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Returns Management for Time-sensitive Products: What is the Value of RFID and Sensor Technologies?

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ABSTRACT

This contribution concerns itself with the value of RFID and sensor technologies to reverse logistics processes. Our research is motivated by the question, to what extent the accuracy of information on product quality delivered by such technologies impacts the total recovered value companies obtain from returned goods in an industry with time-sensitive products. For this purpose, we first present a case study to examine the returns management process at a manufacturer of high-tech consumer electronics. We then develop an analytical model to study the monetary benefits in a scenario with RFID-enabled product disposition. Our results first show that RFID allows for a redesign of the return process which performs more efficiently regarding total recovered value depending on technology costs (i.e. tag costs) and capabilities (i.e. sufficient sensor-delivered parameters to rightly infer the product quality). Second, our results indicate that maximum benefits can be drawn with lower accuracy but early decision on the disposition option.

Keywords

Reverse Logistics, Returns Management, RFID, Sensors, Value Recovery.

INTRODUCTION

The total value of returned products in the U.S. exceeds $100 billion (Stock, Speh, and Shear, 2002). Especially in the electronics industry, returns have become epidemic, with rates reaching 20% in some sectors. According to a recent study by Accenture, consumer electronics manufacturers, communication carriers and electronics retailers in the U.S. spend an annual $13.8 billion on testing, repairing, repackaging, restocking and reselling returned merchandise. In Europe, the figure is estimated at $11.5 billion (Accenture, 2008). This trend poses fresh challenges in terms of managing the reverse product flows to the manufacturing, logistics as well as retail enterprises on a global scale.

In spite of considerable product flows in the reverse channel which poses a source of recoverable assets, only a modest proportion of the returns' value is actually recaptured by the manufacturers (Gecker and Vigoroso, 2006). Ironically, much of the value is lost gradually along the returns process. What could fundamentally be a value stream thus becomes a losing deal for the companies and returns are consequently regarded as a nuisance. Much of the problem lies in the inefficient process design which introduces considerable delays at the collection and inspection stages. Developed in the past typically for much lower return volumes, most returns processes in place today do not focus on value extraction but rather on minimization of logistics and processing costs within the network. This makes them inadequate for the continually increasing return rates and, respectively, the significant value in the stream of recoverable assets nowadays. Continuing to implement such an approach for the reverse channel in the present business environment would substantially reduce profitability in the long run. For an industry with short lifecycles, like the consumer electronics, the problem turns out to be particularly acute. Excessive delays will quickly restrain the set of options for reuse up to the extreme wherein product is only good for scrap. To extract maximum residual value, an early decision on the disposition option is key (Rupnow, 2005).

Automatic data collection technologies, like RFID and sensors, are expected to positively address some of the primary causes that lie beyond the aforementioned issues (Wyld, 2006, 2007). Precise and rich information collected by sensors and embedded on the product by means of an RFID tag may help overcome some of the uncertainties that prevail in the returns and recovery processes. One inherent feature of RFID combined with sensor technologies, for example, is that of enabling each product to gather its status during the usage period. The status information could consist of key parameters related to mechanical, thermal, electrical, magnetic, radiant and chemical conditions. For reverse logistics, such information is highly relevant as it can be used directly at the return point to automate decisions upon the most viable recovery option. Nonetheless, even a good set of such parameters would possibly not deliver the accuracy of workbench inspection. On the other hand, provided an initial investment in technical infrastructure, sorting based on sensorial information becomes cheaper and quicker compared to the typical manual process in place nowadays.

Against this background, our contribution concerns itself with quantifying the value of sensor-equipped RFID tags in the reverse logistics of the high-tech industry for a specific application scenario. We consider the use of RFID in the returns management process and present a quantitative study on the impact of accuracy of timely sensor-delivered information regarding product quality on the recovered value from returned goods. The remainder of the paper is organized as follows. In the next section, we review the related literature on returns and product recovery management for time-sensitive products and describe how companies applied or intend to apply RFID to improve specific processes in the reverse logistics spectrum. By means of a case study, Section 3 presents the reverse logistics process for consumer products at a world-wide manufacturer of imaging and information technologies solutions. It also comprises the description and solution to our modeling approach. Section 4 provides an overview of the main results of a quantitative study that compares an RFID-based returns management process to the traditional process. The paper closes with a summary and an outlook on further research.

