

Association for Information Systems AIS Electronic Library (AISeL)

AMCIS 2007 Proceedings

Americas Conference on Information Systems
(AMCIS)

December 2007

RFID-Enabled Shelf Replenishment with Case-Level Tagging: A Simulation Study

Frederic Thiesse
University of St. Gallen

E. Fleisch
University of St. Gallen

C. Sorensen
University of St. Gallen

Christian Tellkamp

Follow this and additional works at: <http://aisel.aisnet.org/amcis2007>

Recommended Citation

Thiesse, Frederic; Fleisch, E.; Sorensen, C.; and Tellkamp, Christian, "RFID-Enabled Shelf Replenishment with Case-Level Tagging: A Simulation Study" (2007). *AMCIS 2007 Proceedings*. 112.
<http://aisel.aisnet.org/amcis2007/112>

This material is brought to you by the Americas Conference on Information Systems (AMCIS) at AIS Electronic Library (AISeL). It has been accepted for inclusion in AMCIS 2007 Proceedings by an authorized administrator of AIS Electronic Library (AISeL). For more information, please contact elibrary@aisnet.org.

RFID-ENABLED SHELF REPLENISHMENT WITH CASE-LEVEL TAGGING: A SIMULATION STUDY

Frédéric Thiesse

ITEM-HSG, University of St. Gallen
frederic.thiesse@unisg.ch

Christian Tellkamp

Arvato Services Benelux B.V.
christian.tellkamp@arvatoservices.nl

Elgar Fleisch

ITEM-HSG, University of St. Gallen & D-MTEC, ETH Zurich
elgar.fleisch@unisg.ch

Abstract

This contribution tries to quantify the value of RFID data in the FMCG supply chain for a specific application scenario. We consider the use of RFID in the shelf replenishment process in retail stores and present a simulation study on the impact of improved data quality on product availability. First, we show that RFID allows for the redesign of in-store processes which perform more efficiently regarding profits and stock-outs depending on technology costs (i.e. tag costs) and capabilities (i.e. RFID read rates). Further influence factors that need to be considered in detail are personnel costs, inventory holding costs, the respective product's demand rate as well as other characteristics of the logistical process (e.g. case size). Second, our results indicate that in many cases the maximum benefits can only be drawn from RFID use if decisions on the optimization of shelf space are being made in parallel.

Keywords: Radio Frequency Identification (RFID), Retail, FMCG, In-store Logistics, Shelf Replenishment, Inventory Management, Out of Stock.

Introduction

Practical relevance

Today's fast-moving consumer goods (FMCG) supply chain still faces a number of challenges in the context of item identification and process visibility. Despite the introduction of the barcode and related technologies many years ago as well as industry initiatives such as Efficient Consumer Response (ECR), the retail industry has not managed to eliminate several issues. Typical examples of prevailing problems include stock-outs, shrinkage throughout the entire supply chain, invoice inaccuracies, unsaleable products, and inventory inaccuracies.

Against this background, automatic identification technologies such as RFID are expected to further improve physical process efficiency and to positively address some of the primary causes that lie beyond the above-mentioned issues (Alexander et al. 2002). While RFID is actually a rather old technology, the current interest in its practical use was mainly driven by the MIT's Auto-ID Center, founded in 1999, and its successor EPCglobal, who have been developing a family of standards based on the so-called "Electronic Product Code (EPC)" (Sarma 2005). The idea behind EPC technology is to create an "Internet of Things" that consists of various hard- and software components, including low-cost, passive RFID tags that can be used to equip nearly any kind of physical object and thus link it directly to enterprise information systems (Brock 2001).

Although its long-term goal is still item-level tagging, the current adoption of RFID in the retail industry has started at the case and pallet level and covers upstream supply chain processes from the manufacturer to the retail shelf. Companies have been conducting several RFID pilots over the last years. Examples include the Auto-ID Center Field Trial (Albano 2003) and the RFID activities of the Metro Future Store Initiative (see www.future-store.org). These trials have frequently focused on

testing RFID technology, rather than on the commercial viability of adopting RFID (PACG 2005). The tests have largely expanded knowledge on the technological potentials and limitations of passive RFID technology as it exists today. So far, however, companies have yet to proceed to a stage where they can measure actual differences in supply chain performance resulting from the use of RFID: “Most benefits have not been quantified because it’s early days and you can’t quantify anything without doing something first” as John Clarke of Tesco explains (cited in Retail Week 2005). Retailers are increasingly becoming aware of this fact and have only recently begun to work with academia on these issues (Collins 2005).

Research question and structure

There is a large number of white papers and research reports that examine the impact of RFID on supply chain performance. End users, consultants, solution providers and trade publications enumerate several benefits to be expected from RFID in the FMCG supply chain (cf. Table 1). However, there is still some uncertainty concerning the fundamental value of RFID. Critics point to the fact that there is little practical experience and research that demonstrates the benefits of RFID compared to existing solutions, especially the barcode. According to Sheffi (2004), RFID technology “is still not out of the fog of innovation: the benefits of the technology are not entirely clear, especially in terms of the advantages over bar code technology.” Or, as Woods (2004) from Gartner Research puts it: “Much of the enthusiasm for RFID tagging projects came from a fundamental misunderstanding of the state-of-the-art in data collection technologies.” According to Rice (2005), there is a need to realistically assess the benefits of RFID “based on true improvement potential rather than blue sky cases.” A lot of business cases that try to justify RFID might not even require RFID: “One of the most-important problems you face when evaluating business cases that involve radio frequency identification (RFID) is the difficulty in finding benefits that intrinsically flow from RFID tagging. Many of the commercial business cases being promoted have focused on business benefits that are not intrinsic to RFID. Often, the ROI from these business cases flows from data synchronization or systems integration that can be achieved without RFID. In many such cases, RFID is superfluous” (Woods 2003). Özer (2005) observes that “industry reports and white papers are now filled with estimates and proclamations of the benefits and quantified values of RFID. Most of such claims are not substantiated and are educated guesses at best.” Cachon states 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” (cited in KaW 2005). However, as research on information sharing in the supply chain shows, more information does not necessarily provide much additional value (Cachon and Fisher 2000).

