Managing a Retail Perishable Product with RFID-enabled Inventory Visibility

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Abstract: Radio Frequency Identification Technology (RFID) helps reduce or completely eliminate inventory record inaccuracy at retail stores, and thus facilitates inventory visibility in the system. In this paper, we investigate the value of RFID-enabled inventory visibility for a retailer that sells perishable/seasonal merchandise, such as fashion apparel. Because the retailer already commits to a total quantity for the item before the season begins, we cannot anticipate an increase in sales or a reduction in holding cost. Here, we formulate the value as a change in total revenue generated from the product. We characterize how this impact changes with respect to various factors in the model and identify its components.

1 INTRODUCTION

RFID (Radio Frequency Identification) technology has been described as the "best thing since the barcode" (Economist, 2003) since its rise in 2000s. Through a simple chip embedded in each tag, RFID technology offers a higher capacity to carry information; i.e., *Electronic Product Code* (EPC) and thus a unique identification of the labeled product - as opposed to a generic one provided by the barcode. Additionally, identification of a tag does not require line-of-sight and/or scanning; in fact, a sophisticated RFID reader can promptly identify or communicate with an RFID tag through radio waves. Thus, RFID technology offers a superior and a faster way of object identification compared to the barcode technology. Through this enhanced "product visibility," RFID presents numerous implementation and benefit opportunities across different industries, both public and private, in areas such as inventory management, logistics and transportation, cold chain management, safety, security and counterfeit management, and sales and promotion management (Pisello 2006, Swedberg 2013, Collins 2006, Prince 2013). Return expectations regarding RFID technology are especially high in supply chain management. In fact, among others, "such [RFID-enabled] visibility can save labor cost, improve supply chain coordination, reduce inventory, and increase product availability" (Lee and Özer 2007).

Inventory record inaccuracy, which is defined as the discrepancy between the inventory record and the actual inventory level available, is a serious problem in retail. Due to factors such as replenishment errors, transaction errors, employee theft and customer shoplifting, damaged or spoiled goods, incorrect product identification, and incorrect recording of sales, the recorded inventory and the actual levels diverge (DeHoratius and Raman 2008, DeHoratius, Merserau and Schrage 2008). In fact, Kang and Gershwin (2005) report that a global retailer, at the end of the annual physical audit, discovered that in an average store only about 51% of the SKUs had a match between its recorded and actual inventory levels. In fact, for only 76% of the SKUs, the record and the actual inventory levels were in the neighborhood of ± 5 units. Faced with a severe problem like this, retailers suffer from stock-outs due to under- or over-replenishment of stores as well as demand forecasting issues.

RFID technology, by means of fast, efficient, and inexpensive physical inventory audits, facilitates a retailer to track the two inventory levels and correct its records weekly, daily, hourly, and even in real-time if so preferred. Achieving inventory record accuracy through RFID enables correct and prompt replenishment, which in turn is expected to increase availability, and hence sales (Reda 2010). Retail practitioners adopt this mainstream approach as well; Macy's and Wal-Mart both plan to initiate item-level tagging for *replenishment goods* (basics), which are items with relatively stationary demand and are regularly

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stocked and automatically resupplied (Businessweek 2011, Roberti 2010).

Item-level RFID adoption decision is mainly driven by the sales increase or inventory holding cost decrease expectations in retail. Thus, implementation discussion mostly stays limited to "replenishment items (basics)," both in academia and in practice. This trend gives rise to the presumption that there is no value if sales cannot increase or inventory holding cost cannot be reduced. What happens if the product has a short lifecycle (i.e., it is not a "basic") or when the total stock of the product is already fixed at the beginning of the season is not clear at all. In this paper, we address this issue. We study the value of inventory visibility, enabled by a technology like RFID, in managing a retail perishable product.

We characterize the revenue generated by a retailer from a perishable product with and without inventory visibility in his chain. By a perishable product, we mean an item with a short lifecycle (e.g., a fashion product). A retailer typically has to commit to a total buy quantity of the perishable product way before the selling season starts. All inventory left at the end of the regular season, if any, is cleared through markdowns. This estimated change in revenue could guide practitioners in item-level RFID adoption decisions regarding a perishable product. In addition to characterizing the magnitude of the value of visibility, we also investigate how it changes with respect to the various factors in the retail environment.