RELATED WORK

In recent years, reverse logistics has increasingly gained attention in business worldwide due to economic opportunities, regulatory pressures, and social factors like rising green concerns (De Brito and Dekker, 2003). Nonetheless, building a strong business case for reverse logistics which illustrates straightforwardly the impact on revenue is not easy. Often companies tend to focus more on the cost side of returns management rather than on its revenue side. To succeed, aggressive management of the revenue side is required too (Mollenkopf and Closs, 2005). Due to rapid technological development, high-valued products, and shortening product lifecycle, the electronics industry is amongst the prominent ones to address the issue, which is reflected by a substantial amount of trade publications and normative literature (Accenture, 2008; Gecker and Vigoroso, 2006, 2007; Newgistics, 2005; Norman, 2006; Riddleberger, Hawkes, Nied, and Sarma, 2002; Verweij, Bonney, Dang, and Janse, 2008).

With regard to academic studies, only few authors have so far investigated research questions specific to early product differentiation in returns management. A major difference between our model and prior research is that we unequivocally capture the combined impact of products' value of time and inspection inaccuracy on the total recovered value in a process with early product differentiation. (Blackburn, Guide Jr., Souza, and van Wassenhove, 2004) seem to be the first ones to put forward the concept of 'preponement', which refers to early product differentiation, and its importance to the design of responsive reverse supply chains. In a later publication, (Guide Jr., Muyldermans, and van Wassenhove, 2005) quantify the benefits achieved by Hewlett-Packard when the economic value of time aspect was incorporated in their returns management approach. This led to a process redesign which introduced another testing stage within the manufacturer's premises. The additional testing was meant to reduce the number of products shipped for high-touch refurbishment to an Original Design Manufacturer (ODM) who apparently caused significant lead times. The quantitative analysis by (Guide Jr., Souza, van Wassenhove, and Blackburn, 2006) investigates the effects of the decentralized reverse supply chain, with returns' triage taking place already at the retailer. In their proposed model of returns process, new returns are immediately fed back to the forward sales channel, without being sent to the evaluation facility anymore. However, none of the three abovementioned works addresses the accuracy of inspection at the point of return. Moreover, they do not consider the technology as an enabler for easier and cheaper testing.

(Zikopoulos and Tagaras, 2008) and (Tagaras and Zikopoulos, 2008) take into account disposition errors. They examine the profitability of introducing an inaccurate sorting procedure before the actual remanufacturing of returned items. In the first paper, their process sets sorting and remanufacturing activities within the same premises whereas only in the second they adopt a view on the extended reverse supply chain, analyzing a system with multiple collection sites and decentralized sorting. Yet, in both contributions, the volatility of price over time in the secondary market is disregarded.

For the rest of this section, we will survey on a fairly high-level the most relevant contributions that put reverse supply chain and RFID or sensor technology in the same context. This part is mainly intended to serve as a guider for the interested reader.

Some authors emphasize the importance of IT capabilities in reverse logistics, which have the potential to boost economic performance and improve service quality (Daugherty, Richey, Genchev, and Chen, 2005; Tan, Yu, and Arun, 2003). Current technology support for reverse logistics, however, is minimal (Klappich, 2008). Overview depictions of the value of RFID and sensor technology in reverse logistics were given by (Kärkkäinen and Holmström, 2002; McFarlane and Sheffi, 2003). (Thoroe, Melski, and Schumann, 2009) propose a framework for RFID applications in this domain. Similarly, (Jun, Shin, Kim, Kiritsis, and Xirouchakis, 2007) propose a framework for product lifecycle applications based on RFID. (De, Basu, and Das, 2004) demonstrate the efficiency of RFID-systems for conducting recalls of products that have proved defective proposing a model and method for enhanced product tracing using RFID. Case examples were discussed by (Thiesse and Condea, 2009), who consider a trial at Sony Europe, and (Gambon, 2007), who describe the use of RFID for improving the repair service of printers at Hewlett-Packard Brazil. (O'Connor, 2004) as well as (Koh, Schuster, and Lam, 2003) discuss the role of RFID in the detection of return fraud.