Table 1. Studies on the benefits of RFID in the FMCG supply chain

	Industry studies and trade publications									Company information			Survey results		Σ
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1. Handling efficiency	x	x	x	x		x	x	x	x	x	x	x	x	x	13
2. Out-of-stock	x		x		x	x	x	x	x	x	x	x	x	x	12
3. Inventory reduction	x	x	x				x	x	x		x*		x	x	9
3. Order reconciliation	x	x	x	x	x	x	x		x			x			9
3. Theft	x	x	x			x	x	x	x	x			x		9
6. Unsaleables		x	x				x	x	x	x					6
7. Production planning	x				x				x			x			4
7. Promotion execution					x		x	x	x						4
9. Traceability					x				x			x			3
9. Product diversion		x					x		x						3

* Improved internal inventory management

(1) Kambil and Brooks 2002; (2) A.T. Kearney 2003; (3) Behrenbeck, Kuepper, and Magnus 2004; (4) Vogell 2004; (5) Overby, Leaver, and Yuen 2004; (6) GCI 2003; (7) GMA 2004; (8) Alexander, Birkhofer, Gramling, Kleinberger, Leng, Moogimane, and Woods 2002; (9) Lee, Beleg, Rajwat, Sarma, and Subirana 2005; (10) Clarke and Palinkas 2003; (11) Langford 2004; (12) Metro 2005, Ebling and Scharr 2004; (13) Dunlap, Gilbert, Ginsburg, Schmidt, and Smith 2003 [Survey results EPC Symposium 2003; top-5 benefits retailers]; (14) Dunlap, Gilbert, Ginsburg, Schmidt, and Smith 2003 [Survey results EPC Symposium 2003; top-5 benefits manufacturers]

Against this background, this contribution tries to quantify the value of RFID data in the FMCG supply chain for a specific application scenario. We consider the use of RFID in the shelf replenishment process in retail stores and present a simulation study on the impact of improved data quality on product availability. The remainder of the article is structured as follows: First, we provide some background information on retail stock-outs and describe how companies currently intend to apply RFID to improve shelf replenishment. Second, we give an overview of the main results of a simulation study that compares an RFID-based replenishment process to the traditional process with periodic reviews. The article closes with conclusions and recommendations for future research.

Background

Stock-outs in retail

Stock-outs at the retail store are still a major issue in today's retail environment. An ECR Europe study (ECR 2003) came to the conclusion that the number of stock-outs at the upstream echelons in the supply chain is low compared to the number at the retail shelves (cf. Figure 1). Gruen, Corsten, and Bharadwaj (2002) estimate that stock-out levels average 8.3 % whereupon the majority of stock-outs is not caused in the logistical chain from the manufacturer to the store but rather at the retail store itself. The authors estimate that wrong forecasting (13 %) and ordering decisions (34 %) are responsible for approximately 50 % of all stock-outs in store. Another major reason (25 %), however, for retail stock-outs lies in the shelf replenishment process, i.e. products are in the store, but not on the shelf.

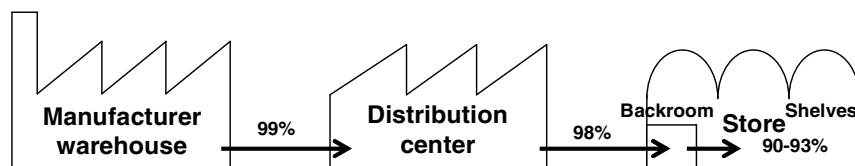


Figure 1. Service levels in the FMCG supply chain

There are different estimates on how stock-outs affect sales. According to Emmelhainz et al. (1991), consumers substitute one item for the other in 73 % of stock-out situations. Approximately 32 % of consumers switch brands while 41 % purchase the same brand. The remaining 27 % delay the purchase, with roughly 14 % buying the product at a different store. Brand and store loyalty can vary considerably by product. For some products, the impact of stock-outs on sales might be higher for retailers than manufacturers, and vice versa.

RFID in the shelf replenishment process

Out-of-shelf (OOS) situations despite sufficiently high inventory levels in the store can either occur because store employees or customers have misplaced the product or because products are not moved from the store backroom to the sales floor in time. The former cause may be of relevance in specific retail situations characterized by a large variety of similar products which customers frequently return to the shelf without buying them, e.g. clothing and books. In the case of FMCG, however, the focus is primarily on the latter cause.

Surveys among retailers indicate that most companies try to avoid store backroom inventory and favor so-called “one-touch replenishment” policies. In fact, Cooper, Browne, and Peters (1994) identify the elimination of backroom inventory as one of three major areas of logistics innovation – apart from the use of IT for supply chain control and the outsourcing of non-core logistics activities – in the UK grocery industry starting in the mid-1980s. There is a number of reasons why retailers nevertheless keep backroom inventory, apart from the fact that such a policy can avoid stock-outs: (a) More products can be stored per unit of floor space in the backroom compared with the sales floor, (b) backroom inventory can act as a buffer when deliveries are uncertain and lead times are long or when deliveries are imperfect, and (c) for some bulky or high velocity product, there may not be enough shelf space available to unload all products directly onto the sales floor (Wong and McFarlane 2003).

The availability and cost of backroom inventory can vary by region. In densely populated areas and countries, space is scarce and expensive. One example is Japan, where retailers such as Seven-Eleven are forced to deliver their products in the required quantity just-in-time (Bensaou 1997). In contrast, in less densely populated areas, space tends to be cheaper and

transportation distances longer. This can make it more attractive for companies to store products locally. Products that can frequently be found in backroom storage areas include certain fast-moving goods (e.g. beverages, toilet paper), promotional items, and bulky products such as TV sets or printers, of which only one or two are placed on the sales floor at the same time.