Our results show that though value of visibility is statistically significant and robust, but not entirely encouraging for some retailers. Inventory visibility has a two-fold benefit: diminished lost sales in the regular season and better yield management in the markdown period. The extent of the visibility impact depends on some characteristics such as including inventory record inaccuracy, the retailer's competence in forecasting and planning, product lifecycle, product perishability, and store service level targets.

The remainder of the paper is organized as follows. In §2 we review the relevant literature and in §3 we introduce the model details. We present our findings in §4. In §5 we highlight our insights and conclude the paper.

2 LITERATURE REVIEW

Our work is mainly related with two bodies of research. One focuses on the inventory record inaccuracy and analytical inventory management models that account for it in a retail environment. The second stream focuses on quantifying the benefit of RFID technology in various settings.

Inventory Record Inaccuracy: Within the operations management literature, there is an extensive body of work which studies the inventory record inaccuracy issue in retail and develops sophisticated models to avert it. DeHoratius and Raman (2008) demonstrate the severity of the inventory discrepancy through an empirical analysis and characterize the factors that mitigate or exacerbate the issue. DeHoratius, Merserau, and Schrage (2008) develop a Bayesian Update methodology to keep track of the actual inventory level in the presence of inventory record inaccuracy. Merserau (2013) studies an information-sensitive inventory management system for a retailer with inventory discrepancy issues. Kök and Shang (2007) characterize the optimal inspection policy that balances the risks and costs associated with inventory discrepancy due to transaction errors with inspections costs. As in all these papers, we study a retailer's performance in the presence of inventory discrepancy but we focus on quantifying the value of inventory visibility under a given inventory management framework.

RFID Uses and Benefits: A substantial stream of research studies the implementation of a RFID technology and its impact on business (i.e., value) due to increased inventory visibility or eliminated inventory record inaccuracy. Kang and Gershwin (2005) demonstrate how inventory shrinkage could "freeze" store inventory by preventing replenishment due to a high inventory record when the product is in fact out of stock. The authors propose RFID technology as a solution to eliminate or alleviate this issue. Similarly, Fleisch and Telkamp (2005) study the RFID impact regarding the elimination of inventory discrepancy in a multi-echelon retail supply chain. Lee and Özer (2007), Karaer and Lee (2007), Gaukler et al. (2008), deKok et al. (2008), Sahin et al. (2008), Rekik et al. (2009), Çakici et al. (2011) study the impact of RFID technology under various settings and they all share a cost-savings perspective. Rekik et al. (2007, 2008) mostly focus on the profit impact of RFID through a Newsvendor-like setting. Our work and all these articles, though in different settings, share the common goal of assessing the value of inventory visibility, enabled by a technology like RFID. We refer the interested reader to Saraç et al. (2010) for an extensive review of the research on RFID and its value.

3 MODEL DETAILS

We model a multiple-store (N) chain of a retailer who maximizes the total revenue generated from the sales of a perishable/fashion product. The retailer manages all his stores through a single distribution center (DC) in the presence of inventory record inaccuracy at the stores. After the regular season is over, the product is marked down so that all leftover inventory is cleared. No transshipment is possible among stores. We adopt a periodic-review inventory environment in our model.

We use a linear function to model the periodic demand at store i. It comprises of a deterministic and an uncertain part; i.e., $d_{it} = K_{it} - ap_{it} + \varepsilon_{it}$, $t = 1, ..., T+1$ where ε_i is iid across stores and periods, and has zero mean. Here, a represents the price sensitivity of consumer demand. Over the regular season, the product is sold at a previously-set regular price p across the chain. In the markdown period the price is discounted so that at each store the leftover inventory is cleared. A store's demand potential over the regular season is stationary whereas it is possibly lower in the markdown period; i.e., $K_{i,T+1} \leq K_{i1} = ... = K_{iT}$. The notation we use in the model is available in Table 1 below.