(Klausner, Grimm, and Hendrickson, 1998) describe the advantages associated with the Electronic Data Log (EDL), a sensor-equipped embedded device introduced by Bosch for the support of reuse decisions of electric motors. (Parlikad and McFarlane, 2007) examine requirements regarding serial-level product information to improve recovery decisions in the context of reuse and recycling of end-of-life products. On the same topic, (Kulkarni, Parlikad, McFarlane, and Harrison, 2005) present two case studies treating electronics product recovery and highlight the benefits of product information provided by RFID-based information systems. (Kulkarni, Ralph, and McFarlane, 2007) assess the potential benefits of RFID-derived product information in remanufacturing processes and compare it to a manual inspection regime using an analytical model. (Karaer and Lee, 2007) quantify the value of RFID regarding the inventory decisions of a manufacturer who has ample production capacity and also uses returned products to satisfy customer demand. (Langer, Forman, and Alan Scheller-Wolf, 2007) conducted a field study with GENCO, a third-party logistics company that deployed RFID at one of their return centers, and concluded RFID was a key factor which led to a significant reduction in the number of customer claims.

MATHEMATICAL ANALYSIS

Case example

The practical background for our research is provided by the example of a world-leading innovator and producer of imaging and information technology solutions. The European presence of this Original Equipment Manufacturer (OEM) is mostly centered on sales and distribution activities. While some reverse channel operations like logistics or repair were outsourced, the company itself is still concerned with partner management, credit issuance, and remarketing. They are committed to recovering greatest value possible from returns and, over the past years, have engaged in several initiatives to improve their reverse logistics processes. Their general opinion is that reverse logistics has yet a lot of hidden costs which, if understood and managed professionally, can be transformed into a source of revenue opportunities. The company's management regards customer satisfaction, legal compliance, and producer responsibility as typical drivers of reverse logistics for their business.

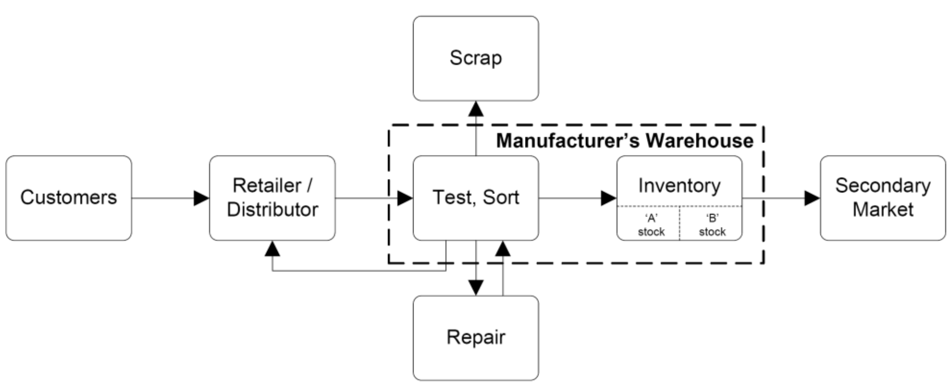

Figure 1. Reverse supply chain for imaging consumer products

The product group in focus of this case study encompasses cameras, video cameras, desktop printers, scanners, etc. destined for the end-consumer. These products have a relatively short lifecycle, with a new model being introduced every 6-9 months on average. The company's approach for managing product returns is depicted in Figure 1. Following a return request issued by a retailer or distributor, returned products are first transported to the central warehouse. The supply of returns consists of commercial returns (i.e. end-users change their mind or found the product defective) and channel returns (i.e. overstocks, stock adjustments). Upon arrival at the warehouse, items undergo basic testing and inspection resulting in products being assigned directly to resalable stock of category 'A' (like new) or 'B' (used), to refurbishment, to scrap, or back to the retailer or the distributor if the necessary conditions for return are not given. Refurbishment is performed by an authorized repair partner. After the repair partner sends the products back, the company adds them to their inventory. The final phase of the process is selling refurbished products to the secondary market.