An analysis conducted by Kurt Salmon at Metro's Extra Future store found that for all categories, at least part of the products delivered were stored in the backroom (Wolfram and Spalink 2004). For non-promotional items, the categories for which storage in the backroom was most likely were vegetables (24 of 36 delivered were stored in the backroom for longer than 12 hours), dairy products (5 of 13 pallets) and beverages (12 of 33 pallets). Promotional items were very often stored in the backroom. Furthermore, there were differences in the movement of pallets between categories: For example, all pallets that contained vegetables were transferred almost directly, i.e. within 12 hours after delivery, onto the sales floor and then returned if products were left. In contrast, the 12 beverage pallets were initially stored in the backroom before being moved onto the sales floor. Returning a beverage pallet once it was moved onto the sales floor was rather unlikely (1.5 of 33 pallets).

There is no detailed data available on the level of backroom inventory in retail stores. However, two anecdotal findings suggest that the level of backroom inventory can in fact vary dramatically between retailers. If the Metro Future Store is typical for other Metro outlets, the example indicates that Metro stores between 20 % and 25 % of pallets delivered in the backroom. Assuming that a pallet stays in the backroom for two weeks and ten inventory turns per year, this gives an estimate of between 8 % and 10 % of store inventory in the backroom. This compares to an average Wal-Mart store where about one third of inventory is stored in the backroom, according to a statement from a company representative (cited by Tarnowski and Longo 2005).

Retailers such as Wal-Mart and Metro seek to improve the shelf replenishment process by placing RFID readers at the gate between backroom and store floor (Langford 2004, Metro 2004, Roberti 2003, 2005). The readers record the movement of cases between the two locations. There is also a RFID reader next to the trash compactor where store employees dispose off empty cases. This reader can improve record keeping and help to ensure that all empty cases are appropriately accounted for. The readers deliver the raw RFID data that allows for distinguishing between sales floor and backroom inventory. From this input, the inventory management system (IMS) can derive an estimate of the number of products available on the sales floor by combining the data on the flow of products from the backroom with POS data and generate an alert if sales floor inventory approaches zero.

Prior research

The works by Gaukler, Seifert, and Hausman (2004), Wong and McFarlane (2003), Lee, Cheng, and Leung (2004), and Hardgrave, Waller, and Miller (2005) are the only ones we are aware of that address the issue of timely shelf replenishment from the backroom. One possible reason for limited research in this area might be the fact that before the advent of RFID, retailers had no cost-effective means for keeping track of product movement from the backroom onto the sales floor.

Gaukler, Seifert, and Hausman (2004) consider RFID at the item level. They examine how the quality of the replenishment process affects profits. Quality problems during shelf restocking not only cause stock-outs and lost sales as shelves are replenished too late, but also lead to underestimations in the demand forecasts. This is because the retailer uses its actual sales to extrapolate demand, which is lower than actual demand due to the stock-out situations caused by the restocking process. In an extension of their base model, the authors consider the decentralized scenario in which manufacturers and retailers are individual profit optimizers and examine how to share RFID tag costs in order to maximize supply chain profits.

Wong und McFarlane (2003) provide a qualitative analysis of the main determinants of suboptimal replenishment performance, e.g. delayed reviews or outdated pick lists. The authors first describe the structure of the traditional process based on (a) a pull policy and (b) a push policy, respectively, depending on the review being done in the backroom or on the sales floor. Against this background, they discuss opportunities for improvement using RFID, e.g. automatic monitoring of stock levels and product movements as well as automatic compilation of pick lists on mobile devices.

The simulation study of a simple supply chain model by Lee, Cheng, and Leung (2004) investigates the effects of (a) the elimination of inventory inaccuracies, (b) the redesign of the shelf replenishment process, and (c) the exchange of inventory level information among a supplier and a retailer. In the second case, the traditional process of inventory management based on periodic reviews is compared to continuous reviews, e.g. through the use of RFID readers in the shelves. Their results indicate that RFID allows for a replenishment process which is better adapted to actual demand while necessitating lower stock levels on the shelves. However, the study's explanatory power is limited since the processes' main parameters "shelf space" and "base stock" are not optimized but chosen arbitrarily, i.e. it is impossible to draw any clear conclusions on the superiority of one of the processes. Furthermore, the authors consider only stock levels and stock-outs as the main performance indicators instead of the overall profitability.

Hardgrave, Waller, and Miller (2005) provide a report on the results of Wal-Mart's pilot project in 12 stores with varying store formats from February to September 2005. 4554 different product were tagged on the case level to allow for monitoring any product movements between the backroom and the sales floor. In this trial, the use of RFID lead to an average reduction of stock-outs by 16 % in comparison to a control group of 12 other stores. In the best case, 62 % reduction could be observed for products with a daily demand of 6 to 15 units (Collins 2006). The authors regard the ability to automatically generate pick-list for store employees as the most important driver for this improvement, which eventually supersedes the need for manual reviews.

Simulation Study

Model formulation

It is the aim of our contribution to compare the performance of the traditional replenishment process based on periodic reviews to an RFID-enabled process and to draw conclusions on real-world implementations in retail stores. For this purpose, we consider a scenario with RFID tagging of individual cases. In contrast to prior research contributions, we do not focus on secondary performance indicators but rather investigate the impact on effective costs and profits. Owing to the intractability of detailed analytical models of the replenishment process, we conduct computer-based simulations to test different operational decisions (cf. Alstrøm and Madsen 1992). Our model was implemented using C#.NET; the following output analysis was done with Microsoft Access and Excel.