Table 1: Notation .

d_{it}	Demand at store i, at period t, $i = 1,..,N$, $t = 1,...,T$
y_{it}	The order-up-to level for store i, for the beg. of period t
x_{it}	The actual inventory level at store i at the beg. of period t
z_{it}	The replenishment sent to store i at the beg. of period t
$\hat{x}_{it}$	The inventory on record at store i at the beg. of period t
ε_{it}	The random shock on demand at store i at period t
θ_{it}	The inaccuracy shock at store i at period t
K_{it}	The demand potential at store i at period t
a	Price sensitivity parameter
p	The chain-wide regular season product price
p_{im}	The realized markdown price at store i

The sequence of events in a regular season period for a retailer without full visibility are summarized below:

(1) The retailer checks the inventory record $\hat{x}_{it}$ at store i and creates an allocation order based on the order-up-to level y_{it} at each store. The orders are shipped if there is enough inventory at the DC to satisfy all allocation orders. If not, the retailer determines the shipment quantities to balance out the store service levels as much as possible[1]. The stores are *instantly* replenished based on the determined shipment quantities (referred to as z_{it}) .

(2) The demand at store i (d_{it}) is realized, and sales $s_{it} = min(d_{it}, x_{it} + z_{it})$ are recorded. In addition to demand, there is also a random inaccuracy shock θ_{it} on the actual inventory level at the store; i.e., $x_{i,t+1} = x_{it} + z_{it} - s_{it} - \theta_{it}$. The inaccuracy shock being positive translates into shrinkage due to theft, shoplifting, misshipment, damages, and etc. The net inaccuracy shock being negative translates into emerging misplacements, misshipments, misidentifications, and etc. Whenever θ_{it} is positive and $x_{it} + z_{it} < d_{it} + \theta_{it}$, we assume the available inventory is split proportionally between customer demand and shrinkage. Note that, we assume θ_{it} is iid across stores and periods, and follows a distribution with mean $\mu_\theta > 0$ and standard deviation $\sigma_\theta > 0$; i.e., inaccuracy shock may be positive or negative but is more likely to be positive than negative. Based on the sales observed, the inventory record to start the next period is calculated as $\hat{x}_{i,t+1} = \hat{x}_{it} + z_{it} - s_{it}$.

The retailer has to sell off all units as the regular season ends. Therefore, in the markdown period, he offers price discounts to generate enough demand to clear away the leftover inventory. Thus, after $\varepsilon_{i,T+1}$ is realized, the clearance price p_{im} ($p_{i,T+1}$) is observed so that $K_{i,T+1} - ap_{im} + \varepsilon_{i,T+1}$ equals the available inventory at store i at the beginning of the markdown period. Markdown price cannot be greater than the regular season price and has to be nonnegative.

4 ANALYSIS

To evaluate the value of inventory visibility in managing a perishable/fashion product, we compare two types of retailers:

(1) *Uninformed Retailer (U)*: This retailer relies on the current information system, and hence cannot observe the actual inventory levels at the stores. He makes allocation/replenishment decisions based on the inventory on record.

(2) *Retailer with Full Visibility (F)*: This retailer, through a technology like RFID, has visibility over the actual inventory levels at the stores. At the beginning of each period, he conducts a physical audit at the stores and updates his system with the actual inventory levels observed. He uses these values in allocation/replenishment decisions.

We compare the two retailers in total revenue generated from the product. Specifically, we seek to assess the % difference in total revenue (Δ) as our primary metric for the value of inventory visibility:

$$\Delta_{F-U} = \frac{\Pi_F - \Pi_U}{\Pi_U} * 100 \qquad (1)$$

[1] At the beginning of period T, which is the last period in the regular season, the retailer ignores the pre-set y_{it} and determines allocation orders to clear away all the inventory at the DC and balance out the expected service level at each store.

where Π stands for revenue. .

We adopt simulation as our analysis methodology. This allows us to avoid simplifications that would otherwise be essential to generate analytical results, and at the same time characterize its magnitude and the impact of various factors on it. For a given set of parameters, we run 250 replications. For each realization/instance, we calculate the revenue generated by the uninformed and full visibility retailers, and calculate the % gap (Δ_{F-U}). We calculate the 95% confidence intervals for this gap. When we need to present a single value for Δ_{F-U}, we refer to the mean values when the gap is statistically significant.

Note that we assume the retailer works with 1 period between reviews and instant replenishment; i.e., zero lead time. Thus, when he sets the order-up-to levels at the stores, he uses a type-1 service level target to cover the exposure demand of 1 period. We also assume there is no discounting due to time value of money across periods.