Model development

In contrast to prior works in this area, we focus on the use of a technology for early product differentiation at the retailer. It is the aim of our contribution to compute the impact of RFID and sensors under sorting inaccuracies on profit. For this reason, we develop an analytical model of the returns management process. We consider a profit maximizing manufacturer facing a stream of returned products. The facilities in the extended reverse supply chain include: customer or retailer acting as the source for returns, manufacturer's evaluation center, recycling partner, and repair partner. The manufacturer has two options for recovery at hand: *recycling* and *repair*. His intention is to optimally distribute the returned items between the two disposition options such that the total recovered value, i.e., profit, is increased.

We compare a *traditional* scenario with an *RFID-enabled* scenario (cf. Figure 2). In the former, the traditional returns process entailed the manufacturer having to transport each product to an evaluation center for a thorough, yet manual, inspection by means of disassembly and workbench tests. This had the downside of long delays and high cost, despite a high level of inspection accuracy. In the latter, the process changes due to various knowledge controls embedded in the product whose input is read and transmitted electronically to the manufacturer. He is thus able to use this sensorial information for a more rapid, albeit less accurate, decision on the appropriate disposition option. Such a decision can be taken directly at the point of return.

The purpose of this model is to make rigorous the comparison between the traditional and RFID-enabled process and decide in a quantitatively precise fashion whether RFID and sensor implementation is a feasible and economically viable approach. Consequently, at the end of this section, we illustrate our findings numerically with realistic field parameters of a consumer electronics company and conduct a sensitivity analysis.

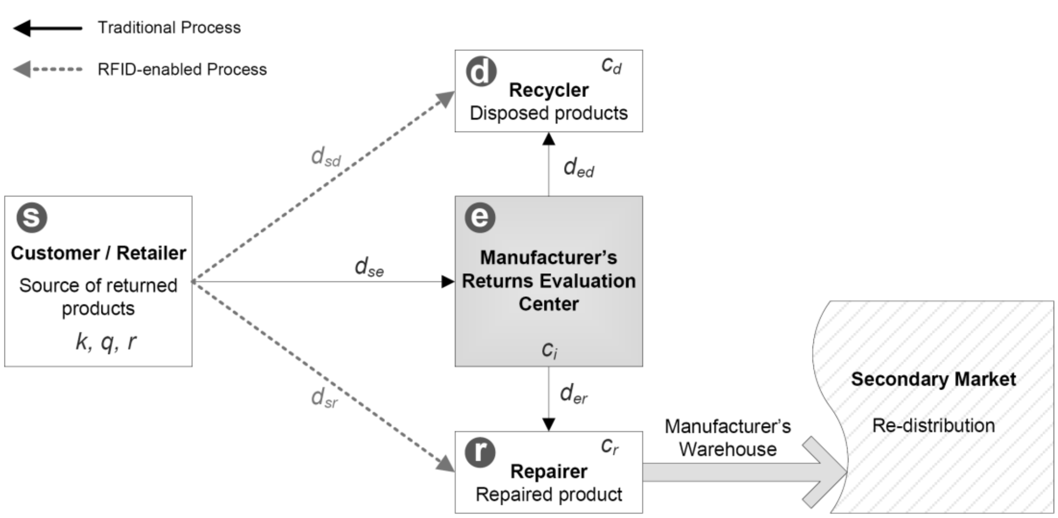

Figure 2. Reverse supply chain model

We first formulate the model in general terms as a basis for the two scenarios we investigate later on. We proceed as follows. Each returned product $\mathcal{P}$ is characterized by an age $0 \leq k \leq a_{\max}$ and a quality $0 \leq q \leq q_{\max}$. The total volume of returns is denoted by r. In case product $\mathcal{P}$ is repaired and resold, it has a time-evolving price on the secondary market given by $p(k) = p_0 - k \cdot \lambda$, where p_0 is the starting price for a young reconditioned product. With this formula, we assume the price erodes linearly at a rate λ over the product lifecycle, which we regard the maximum age $a_{\max}$ beyond which products have lost most of their value[1]. If product $\mathcal{P}$ is recycled it yields a benefit b, which we assume to be independent of the age or quality of the product.

In the RFID-enabled scenario, dispositioning of products based on sensorial information is subject to errors. Specifically, we assume a certain proportion α of the repairables is misclassified as recyclables (type I error) whereas a proportion β of the recyclables is misclassified as repairables (type II error).