In the following section, we first develop the structure of the simulation model and the two replenishment processes. A reference list of the model parameters is given in table 2. Our model constitutes a simplification of reality, insofar as we assume error-free identification of (a) inbound deliveries and (b) sales units at POS, i.e. the total stock level in the store is always known. This excludes shrinkage through theft as well as other factors that result in inaccuracies in the IMS. A more in-depth discussion of the use of RFID in the context of inventory inaccuracies was, for example, provided by Atali, Lee, and Özer (2005), Fleisch and Tellkamp (2005), and Kök and Shang (2006).

Process under the periodic review policy

The traditional process of shelf replenishment makes use of periodic reviews of the number of sales units on the shelf. Every R time units, a store employee checks the current number of products available. If the stock level is below the threshold value s , a replenishment is triggered in order to refill the shelf up to the maximum reserved shelf space S after a time delay d . This procedure is known from academic literature as the “(R, s, S) policy” (Silver, Pyke, and Peterson 1998, p. 240). Since we consider a process with sales units that are stored and transported in cardboard cases, S is always a multiple of the number of units per case u .

Reviews and replenishments lead to personnel costs c^{Rev} and c^{Rep} , respectively. Furthermore, inventory holding costs c^{Inv} must be taken into account for the reservation of shelf space per sales unit. Parameter p denotes the sales margin per unit excluding these in-store logistics costs. It is the retailer's aim to choose R , s , and S such that the overall profit F^{PR} is maximized. The number of reviews V^{Rev} within a planning horizon T is directly determined by R , whereas the number of replenishments V^{Rep} and the number of sold units V^{Sal} is also influenced by s and S . The objective function can accordingly be formulated as follows:

$$\max_{R,s,S} F^{PR} = \max_{R,s,S} \left(pV^{Sal} - c^{Rev}V^{Rev} - c^{Rep}V^{Rep} - c^{Inv}S \cdot T \right)$$

Process under the RFID-based policy

The idea of the RFID-based process is to supersede any manual inventory control through the automatic tracking of product movements between the backroom and the sales floor. With the aid of RFID-generated information on shelf replenishments and POS data, the store's IMS can anytime calculate an estimate I_t^S of the actual physical shelf inventory level I_t^P ($I_t^S \leq I_t^P$), which serves as a basis for triggering replenishments. The quality of this estimate is determined by the read rate of the RFID infrastructure which rarely achieves 100 % under real-world conditions. Depending on the transponder and product type, read rates can even drop below 30 % for the bulk identification of objects that contain metal or liquids (EPCglobal France 2005). For this reason, we explicitly model the RFID read rate in the form of a parameter $\varphi \in [0..100]$.

Accordingly, the random variable $r_i \in [0,1]$ denotes the identification ($r_i = 1$) or non-identification ($r_i = 0$) of a case i upon transfer from the backroom to the sales floor. The probability of detecting the case is given by:

$$p(r_i = 1) = \frac{\varphi}{100}$$

Let t' and t denote the points in time immediately before and after the transfer to the sales floor, respectively. The stock level information in the IMS will then be updated as follows:

$$I_t^{IS} := I_{t'}^{IS} + r_i \cdot u$$

On the other hand, I_t^{IS} decreases by 1 whenever a product leaves the store at the POS. It is evident that – owing to our initial assumption of suboptimal read rates at the backroom door and perfect read rates at the POS – I_t^{IS} would decline infinitely on the long run if we do not include a third data source in our model: Whenever a shelf is replenished, empty cases are removed and transported to the trash compactor. If the RFID reader at the compactor detects a case that was not identified when it left the backroom, the IMS is updated and thus the read error is corrected retroactively:

$$I_t^{IS} := I_{t'}^{IS} - (1 - r_i) \cdot u$$

The RFID-based process does not require any manual reviews, and thus no corresponding personnel costs arise at all. However, equipping every case with RFID tags leads to transponder costs c^{Tag} per case which eventually reduces the retailer's margin. The decision space for maximizing the objective function F^{RFID} is accordingly limited to the parameters s and S :

$$\max_{s,S} F^{RFID} = \max_{s,S} \left((p - c^{Tag})V^{Sal} - c^{Rep}V^{Rep} - c^{Inv}S \cdot T \right)$$

Simulation results

The starting point of our simulation experiments is the case of a typical consumer good with a daily demand of 12 units and a sales price of 5 \$, e.g. a package of razor blades. The products are transported in cardboard cases with $u = 12$ units each, which are designed to be opened and put in the shelf upon replenishment (cf. Figure 2 for an example). We consider a store that is open for 10 hours a day and simulate it for $T = 1000$ days per simulation run. Customer arrivals are accordingly modeled as a poisson process with arrival rate $\lambda = 12$ and we generate a sequence of random arrival times t_k for each replication.



Figure 2. Case of razor blades (closed & opened)

For this simulated store, we assume costs per review $c^{Rev} = 0.5$ \$, costs per replenishment $c^{Rep} = 1$ \$, and inventory holding costs $c^{Inv} = 0.05$ \$ per sales unit per day. Furthermore, we assume that manufacturing and transport logistics costs add up to 90 % of the product price, i.e. the retailer's sales margin excluding in-store logistics costs is $p = 0.5$ \$. As will be shown later

on, this cost structure eventually leads to realistic earnings of approximately 0.3 \$ per unit (i.e. 6 % of the product's sales price). In addition, we assume that the time delay between a review and a replenishment is $d = 0.05$ days (i.e. 30 minutes). In order to determine cost optimal values for R , s , and S under the periodic review policy, we simulated all parameter settings for $0 < R \leq 3$ and $0 < s \leq R \leq 60$ with $N = 50$ different replications per setting. For the RFID-based process, we simulated the same parameter settings for s and S , and determined the optimum for the entire possible range of read rates from 0 to 100 % in steps of 10 %. Furthermore, we calculated the resulting values of F^{RFID} for three tag classes. First, we consider the case of simple standard tags that carry only a fixed product ID. For this scenario, we assume tag costs $c^{Tag} = 0.05$ \$ per transponder label. In contrast to that, $c^{Tag} = 0.2$ \$ denotes the case of more sophisticated tags, e.g. with a bigger antenna or a certain amount of read/write memory. Third, we also considered the case of special transponders designed for improved robustness and durability with $c^{Tag} = 0.5$ \$. The results of our simulations are depicted in Figure 3.