4.1 Value of Full Inventory Visibility

In our simulation studies, we use discretized Normal distribution to model periodic demand uncertainty ($\varepsilon \sim N(0, 6.5)$) and inaccuracy shock ($\theta \sim N(1, 2)$). We use the regular season price $p = 50$, price sensitivity parameter $a = 0.7$, regular season market potential ($K_r = K_{it}\ \forall i,\ \forall t \leq T$) 100, and markdown period market potential ($K_m = K_{i,T+1}\ \forall i$) 60. Thus, the expected inaccuracy shock in a period is about 1.54% of the expected demand. We conducted experiments with number of periods 4 through 10; number of stores 5, 14, 20, and 40; store service levels 95%, 97%, 99%; and a wide-range of total buy quantity Q. Below we present our main insights regarding the value of visibility and its change with respect to the various factors in our model.

Result #1: *Value of inventory visibility is high, and thus investment in a technology like RFID is more worthwhile if the retailer's gross margin percentage is low and if the product price is high.*

In our studies, value of inventory visibility is about $1-5\%$. Although it is highly sensitive and can increase considerably with some product/retailer characteristics (e.g. product life, inaccuracy rate, etc.), the current numbers show that inventory visibility has limited returns for a perishable/fashion product retailer. Thus, *inventory visibility by itself may or may not justify investment into a new technology like RFID for some retailers*. For a major retailer that generates revenue in the order of billion dollars, however, this "limited return" is still quite substantial.

Inventory visibility enables the retailer to sell at a higher average price and thus increases total revenue. The increase in sales will directly be reflected in the total gross margin. Then for the total gross margin, we should expect a higher impact percentage with the same magnitude of increase in the numerator but a lower value (than revenue) in the denominator; i.e., gross margin impact can easily pass the 10% mark. Thus, the lower a retailer's gross margin percentage in an average product, the more valuable inventory visibility is.

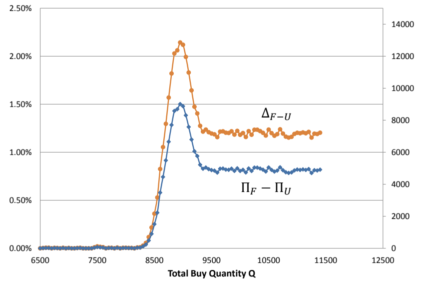
A $1-5\%$ revenue impact also helps characterize the cost-return tradeoff for RFID investment. In addition to the fixed implementation cost regarding infrastructure, RFID investment implies a tag cost to be incurred for each labeled product, and thus practically increases the retailer's unit product cost. Based on our current estimations, tag cost will not be deterring if the product price is high enough. If we take a passive RFID tag cost as $5-6$ cents (Ashton 2011), a product price of \$$5-6$ easily justifies the technology investment.

Result #2: *Value of inventory visibility has two components: increase in regular season sales and increase in margin in markdown sales.*

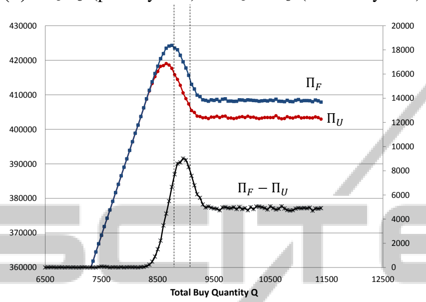
Result #3: *Value of inventory visibility is highest when the retailer is a competent planner but slightly "buys into markdown."*

Figure 1 depicts the value of inventory visibility with respect to the total buy quantity in a 14-store retail chain. In Figure 1(a), we see that Δ_{F-U} becomes significant only when the buy quantity Q is high enough, reaches a peak as Q increases, and then stabilizes to a certain level as Q increases further. If the retailer does not buy enough units to meet the demand, inventory visibility does not have any return for the retailer. The retailer will sell all units at full price regardless of whether he has inventory visibility or not. If the retailer bought too many units compared to the demand, he will have to offer significant discounts at markdown (practically give the product away for free) in either case. The stabilized level of Δ_{F-U} for high Q values here represents the value saved from regular season lost sales with better replenishment performance.