The list of reference parameters and notation is given in Table 1. As stated above, for ease of argument, we attempted to formulate the model generically enough to fit both the traditional and the RFID-enabled scenarios. Yet, certain parameters are scenario-specific. For instance, the delays or the transportation costs will differ in both scenarios. We thus introduce a set of parameters that allow us to make the appropriate distinctions in computations. As a general rule, for a parameter p in the generic formulation, we denote by p_{old} and p_{new} the corresponding parameters in the two scenarios, respectively.

Notation	Description
Parameters for the generic model formulation	
r	Volume of returns
k	Age of a returned product, $0 \leq k \leq a_{\max}$
$d\mu_k$	Distribution function for the age of returned stock
q	Quality of a returned product, $0 \leq q \leq q_{\max}$
$d\mu_q$	Distribution function for the quality of returned stock
b	Benefit per recycled product
λ	Price decay rate of a product on the secondary market (i.e, % decay per unit time)
c_i	Cost of inspection at the evaluation facility
$c_{t,\text{disp}}$	Cost of transportation for disposition option $\text{disp} \in \{\text{recycle}, \text{repair}\}$.
c_d	Cost of disposal for recycling
c_m	Manufacturing costs
δ	Delay introduced by the reverse supply chain processing
α	Fraction of recyclables misclassified as repairables
β	Fraction of repairables misclassified as recyclables
Π	Total recovered value
Parameters enabling scenario specific computations	
i, j	Subscripts for nodes: (s) source of returns, e.g. customer or retailer, (e) evaluation facility, (d) disposal at a recycling partner, (r) repair partner, and (w) warehouse
$c_t^{\text{d}_{\text{unit}}}$	Cost of transportation per unit distance, e.g., kilometer
d_{ij}	Direct distance between nodes i and j
t_{ij}	Transportation time between nodes i and j
τ_i	Processing time at node $i \in \{e, r\}$

Table 1. Parameters of the Model

[1] The assumption about price depreciation is adopted from (Guide Jr. et al., 2005)

The objective function is represented by the total recovered value Π which the OEM wants to maximize. In both scenarios, this function encompasses total reclaimed assets from both recycling and repair:

$$\Pi = \Pi_{\text{recycle}} + \Pi_{\text{repair}}$$

Although in the real world many of the quantities we are dealing with are discrete, for the ease of analysis we will assume that all our variables are continuous.

The profit from recycling a single product is $\pi_{\text{recycle}} = b - c_{t,\text{recycle}} - c_i - c_d$ whereas the profit from repairing this product is $\pi_{\text{repair}} = p(k+\delta) - c_{t,\text{repair}} - c_i - c_r(q)$, where k is the real age of the product and q is the real quality of the product.

Classifying a product into a recyclable or repairable is now straightforward. Whichever profit π_{recycle} or π_{repair} is larger should determine the fate of the product. Thus, the threshold q^* should be given for each product $\mathcal{P}$ by the equality:

$$b - c_{t,\text{recycle}} - c_i - c_d = p(k+\delta) - c_{t,\text{repair}} - c_i - c_r(q^*)$$

Note that in this setup, the threshold q^* is a function of k:

$$q^*(k) = \frac{q_{\max}}{c_m}\left(b + c_{t,\text{repair}} - c_{t,\text{recycle}} + c_m - c_d - p(k+\delta)\right)$$

The total volume r of returns of the product $\mathcal{P}$ has an age-quality distribution $d\mu_{k,q} = \Pr(x = k \wedge y = q)$ which cumulates to correlated distributions $d\mu_k = \Pr(x = k)$ and $d\mu_q = \Pr(y = q)$. Let χ_S be the characteristic function which is 1 if the statement S is true and 0 otherwise.