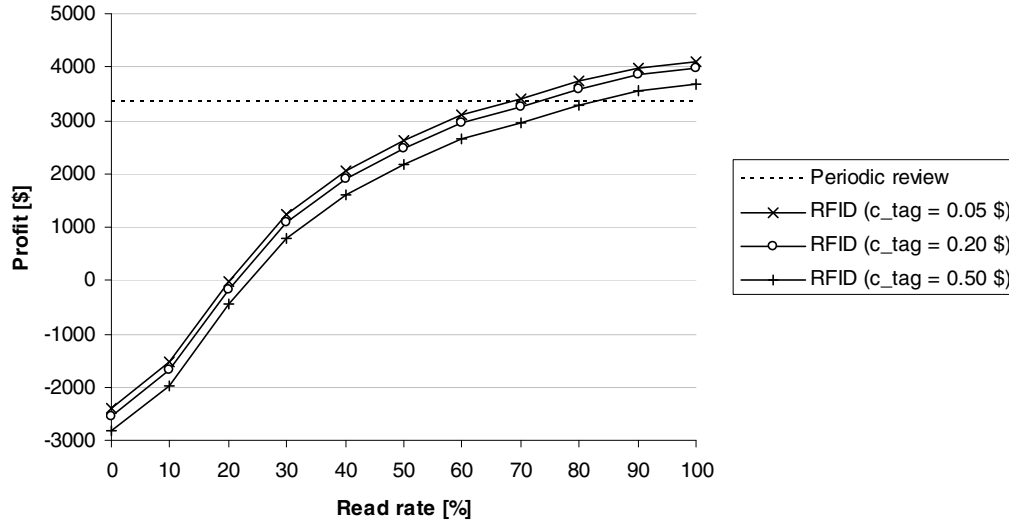


Figure 3. Comparison of the periodic review and the RFID-based policy

In our base case, the optimal average profit F^{PR} is 3349.92 \$. Depending on the tag costs and the RFID read rate, the RFID-based policy is able to outperform the periodic review policy by up to 22.6 %, i.e. average $F^{RFID} = 4107.88$ \$ with $\varphi = 100$ % and $c^{Tag} = 0.05$ \$. For bad read rates, however, the RFID process leads to suboptimal results.

In a second step, we calculated the average stock-out ratio OOS for both policies from the number of sold products V^{Sal} and the total number of customers V^{Cus} :

$$OOS = 100 \cdot \frac{V^{OOS}}{V^{Sal} + V^{OOS}}$$

We compared the periodic review policy to the RFID-based policy with $c^{Tag} = 0.2$ \$ and $\varphi = 90$ %. As depicted in Table 2, the two policies lead to OOS ratios of 4.48 % and 4.73 %, respectively. In the case of RFID, the number of stock-outs decreases with dropping φ since bad read rates necessitate larger buffers in the form of additional shelf space. Unfortunately though, our initial hope was not fulfilled that the use of RFID would inevitably eliminate stock-outs. In order to verify whether different parameter settings could lead to better results with regard to stock-outs, we repeated our output analysis with a limitation to data sets with $OOS < 1$ %. As the results in the second part of Table 2 show, the objective of reducing stock-outs can most of all be achieved by increasing S . However, this improvement is achieved at the expense of slightly lower profits, e.g. -2.71 % for RFID compared to the optimal case.

Our results indicate that optimal profits under the RFID-based policy might only be achievable if the reserved shelf space for a product type is adjusted to the RFID read rate. In reality, however, this is often not feasible owing to given store layouts, contracts with suppliers, etc. For this reason, we ran an additional analysis to determine the optimal values of F^{PR} and F^{RFID} , respectively, for fixed S . The results depicted in Figure 4 support our hypothesis particularly for good read rates (i.e. $\varphi > 50$ %).

Table 2. Comparison of periodic review and RFID policies ($c^{Tag} = 0.2$ \$)

	Policy	φ [%]	R [d]	s	S	\overline{V}^{Cus}	\overline{V}^{Sal}	\overline{V}^{Rev}	\overline{V}^{Rep}	\overline{OOS} [%]	\overline{F} [\$]
optimal	P.Rev.	-	1.2	13	24	11976.57	11440.23	833	753.70	4.48	3349.92
	RFID	0	-	1	12	11976.57	11510.87	-	7500.63	3.89	-2537.05
		10	-	1	24	11976.57	11971.33	-	6256.57	0.04	-1670.42
		20	-	1	48	11976.57	11976.17	-	3546.77	0.00	-158.29
		30	-	1	48	11976.57	11974.63	-	2304.93	0.02	1082.81
		40	-	1	48	11976.57	11971.50	-	1497.07	0.04	1889.16
		50	-	1	36	11976.57	11949.60	-	1496.07	0.23	2479.57
		60	-	1	36	11976.57	11926.20	-	1004.23	0.42	2960.10
		70	-	1	36	11976.57	11900.03	-	686.60	0.64	3265.08
		80	-	1	24	11976.57	11772.40	-	895.93	1.70	3594.06
		90	-	1	24	11976.57	11732.17	-	625.43	2.04	3845.11
		100	-	1	12	11976.57	11410.57	-	950.43	4.73	3964.67
OOS < 1 %	P.Rev.	-	1.8	23	36	11976.57	11878.57	555	550.27	0.82	3311.52
	RFID	0	-	1	24	11976.57	11976.57	-	7500.63	0.00	-2911.96
		10	-	1	24	11976.57	11971.33	-	6256.57	0.04	-1670.42
		20	-	1	48	11976.57	11976.17	-	3546.77	0.00	-158.29
		30	-	1	48	11976.57	11974.63	-	2304.93	0.02	1082.81
		40	-	1	48	11976.57	11971.50	-	1497.07	0.04	1889.16
		50	-	1	36	11976.57	11949.60	-	1496.07	0.23	2479.57
		60	-	1	36	11976.57	11926.20	-	1004.23	0.42	2960.10
		70	-	1	36	11976.57	11900.03	-	686.60	0.64	3265.08
		80	-	1	36	11976.57	11869.90	-	494.37	0.89	3442.75
		90	-	2	24	11976.57	11891.83	-	868.37	0.71	3679.35
		100	-	2	24	11976.57	11874.50	-	682.27	0.85	3857.08

