG KH (2007) Inspection and replenishment policies for systems with inventory record inaccuracy. *Manufacturing & Service Operations Management* **9(2),** 185–205.

LACY S (2005) RFID: plenty of mixed signals. BusinessWeek Online, 31 January 2005.

LEE CP and SHIM JP (2007) An exploratory study of radio frequency identification (RFID) adoption in the healthcare industry. *European Journal of Information Systems* **16(6),** 712–724.

LEE HL and ÖZER Ö (2007) Unlocking the value of RFID. *Production and Operations Management* **16(1),** 40–64.

LEE YF, CHENG F and LEUNG Y (2004) Exploring the impact of RFID on supply chain dynamics. 2004 Winter Simulation Conference, Washington, D.C.

LEIMEISTER JM, KNEBEL U and KRCMAR H (2007) RFID as enabler for the boundless real-time organisation: empirical insights from Germany. *International Journal of Networking and Virtual Organisations* **1(4),** 45–64.

LEONARDI PM (2007) Activating the informational capabilities of information technology for organizational change. *Organization Science* **18(5),** 813–831.

LI T, VAN HECK E and VERVEST P (2009) Information capability and value creation strategy: advancing revenue management through mobile ticketing technologies. *European Journal of Information Systems* **18(1),** 38–51.

LOEBBECKE C (2007a) Piloting RFID along the supply chain: a case analysis. *Electronic Markets* **17(1),** 29–37.

LOEBBECKE C (2007b) Use of innovative content integration information technology at the point of sale. *European Journal of Information Systems* **16(3),** 228–236.

LOEBBECKE C and HUYSKENS C (2008) A competitive perspective on standard-making: Kaufhof's RFID project in fashion retailing. *Electronic Markets* **18(1),** 30–38.

LOEBBECKE C and PALMER JW (2006a) RFID in the fashion industry: Kaufhof department stores ag and gerry weber international AG, fashion manufacturer. *MIS Quarterly Executive* **5(2),** 15–25.

LOEBBECKE C and PALMER JW (2006b) *A Real-World Pilot of RFID in the Fashion Industry: Kaufhof and Gerry Weber in Germany* Academy of Management Annual Meeting (OCIS Division), Atlanta, GA.

LOVEMAN GW (1994) Assessing the productivity impact of information technologies. In *Information Technology and the Corporation of the 1990s* (ALLEN TJ and SCOTT-MORTON M, Eds), pp 84–110, Oxford University Press, New York, NY.

LUO Z, YEN B, TAN Z and NI Z (2008) Value analysis framework for RFID technology adoption in retailers in China. *Communications of the AIS* **23,** 295–318.

MANTHOU V and VLACHOPOULO M (2001) Bar-code technology for inventory and marketing management systems: a model for its development and implementation. *International Journal of Production Economics* **71(1–3),** 157–164.

MATA FJ, FUERST WL and BARNEY JB (1995) Information technology and sustained competitive advantage: a resource-based analysis. *MIS Quarterly* **19(4),** 487–505.

MCFARLANE D and SHEFFI Y (2003) The impact of automatic identification on supply chain operations. *International Journal of Logistics Management* **14(1),** 1–18.

MELVILLE N, KRAEMER K and GURBAXANI V (2004) Information technology and organizational performance: an integrative model of it business value. *MIS Quarterly* **28(2),** 283–322.

MEREDITH J (1998) Building operations management theory through case and field research. *Journal of Operations Management* **16(4),** 441–454.

METRO (2005) *RFID in Practice: A Pilot Project by Kaufhof and Gerry Weber*. Metro Group Future Store Initiative, Duesseldorf, Germany.

MOON KL and NGAI EWT (2008) The adoption of RFID in fashion retailing: a business value-added framework. *Industrial Management & Data Systems* **108(5),** 596–612.

MOONEY JG, GURBAXANI V and KRAEMER K (1996) A process oriented framework for assessing the business value of information technology. *The Data Base for Advances in Information Systems* **27(2),** 68–81.

MORRISON CJ and BERNDT ER (1990) Assessing the productivity of information technology equipment in the U.S. manufacturing industries. Working Paper 3582, National Bureau of Economic Research, Cambridge, MA.

MUKHOPADHYAY T, KEKRE S and KALATHUR S (1995) Business value of information technology: a study of electronic data interchange. *MIS Quarterly* **19(2),** 137–156.