On the assumption of completely precise inspection, the total profits from recycling and repair are:

$$\begin{aligned}
\Pi_{\text{recycle}} &= \int_{k,q} \chi_{q<q^*(k)}(b - c_{t,\text{recycle}} - c_i - c_d)d\mu_{k,q} \\
\Pi_{\text{repair}} &= \int_{k,q} \chi_{q\geq q^*(k)}(p(k+\delta) - c_{t,\text{repair}} - c_i - c_r(q))d\mu_{k,q}
\end{aligned}$$

In a next step, we additionally consider the impact of inspection inaccuracies on the decision whether to recycle or repair a product and the total recovered profits. The actual decision process can vary immensely, but for the purposes of modeling we will make the following characterization. We assume that the age of the product can be determined exactly. However, the investigation about the actual quality of a product is noisy. We further assume that the noise ζ comes from a normal distribution $d\mu_\zeta = N(0,\sigma_n)$ and denote by $q' = q + \zeta$ the perceived quality of the product. For a single product the actual decision is now the following. If the perceived quality q' is larger than q^*, then the product is sent to be repaired, otherwise it is recycled.

As we have seen, the threshold q^* is calculated for each product as a function of age k and certain other factors which are extrinsic to the product. In order to effectively compute the total profits for this situation we need to rework the formulae:

$$\begin{aligned}
\Pi_{\text{recycle}} &= \int_{k,q} \chi_{q'<q^*(k)}(b - c_{t,\text{recycle}} - c_i - c_d)d\mu_{k,q} \\
&= \int_{k,q}\int_{\zeta=-\infty}^{q^*(k)-q} (b - c_{t,\text{recycle}} - c_i - c_d)d\mu_{k,q}d\mu_\zeta \\
&= \int_{k,q} (b - c_{t,\text{recycle}} - c_i - c_d)\left(\int_{\zeta=-\infty}^{q^*(k)-q} d\mu_\zeta\right)d\mu_{k,q} \\
&= \int_{k,q} (b - c_{t,\text{recycle}} - c_i - c_d)\Phi_{0,\sigma_n}(q^*(k)-q)d\mu_{k,q}
\end{aligned}$$

where $\Phi_{\mu,\sigma}(x) = \int_{-\infty}^{x} d\mu_\zeta = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{(y-\mu)^2}{2\sigma^2}\right)dy$.

Similarly,

$$\begin{aligned}\Pi_{\text{repair}} &= \int_{k,q} \chi_{q' \geq q^*(k)} (p(k+\delta) - c_{t,\text{repair}} - c_i - c_r(q)) d\mu_{k,q} \\ &= \int_{k,q} \int_{\zeta = q^*(k)-q}^{\infty} (p(k+\delta) - c_{t,\text{repair}} - c_i - c_r(q)) d\mu_\zeta d\mu_{k,q} \\ &= \int_{k,q} (p(k+\delta) - c_{t,\text{repair}} - c_i - c_r(q)) \left(1 - \Phi_{0,\sigma_n}(q^*(k) - q)\right) d\mu_{k,q}.\end{aligned}$$

Finally, the two formulae yield:

$$\Pi = \int_{k,q} \left((b - c_{t,\text{recycle}} - c_i - c_d)\Phi_{0,\sigma_n}(q^*(k) - q) + (p(k+\delta) - c_{t,\text{repair}} - c_i - c_r(q)) \left(1 - \Phi_{0,\sigma_n}(q^*(k) - q)\right)\right) d\mu_{k,q}$$

We stipulate that all variables are easily computable, or there are standard choices based on practical experience. The only component that remains elusive is the standard deviation σ_n of the inspection accuracy. Nevertheless, one related quantity that can be easily measured is the proportion of false-positives which can be measured at the recycling / repair facility. For example, the proportion α of products that are declared repairable but in fact is recyclable is:

$$\frac{\int_{k,q} \chi_{q' \geq q^*(k) > q} d\mu_{k,q}}{\int_{k,q} \chi_{q < q^*(k)} d\mu_{k,q}}$$

This is a function of σ_n and since the quantity can be measured, a value for σ_n can be estimated.

Traditional scenario

Under the traditional scenario, the threshold $q^*_{\text{old}}(k)$ is defined as:

$$q^*_{\text{old}}(k) = \frac{q_{\max}}{c_m} \left(b + c_{t,\text{repair,old}} - c_{t,\text{recycle,old}} + c_m - c_d - p(k + \delta_{\text{old}})\right)$$

where

$c_{t,\text{repair,old}} = c_t^{\text{d}_{\text{unit}}} \cdot (d_{se} + d_{er})$	is the cost of transportation for a repaired item,
$c_{t,\text{recycle,old}} = c_t^{\text{d}_{\text{unit}}} \cdot (d_{se} + d_{ed})$	is the cost of transportation for a recycled item, and
$\delta_{\text{old}} = t_{se} + \tau_e + t_{er} + \tau_r$	is the delay incurred along the reverse supply chain.