Value of inventory visibility is highest when the total quantity bought roughly matches the demand; i.e., if the retailer is competent at forecasting to match the demand. Figure 1(b) shows that inventory visibility brings the highest return when the retailer slightly overbuys compared to the optimal supply required. This practice can also be characterized as "buying into markdown"; i.e., the retailer also plans for the demand over the markdown period or slightly overestimates



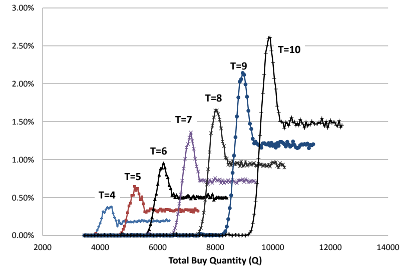
(a) Δ_{F-U} (primary axis) vs. $\Pi_F - \Pi_U$ (secondary axis)



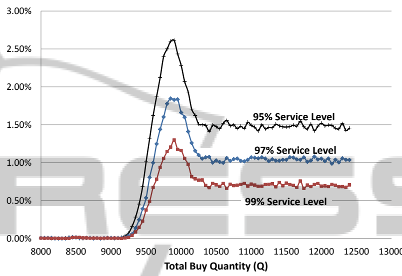
(b) Π_F, Π_U (primary axis) vs. $\Pi_F - \Pi_U$ (secondary axis)

Figure 1: Value of Inventory Visibility WRT Total Buy Quantity Q in a 14-Store Chain.

Note: The following values were used to generate Figure 1, (T=9, N=14, $p = 50$, Store service level=95%, $K_{it} = 100$ ($\forall i, \forall t \leq T$), $K_{i,10} = 60$ ($\forall i$), $\varepsilon_{it} \sim N(0, 6.5)$ (discretized) ($\forall i, \forall t \leq T+1$), $\theta_{it} \sim N(1, 2)$ (discretized) ($\forall i, \forall t \leq T$))



(a) Δ_{F-U} WRT Total Product Life (Number of Periods in a Season)



(b) Δ_{F-U} WRT Service Level

Figure 2: Value of Inventory Visibility WRT Product Life and Service Level.

Note: The following values were used to generate Figure 2, (T=10, N=14, $p = 50$, $K_{it} = 100$ ($\forall i, \forall t \leq T$), $K_{i,11} = 60$ ($\forall i$), $\varepsilon_{it} \sim N(0, 6.5)$ (discretized) ($\forall i, \forall t \leq T+1$))

the total demand. In this range, in addition to a better regular season performance, the retailer with full visibility can now make a difference in the markdown period and achieve better yield management. Thus, we see both components of the value of visibility when the buy quantity is at reasonable levels but is slightly more than the optimal level required.

Result #4: *Value of inventory visibility increases as the product lasts longer; i.e., as replenishment opportunities increase.*

Result #5: *Value of inventory visibility diminishes as the retailer's store service level increases.*

Figure 2(a) characterizes the change in the value of inventory visibility with respect to the product life; the number of regular season periods. Every period an inaccuracy shock occurs, and the retailer with full visibility seizes an opportunity to correct his records whereas the uninformed retailer faces with accumulation of the errors over the season. Thus, as the product life extends, value of inventory visibility increases.

Figure 2(b) shows that as the retailer's store service levels increase, value of visibility decreases. When the retailer operates with a high service level like 99%, even an uninformed retailer successfully prevents the regular season lost sales. Additionally, since a high-service retailer has more inventory leftover for markdown, even a balanced inventory across stores *-enabled by visibility-* cannot sustain high markdown gross margins. Thus, value of inventory visibility is not as high if the retailer already operates with high store service level targets. In fact, the value of visibility (both Δ_{F-U} and $\Pi_F - \Pi_U$) more than doubles between 99% and 95% service levels.

5 CONCLUSIONS

To our knowledge, this is the first study that focuses on RFID-enabled inventory visibility in managing a retail perishable product. We find that value of visibility has two components: growth in regular season sales and improved yield management in the markdown period. Through extensive numerical simulations, we show that value of inventory visibility is robust across retailers, but potentially not impressive for some retailers. Thus, return-on-investment in an enabler technology like RFID needs to be carefully evaluated by each individual retailer. We also find that retailers that sell products with prices above the $\$5-6$ mark, that carry products with relatively long lifecycles, that operate with relatively low service levels, and that plan his sales well or even "buy into markdown" should expect higher returns from inventory visibility.