MUKHOPADHYAY T, RAJIV S and SRINIVASAN K (1997) Information technology impact on process quality and output. *Management Science* **43(12),** 1645–1659.

NELSON JE (2001) Scanning's silver celebration. In *Twenty-Five Years Behind Bars* (HABERMAN AL, Ed), pp 25–33, Harvard University Press, Cambridge, MA.

NGAI EWT, MOON KKL, LIU JNK, TSANG KF, LAW R, SUK FFC and WONG ICL (2008a) Extending CRM in the retail industry: an RFID-based personal shopping assistant system. *Communications of the AIS* **23,** 277–294.

NGAI EWT, MOON KKL, RIGGINS FJ and YI CY (2008b) RFID research: an academic literature review (1995–2005) and future research directions. *International Journal of Production Economics* **112(2),** 510–520.

NIKITIN PV, RAO KVS and LAZAR S (2007) An overview of near field UHF RFID. IEEE RFID 2007 Conference, Grapevine, TX.

PARE G (2004) Investigating information systems with positivist case study research. *Communications of the AIS* **13,** 233–264.

PARE G, BOURDEAU S, MARSAN J, NACH H and SHURAIDA S (2008) Re-examining the causal structure of information technology impact research. *European Journal of Information Systems* **17(4)**, 403–416.

PATTON MQ (2002) *Qualitative Evaluation and Research Methods*. Sage Publications, Newbury Park, CA.

PEPPARD J and WARD J (2005) Unlocking sustained business value from IT investments. *California Management Review* **48(1)**, 52–69.

POMMER MD, BERKOWITZ EN and WALTON JR (1980) UPC scanning: an assessment of shopper response to technological change. *Journal of Retailing* **56(2)**, 25–44.

PWC CONSULTING (2002) *Focus on Retail: Applying Auto-ID to Improve Product Availability at the Retail Shelf*. Auto-ID Center, MIT, Cambridge, MA.

RADHAKRISHNAN A, ZU X and GROVER V (2008) A process-oriented perspective on differential business value creation by information technology: an empirical investigation. *Omega* **36**, 1105–1125.

RAI A, PATNAYAKUNI R and PATNAYAKUNI N (2006) Firm performance impacts of digitally enabled supply chain integration capabilities. *MIS Quarterly* **30(2)**, 225–246.

RAVICHANDRAN T and LERTWONGSATIEN C (2005) Effect of information systems resources and capabilities on firm performance: a resource-based perspective. *Journal of Management Information Systems* **21(4)**, 237–276.

RAY G, MUHANNA WA and BARNEY JB (2005) Information technology and the performance of the customer service process: a resource-based analysis. *MIS Quarterly* **29(4)**, 625–652.

REKIK Y, JEMAI Z, SAHIN E and DALLERY Y (2007) Improving the performance of retail stores subject to execution errors: coordination versus RFID technology. *OR Spectrum* **29(4)**, 597–626.

REKIK Y, SAHIN E and DALLERY Y (2008) Analysis of the impact of the RFID technology on reducing product misplacement errors at retail stores. *International Journal of Production Economics* **112(1)**, 264–278.

ROACH S (1987) America's Technology Dilemma: A Profile of the Information Economy. Special Economic Study, Morgan Stanley, New York.

SANTHANAM R and HARTONO E (2003) Issues in linking information technology capability to form performance. *MIS Quarterly* **27(1)**, 125–153.

SEGARS AH, GROVER V and TENG JTC (1998) Strategic information systems planning: planning system dimensions, internal coalignment, and implications for planning effectiveness. *Decision Sciences* **29(2)**, 303–345.

SELLITTO C, BURGESS S and HAWKING P (2007) Information quality attributes associated with RFID-derived benefits in the retail supply Chain. *International Journal of Retail & Distribution Management* **35(1)**, 69–87.

SHEFFI Y (2004) RFID and the innovation cycle. *International Journal of Logistics Management* **15(1)**, 1–10.

SHIH DH, CHIU YW, CHANG SI and YEN DC (2008) An empirical study of factors affecting RFID's adoption in Taiwan. *Journal of Global Information Management* **16(2)**, 58–80.

SHIN N (1997) The impact of IT on coordination costs: implications for firm productivity. Eighth International Conference on Information Systems, Atlanta, GH.

SOH C and MARKUS ML (1995) How IT creates business value: A process theory synthesis. 16th International Conference on Information Systems, Amsterdam.