Then, the total recovered value in the traditional scenario is given by:

$$\begin{aligned}\Pi_{\text{old}} &= \int_{k,q} \chi_{q < q^*_{\text{old}}(k)} (b - c_{t,\text{recycle,old}} - c_{i,\text{old}} - c_d) d\mu_{k,q} \\ &+ \int_{k,q} \chi_{q \geq q^*_{\text{old}}(k)} (p(k + \delta_{\text{old}}) - c_{t,\text{repair,old}} - c_{i,\text{old}} - c_r(q)) d\mu_{k,q}\end{aligned}$$

RFID-enabled scenario

Under the RFID-enabled scenario, the threshold $q^*_{\text{new}}(k)$ is defined as:

$$q^*_{\text{new}}(k) = \frac{q_{\max}}{c_m} \left(b + c_{t,\text{repair,new}} - c_{t,\text{recycle,new}} + c_m - c_d - p(k + \delta_{\text{new}})\right)$$

where

$c_{t,\text{repair,new}} = c_t^{\text{d}_{\text{unit}}} \cdot d_{sr}$	is the cost of transportation for a repaired item,
$c_{t,\text{recycle,new}} = c_t^{\text{d}_{\text{unit}}} \cdot d_{sd}$	is the cost of transportation for a recycled item, and
$\delta_{\text{new}} = t_{sr} + \tau_r$	is the delay incurred along the reverse supply chain.

Then, the total recovered value in the RFID-enabled scenario is given by:

$$\Pi_{\text{new}} = \int_{k,q} (b - c_{t,\text{recycle,new}} - c_{i,\text{new}} - c_d)\Phi_{0,\sigma_n}(q^*_{\text{new}}(k) - q)d\mu_{k,q} + \int_{k,q} (p(k + \delta_{\text{new}}) - c_{t,\text{repair,new}} - c_{i,\text{new}} - c_r(q))\,(1 - \Phi_{0,\sigma_n}(q^*_{\text{new}}(k) - q))\,d\mu_{k,q}$$

NUMERICAL EVALUATION

Base case

In order to estimate the values for Π in the traditional and RFID-enabled scenarios, we would have to compute the integrals defining them. By far the easiest solution is to discretize the computation. For each $k \in \{0, 1, \ldots, a_{\max}\}$ and $q \in \{0, 1, \ldots, q_{\max}\}$ estimate $\Pr(x = k \wedge y = q)$ as a number and the expression under the integral over all such k and q.

Supply of returns $r = 1000$, subdivided into age classes and quality classes. For the age classes ($k <$ age $\leq k - 1$) we use the following distribution: k = 1: 0 units; k = 2..5: 25 units; k = 6..15: 80 units; k = 16..19: 25 units in each class. For the quality classes ($q <$ quality $\leq q + 1$), we use the following distribution: q = 1, 2: 50 units; q = 3..6: 75 units; q = 7..10: 150 units. Although in reality the two distributions might be correlated, for the following numerical analysis we considered them independent. This assumption should however, not influence the behavior of the results.

Costs include c_d = 2 dollars per unit, c_m = 60 dollars per unit. Cost of the manual inspection in the traditional scenario is $c_{i,\text{old}}$ = 4 dollars per unit. In the RFID-enabled scenario, the cost of inspection is lower, set at $c_{i,\text{new}}$ = 3.5 dollars per unit, which we implicitly regard as the technology / smart tag cost. This is because, given a certain initial investment in the technical infrastructure, retrieving the information for diagnosis from the smart tag can be achieved at very low (possibly inexistent) marginal cost. Transportation comes for each unit at $c_t^{\text{d}_{\text{unit}}}$ = 0.02 dollars per km. Distances that impact profit are set by $d_{se} = d_{er} = d_{ed}$ = 200 km and $d_{sr} = d_{sd}$ = 300 km. We set them in such a manner that transportation costs in the RFID-enabled scenario would rise up to three quarters of those in the traditional scenario for no need to bring them to the evaluation facility. Along the same reasoning, avoiding the manual inspection makes overall reverse channel delay in the RFID-enabled scenario δ_{new} = 2.5 months lower than δ_{old} = 3 months in the traditional scenario. Revenue from recycling is given by b = 5 dollars per unit. For estimating revenues from secondary market sales, we consider a starting price $p_0 = 100$ dollars per unit and a price erosion rate $\lambda = 2$ dollars per month.