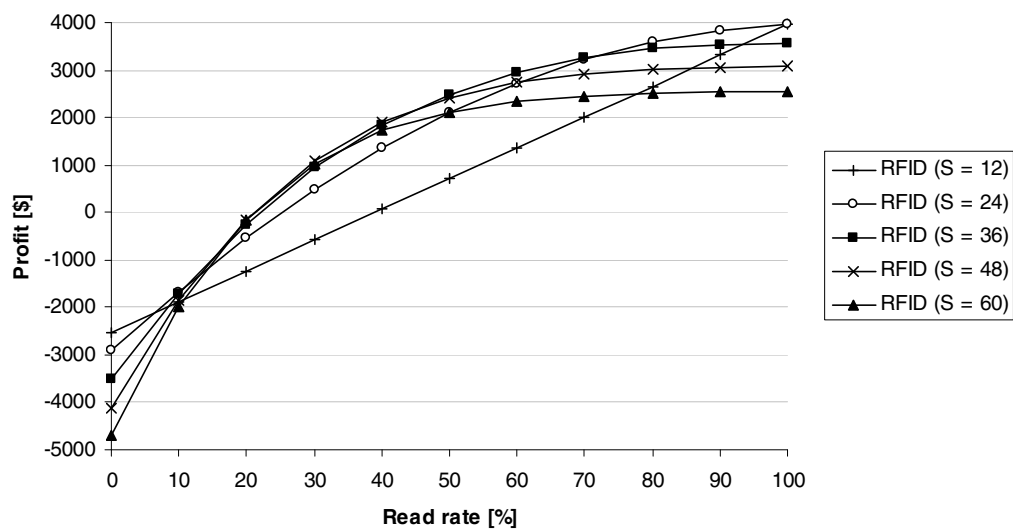


Figure 4. Comparison of RFID policies with fixed shelf space ($c^{Tag} = 0.2$ \$)

Sensitivity analysis

In the previous section, our analysis of the two policies depended on a number of cost parameters that we assumed to be constant. In corporate reality, however, personnel and inventory holding costs can differ significantly depending on the respective store format, the retailer’s assortment strategy, the store location and geographic region, etc. For this reason, this section investigates the impact of changing costs c^{Rev} , c^{Rep} , and c^{Inv} to profits and stock-outs. Furthermore, we consider the performance of both policies under different demand rates λ and different numbers of products per case u . Each parameter is varied by the factors 0.25, 0.5, 2.0, and 4.0. We compared the periodic review policy to a RFID-based policy with $c^{Tag} = 0.2 \$$ and $\varphi = 90 \%$ (cf. Table 3):

- *Review cost.* As expected, the periodic review policy suffers from growing review costs, whereas the RFID-based policy remains unaffected.
- *Replenishment cost.* It can be observed that increasing c^{Rep} leads to a reduction in V^{Rep} which is compensated by additional shelf space. The relative difference between the two policies, however, remains on a similar level for all cases: On the one hand, the RFID-based policy benefits from low c^{Rep} since it allows for serving customers efficiently with less shelf space. On the other hand, the policy performs better under high c^{Rep} as well since its replenishments are better adapted to customer demand than the periodic review policy even with smaller V^{Rep} .
- *Inventory holding cost.* As expected, the periodic review policy suffers from high costs that result in dramatically reduced profits. In contrast to that, low costs allow for higher stock levels that are eventually reflected by fewer lost sales and profits similar to the process under the RFID-based policy.
- *Demand rate.* It can be observed that the RFID-based policy performs best for slow-moving items, i.e. the relative difference between profits grows with decreasing λ . This can be explained by the fact that the standard deviation of the number of customers within a particular time interval becomes small with increasing demand. As a consequence, the periodic review policy becomes more efficient, i.e. the number of unnecessary reviews drops and V^{Rev} converges towards V^{Rep} . For low demand rates, however, the RFID-based policy leads to better results since it triggers replenishments only if needed.
- *Case size.* Our analysis indicates that for small u , the RFID-based policy performs worse than the traditional process. This is owing to the cost of RFID tagging per item which is greater if cases are small. For large cases, however, the RFID-based process also leads to worse results than in the base case because increasing u reduces the retailer’s flexibility regarding shelf space decisions. A second influence factor is suboptimal RFID read rates which have a more severe impact if cases are large. The latter phenomenon is reflected by a large number of replenishments that are triggered though the shelf is not empty.

Table 3. Sensitivity analysis of profits [\$] and stock-out ratios [%]