SRIVASTAVA B (2004) Radio frequency ID technology: the next revolution in SCM. *Business Horizons* **47(6)**, 60–68.

SZMEREKOVAKY JG and ZHANG J (2008) Coordination and adoption of item-level RFID with vendor managed inventory. *International Journal of Production Economics* **114**, 388–398.

TAJIMA M (2007) Strategic value of RFID in supply chain management. *Journal of Purchasing & Supply Management* **13(4)**, 261–273.

TALLON PT, KRAEMER KL and GURBAXANI V (2000) Executives' perceptions of the business value of information technology. *Journal of Management Information Systems* **16(4)**, 145–173.

THATCHER ME and PINGRY DE (2007) Modeling the IT value paradox. *Communications of the ACM* **50(8)**, 41–45.

THE ECONOMIST (2007) Radio silence. *The Economist*, 9 June, pp 20–21.

THIESSE F (2007) RFID, privacy and the perception of risk. *Journal of Strategic Information Systems* **16(2)**, 214–232.

THIESSE F and CONDEA C (2009) RFID data sharing in supply chains: what is the value of the EPC network? *International Journal of Electronic Business* **7(1)**, 21–43.

THIESSE F, TELLKAMP C and FLEISCH E (2007) RFID-enabled shelf replenishment with case-level tagging: a simulation study. 13th Americas Conference on Information Systems, Keystone, CO.

TZENG SF, CHEN WH and PAI FY (2008) Evaluating the business value of RFID: evidence from five case studies. *International Journal of Production Economics* **112**, 601–613.

UHRICH F, SANDNER U, RESATSCH F, LEIMEISTER JM and KRCMAR H (2008) RFID in retailing and customer relationship management. *Communications of the AIS* **23**, 219–234.

VEERAMANI D, TANG J and GUTIERREZ A (2008) A framework for assessing the value of RFID implementation by tier-one suppliers to major retailers. *Journal of Theoretical and Applied Electronic Commerce Research* **3(1)**, 55–70.

VIJAYARAMAN BS and OSYK BA (2006) An empirical study of RFID implementation in the warehousing industry. *International Journal of Logistics Management* **17(1)**, 6–20.

WADE M and HULLAND J (2004) The resource-based view and information systems research: review, extension, and suggestions for future research. *MIS Quarterly* **28(1)**, 107–142.

WAMBA SF and BENDAVID Y (2008) Understanding the impact of emerging technologies on process optimization: the case of RFID technology. 13th Asian-Pacific Decision Sciences Conference, Brisbane.

WAMBA SF, LEFEBVRE LA, BENDAVID Y and LEFEBVRE E (2008) Exploring the impact of RFID technology and the EPC network on mobile B2B eCommerce: a case study in the retail industry. *International Journal of Production Economics* **112(2)**, 614–629.

WEILL P (1992) The relationship between investment in information technology and firm performance: a study of the valve manufacturing sector. *Information Systems Research* **3(4)**, 307–333.

WHARTON (2005) *Who Gains, Who Loses, from RFID's Growing Presence in the Marketplace? Knowledge@Wharton, March 2005*. Wharton School of Business, University of Pennsylvania, Philadelphia, PA.

WHITAKER J, MITHAS S and KRISHNAN MS (2007) A field study of RFID deployment and return expectations. *Production and Operations Management* **16(5)**, 599–612.

WONG CYD and MCFARLANE D (2007) Radio frequency identification data capture and its impact on shelf replenishment. *International Journal of Logistics: Research & Applications* **10(1)**, 71–93.

WOODS J (2004) Prepare for Disillusionment With RFID. Research Note SPA-23–1513, Gartner, Inc., Stamford, CT.

WYLD DC (2006) RFID 101: the next big thing for management. *Management Research News* **29(4)**, 154–173.

YAO Y, DONG Y and DRESNER ME (2007) Analyzing information-enabled stockout management under vendor-managed inventory. *Information Technology and Management* **8(2)**, 133–145.

YIN RK (2003) *Case Study Research: Design and Methods*. Sage Publication, Thousand Oaks, CA.

ZHU K (2004) The complementarity of information technology infrastructure and E-Commerce capability: a resource-based assessment of their business value. *Journal of Management Information Systems* **21(1)**, 167–202.

ZHU K, XU SX and DONG S (2009) Information technology in supply chains: the value of IT-enabled resources under competition. *Information Systems Research* **20(1)**, 18–32.