Our findings suggest further extensions, especially regarding the retailer's planning methodology and the chain structure. One wonders how value of visibility would change if the retailer adopted a dynamic approach and updated his forecast and inventory targets based on observed sales, or if the stores in the chain were not identical. One would also wonder the interaction of inventory visibility with price promotion decisions for a retailer. These settings could further help characterize the value of inventory visibility in a perishable/fashion retail environment.

REFERENCES

Ashton, K. (2011). Whither the Five-Cent Tag? www.rfidjournal.com (retrieved: August 1, 2014).

Çakıcı, O. E., Groenevelt, H., and Seidmann, A. (2011). Using RFID for the Management of Pharmaceutical Inventory - System Optimization and Shrinkage Control. *Decision Support Systems*, 51.

Collins, J. (2006). RFID Goes Underground in London. www.rfidjournal.com (retrieved: August 1, 2014).

de Kok, A. G., Donselaar, K. H. V., and Woensel, T. V. (2008). A Break-even Analysis of RFID Technology for Inventory Sensitive to Shrinkage. *International Journal of Production Economics*, 112.

DeHoratius, N., Merserau, A. J., and Schrage, L. (2008). Retail Inventory Management When Records are Inaccurate. *Manufacturing & Service Operations Management*, 10(2):257–277.

DeHoratius, N. and Raman, A. (2008). Inventory Record Inaccuracy: An Empirical Analysis. *Management Science*, 54.

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.

Gaukler, G. M., Özer, O., and Hausman, W. H. (2008). Order Progress Information: Improved Dynamic Emergency Ordering Policies. *Production and Operations Management*, 17(6):599–613.

Kang, Y. and Gershwin, S. B. (2005). Information Inaccuracy in Inventory Systems: Stock Loss and Stockout. *IIE Transactions*, 37.

Karaer, O. and Lee, H. L. (2007). Managing the Reverse Channel with RFID-Enabled Negative Demand Information. *Production and Operations Management*, 16(5):625–645.

Kök, A. G. and Shang, K. H. (2007). Inspection and Replenishment Policies for Systems with Inventory Record Inaccuracy. *Manufacturing & Service Operations Management*, 9(2):185–205.

Lee, H. L. and Özer, O. (2007). Unlocking the Value of RFID. *Production and Operations Management*, 16(1):40–64.

Merserau, A. J. (2013). Information-Sensitive Replenishment when Inventory Records are Inaccurate. *Production and Operations Management*, 22(4).

Pisello, T. (2006). The ROI of RFID in the Supply Chain. www.rfidjournal.com (retrieved: August 1, 2014).

Prince, P. (2013). Hospitals in Japan, China Seek to Save Lives via Pocketsize Reader. www.rfidjournal.com (retrieved: August 1, 2014).

Reda, S. (2010). Ready (Finally) For Item Level Deployment. Stores.org (retrieved: August 1, 2014).

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 Spektrum*, 29.

Rekik, Y., Sahin, E., and Dallery, Y. (2008). Analysis of the Impact of RFID Technology on Reducing Product Misplacement Errors at Retail Stores. *International Journal of Production Economics*, 112.

Rekik, Y., Sahin, E., and Dallery, Y. (2009). Inventory Inaccuracy in Retail Stores due to Theft: An Analysis of the Benefits of RFID. *International Journal of Production Economics*, 118.

Roberti, M. (2010). Wal-Mart Relaunches EPC RFID Effort, Starting With Men's Jeans and Basics. www.rfidjournal.com (retrieved: August 1, 2014).

Sahin, E., Buzacott, J., and Dallery, Y. (2008). Analysis of a Newsvendor Which Has Errors in Inventory Data Records. *European Journal of Operational Research*, 188.

Saraç, A., Absi, N., and Dauzere-Peres, S. (2010). A Literature Review on the Impact of RFID Technologies on Supply Chain Management. *International Journal of Production Economics*, 128.

Staff (2003). The best thing since the bar-code. www.economist.com (retrieved: August 1, 2014).

Staff (2011). Macy's pushing to get RFID technology into stores. www.businessweek.com (retrieved: August 1, 2014).

Swedberg, C. (2013). Russian Tag Company Reaches for a Worldwide Audience. www.rfidjournal.com (retrieved: August 1, 2014).