		Varied Parameter										
		c^{Rev}		c^{Rep}		c^{Inv}		λ		u		
		\bar{F}	\overline{OOS}	\bar{F}	\overline{OOS}	\bar{F}	\overline{OOS}	\bar{F}	\overline{OOS}	\bar{F}	\overline{OOS}	
Variation factor	0.25	P.Rev.	3688.22	2.13	3956.45	1.84	4797.75	1.25	145.55	22.80	3703.03	2.50
		RFID	3845.11	2.04	4516.17	4.66	4883.01	1.22	338.34	1.22	3461.47	1.76
	0.5	P.Rev.	3572.53	3.17	3744.58	3.17	4234.85	1.76	1075.48	4.96	3606.82	3.05
		RFID	3845.11	2.04	4157.83	2.04	4445.11	2.04	1339.81	1.05	3797.89	2.47
	1.0	P.Rev.	3349.92	4.48	3349.92	4.48	3349.92	4.48	3349.92	4.48	3349.92	4.48
		RFID	3845.11	2.04	3845.11	2.04	3845.11	2.04	3845.11	2.04	3845.11	2.04
	2.0	P.Rev.	3088.05	2.48	2859.62	3.25	2149.92	4.48	8482.27	1.76	2826.33	1.16
		RFID	3845.11	2.04	3219.68	2.04	2707.17	4.66	8786.10	1.17	3350.38	2.41
	4.0	P.Rev.	2640.95	4.10	2025.48	6.22	516.57	33.33	19217.40	0.89	2185.03	11.24
		RFID	3845.11	2.04	2377.91	1.22	1507.17	4.66	19268.17	0.61	2469.57	1.17

Conclusion

It was the aim of this contribution to draw conclusions on the advantages of a RFID-based shelf replenishment process in retail stores over the current process with periodic reviews using a simplified simulation model. As for other simulation studies, however, the presented results should be interpreted with care regarding their practical applicability. On the one

hand, our model comprises a number of simplifications in comparison to the real process, e.g. shrinkage because of deterioration, theft, or product misplacement. On the other hand, some constraints and influence factors, which would have to be taken into account in a real-world implementation, lie beyond the scope of our study. These include agreements with suppliers regarding shelf space allocations, given store layouts, the retailer's assortment strategy as well as various aspects of consumer psychology.

Nevertheless, our simulation results allow for drawing a few fundamental conclusions on the use of RFID, that are also relevant to corporate practice. First, we have shown that RFID allows for the redesign of in-store processes which perform more efficiently regarding profits and stock-outs depending on technology costs (i.e. tag costs) and capabilities (i.e. RFID read rates). Further influence factors that need to be considered in detail are personnel costs, inventory holding costs, the respective product's demand rate as well as other characteristics of the logistical process (e.g. case size). Second, our results indicate that in many cases the maximum benefits can only be drawn from RFID use if decisions on the optimization of shelf space are being made in parallel. From a practitioner's perspective, our model offers a simple approach for the evaluation of RFID use in the context of in-store logistics which, however, must be complemented by additional considerations of system integration costs, among others.

Our contribution could serve as a starting point for further research in various directions. One opportunity for improvement might be refinements of the model, e.g. by integrating the impact of shrinkage. Furthermore, we propose to include different demand distributions in the analysis as well as to compare the results for RFID on the case-level to a process with item-level tagging which has already been implemented in some first pilot projects.

References

- A.T. Kearney "Meeting the Retail RFID Mandate," A.T. Kearney, Chicago, USA, 2003
- Albano, S. "Lessons Learned in the Real World," Presentation at EPC Symposium, Chicago, USA, September 2003.
- Alexander, K., Birkhofer, G., Gramling, K., Kleinberger, H., Leng, S., Moogimane, D. and Woods, M. "Focus on Retail: Applying Auto-ID to Improve Product Availability at the Retail Shelf," Auto-ID Center, MIT, Cambridge, USA, 2002.
- Alstrøm, P. and Madsen, P. "Simulation of inventory control systems," *International Journal of Production Economics* (26:1-3), 1992, pp. 125-134.
- Atali, A., Lee, H. and Özer, Ö. "If the Inventory Manager Knew: Value of RFID Under Imperfect Inventory Information," MSOM Conference, Evanston, USA, 2005.
- Behrenbeck, K., Kuepper, J. and Magnus, K.-H. "RFID: Ein kleiner Chip löst große Hoffnungen aus," *akzente* (33:9), 2004, pp. 16–23, McKinsey & Co., Düsseldorf, Germany.
- Bensaou, B.M. "Seven-Eleven Japan: Managing a Networked Organization," Euro-Asia Center, INSEAD, Fontainebleau, France, 1997.
- Brook, D.L. "The Electronic Product Code (EPC): A Naming Scheme For Physical Objects," Auto-ID Center, MIT, Cambridge, USA, 2001.
- Cachon, G. and Fisher, M. "Supply Chain Inventory Management and the Value of Shared Information," *Management Science* (46:8), 2000, pp. 1032–1048.
- Chappell, G., Durdan, D., Gilbert, G., Ginsburg, L., Smith, J. and Tobolski, J. "Auto-ID in the Box: The Value of Auto-ID Technology in Retail Stores," Auto-ID Center, MIT, Cambridge, USA, 2003.
- Clarke, J. and Palinkas, S. "Tesco: Radio Barcodes Update," Presentation at EPCglobal FMCG Business Action Group Meeting, November 2003, London, UK.
- Collins, J. "School Studies RFID's Effect on Wal-Mart," *RFID Journal*, April 18, 2005.
- Collins, J. "RFID's Impact at Wal-Mart Greater Than Expected," *RFID Journal*, May 4, 2006.
- Cooper, J., Browne, M. and Peters, M. "European Logistics: Markets, Management and Strategy," Blackwell Publishing, Oxford / Cambridge, UK, 1994.
- Corsten, D. and Gruen, T.W. Stock-Outs cause Walkouts, *Harvard Business Review* (82:5), 2004, pp. 26-28.
- Dunlap, J., Gilbert, G., Ginsburg, L., Schmidt, P. and Smith, J. "If You Build It, They Will Come: EPC Forum Market Sizing Analysis," Auto-ID Center, MIT, Cambridge, USA, 2003.
- Ebling, R. and Scharr, U. "RFID in der Logistik am Beispiel von METRO Group und Procter & Gamble," Presentation at RFID-Fachkongress für die Partner der METRO Group, May 2004, Cologne, Germany, 2004.
- ECR Europe "Optimal Shelf Availability: Increasing Shopper Satisfaction at the Moment of Truth," ECR Europe, Brussels, Belgium, 2003.
- Emmelhainz, M.A., Stock, J.R. and Emmelhainz, L.W. "Consumer Responses to Retail Stock-Outs," *Journal of Retailing* (67:2), 1991, 138–147.

- Fleisch, E. and Tellkamp, C. "Inventory Inaccuracy and Supply Chain Performance: A Simulation Study of a Retail Supply Chain," *International Journal of Production Economics* (95:3), 2005, pp. 373-385.
- Gaukler, G.M, Seifert, R.W. and Hausman, W.H. "Item-Level RFID in the Retail Supply Chain," Working Paper, Stanford University, Palo Alto, USA, 2004.
- GCI "EPC Roadmap," Global Commerce Initiative, Cologne, Germany, 2003.
- GMA "Invoice Accuracy: 2002 Industry Survey & Benchmarks," Grocery Manufacturers of America, Washington D.C., USA, 2002.
- GMA "A Balanced Perspective: EPC/RFID Implementation in the CPG Industry," Grocery Manufacturers of America, Washington D.C., USA, 2004.
- Gruen, T.W., Corsten, D.S. and Bharadwaj, S. "Retail Out-of-Stocks: A Worldwide Examination of Extent, Causes and Consumer Responses," Grocery Manufacturers of America, Washington D.C., USA, 2002.
- Hardgrave, B.C., Waller, M. and Miller, R. "Does RFID Reduce Out of Stocks? A Preliminary Analysis," Information Technology Research Institute, University of Arkansas, Fayetteville, USA, 2005.
- Hollinger, R.C. and Davis, J.L. "National Retail Security Survey 2001," Department of Sociology and the Center for Studies in Criminology and Law, University of Florida, Gainesville, USA, 2002.
- Kambil, A. and Brooks, J. "Auto-ID Across the Value Chain: From Dramatic Potential to Greater Efficiency & Profit," Auto-ID Center, MIT, Cambridge, USA, 2002.
- KaW "Who Gains, Who Loses, from RFID's Growing Presence in the Marketplace?," Knowledge@Wharton, Wharton School of Business, University of Pennsylvania, March 23, 2005.
- Kök, A.G. and Shang, K.H. "Inspection and Replenishment Policies for Systems with Inventory Record Inaccuracy," Fuqua School of Business, Duke University, Durham, USA, 2006.
- Langford, S. "Wal-Mart RFID," Presentation at the FTC Workshop 'Radio Frequency Identification: Applications and Implications for Consumers', June 2004, Washington D.C., USA.
- Lee, H.L., Beleg, P., Rajwat, P., Sarma, S. and Subirana, B. "Assessing the Value of RFID/EPC Technology and EPCglobal Standards for Manufacturers," EPCglobal Inc., Lawrenceville, USA, 2005.
- Lee, Y.M., Cheng, F. and Leung, Y.T. "Exploring the Impact of RFID on Supply Chain Dynamics," *Proceedings of the 36th conference on Winter simulation*, December 05-08, 2004, Washington D.C., USA, ACM Press, pp. 1145-1152.
- Metro "RFID: Benefits for Retailers and Suppliers through Effective Deployment and Roll-out," Future Store Initiative, Metro Group, Düsseldorf, Germany, 2004.
- Metro "Guidelines for the METRO Group RFID Roll-out – Version 3.0," Future Store Initiative, Metro Group, Düsseldorf, Germany, 2005.
- Overby, C.S., Leaver, S. and Yuen, E.H. "Revealing RFID's Benefits in Consumer Goods," Forrester Research, Cambridge, USA, 2004.
- Özer, Ö. "Unlocking the True Value of RFID Innovation: Visibility and Inventory Management," Presentation at Stern School of Business Operations Management Research Seminar, April 2005, New York University, New York, USA.
- PACG "Avoiding the RFID Money Pit," PA Consulting Group, London, UK, 2005.
- Raman, A. "Retail-Data Quality: Evidence, Causes, Costs, and Fixes," *Technology in Society* (22:1), 2000, pp. 97-109.
- Retail Week "Faith, Hope, and RFID," *Retail Week*, July 8, 2005.
- Rice, J. "RFID Innovation and Values," *Stanford Global Supply Chain Management Forum Newsletter*, Winter 2005, 7–8, Stanford University, Palo Alto, USA.
- Roberti, M. "Wal-Mart Tackles Out-of-Stocks," *RFID Journal*, March/April 2005, pp. 30-36.
- Roberti, M. "Wal-Mart Lays Out RFID Roadmap," *RFID Journal*, November 10, 2003.
- Sarma, S. "A History of the EPC," in Garfinkel, S. and Rosenberg, B. (Eds.) "RFID," Addison-Wesley, Upper Saddle River, 2005, pp. 37–55.
- Sheffi, Y. "RFID and the Innovation Cycle," *International Journal of Logistics Management* (15:1), 2004, pp. 1–10.
- Silver, E.A., Pyke, D.F. and Peterson, R. "Inventory management and production planning and scheduling," Wiley, New York, USA, 1998.
- Tarnowski, J., Longo, D. "RFID Driving Future of Tech," *Progressive Grocer* (84:3), 2005, p. 7.
- Vogell, K. "RFID / EPC: Prozessveränderungen in der Supply Chain," GS1 Germany, Cologne, Germany, 2005.
- Wolfram, G. and Spalink, H. "RFID im Lebensmitteleinzelhandel am Beispiel des Extra Future Stores," Presentation at RFID-Fachkongress für die Partner der METRO Group, May 2004, Cologne, Germany.
- Wong, C.Y. and McFarlane, D. "The Impact of Auto-ID on Retail Shelf Replenishment Policies," Auto-ID Center, MIT, Cambridge, USA, 2003.
- Woods, J. "Use RFID Only If It's Intrinsic to the Business Case," Gartner Research, Stamford, USA, 2003.
- Woods, J. "Prepare for Disillusionment With RFID," Gartner Research, Stamford, USA, 2004.