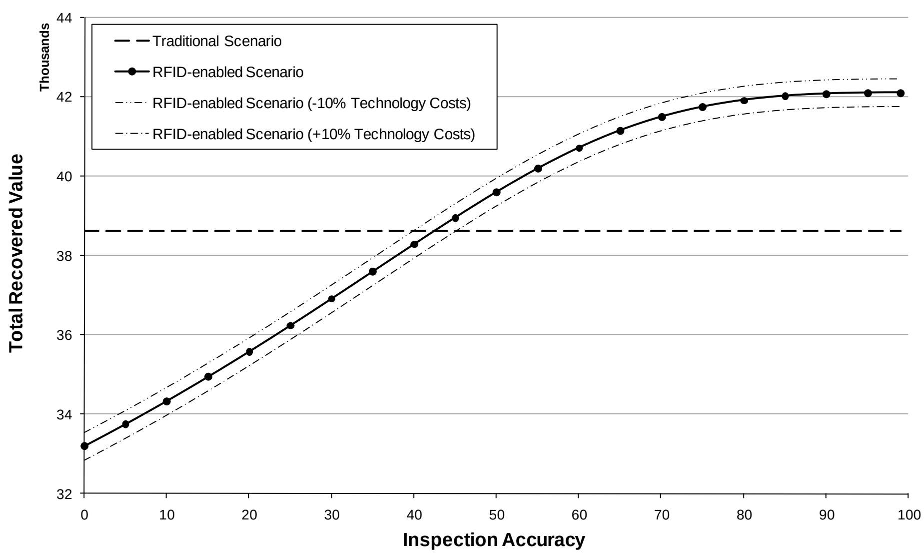

Figure 3. Impact of inspection accuracy on total recovered value

In order to show the impact of early inspection under inaccuracy on profit in the RFID-enabled scenario, we varied the standard deviation σ_n of the noise for 100 values in the range $[0, q_{\max}]$. Furthermore, we calculated the total recovered value

Π_{new} for three cases of technology costs, introducing a 10% increase, respectively decrease, in the cost of smart tags. Sophisticated tags, e.g., with a bigger amount of memory or multiple sensor measurements, will serve for a more precise diagnosis, yet come at a higher price. In the traditional scenario, inspection is assumed to be always perfect and Π_{old} mainly depends on the physical reverse supply chain, which allows us to regard this case as a benchmark. Our results are depicted in Figure 3. We can observe that early product differentiation positively impacts the profit, even if the accuracy of inspection is not ideal. Depending on technology costs, a minimal accuracy level can be deduced beyond which the RFID-based returns management process will outperform the traditional one.

Sensitivity analysis

Our previous analysis of the returns process efficiency in the two scenarios depended on a number of cost parameters that we assumed to be constant. In corporate reality, however, manufacturing, transportation, disposal or inspection costs can vary significantly depending on the factory or store location, geographic region, logistics provider, technology, etc. For this reason, we varied c_m, $c_t^{\text{d}_{\text{unit}}}$, c_d, and c_i ($c_{i,\text{old}}$ and $c_{i,\text{new}}$, respectively) by a factor of 0.25, 0.5, 2, and 4, respectively and investigated their impact on profitability. In the same manner, we additionally considered different price depreciation rates λ and delays in the reverse channel δ (δ_{old} and δ_{new}, respectively). Figure 4 summarizes our results. For all computations, we have fixed the inspection accuracy by defining $\sigma_n = 0.1 \cdot q_{\max}$. As expected, both the traditional and the RFID-based return process suffer from growing costs, with price depreciation and cost of manufacturing being the variables that create most impact. This confirms that our findings are valid for business environments commercializing products of high-market value and sharp price volatility. Yet, the RFID-enabled process shows in general less sensitivity to parameter changes, which makes this technology particularly attractive in business environments characterized as above.

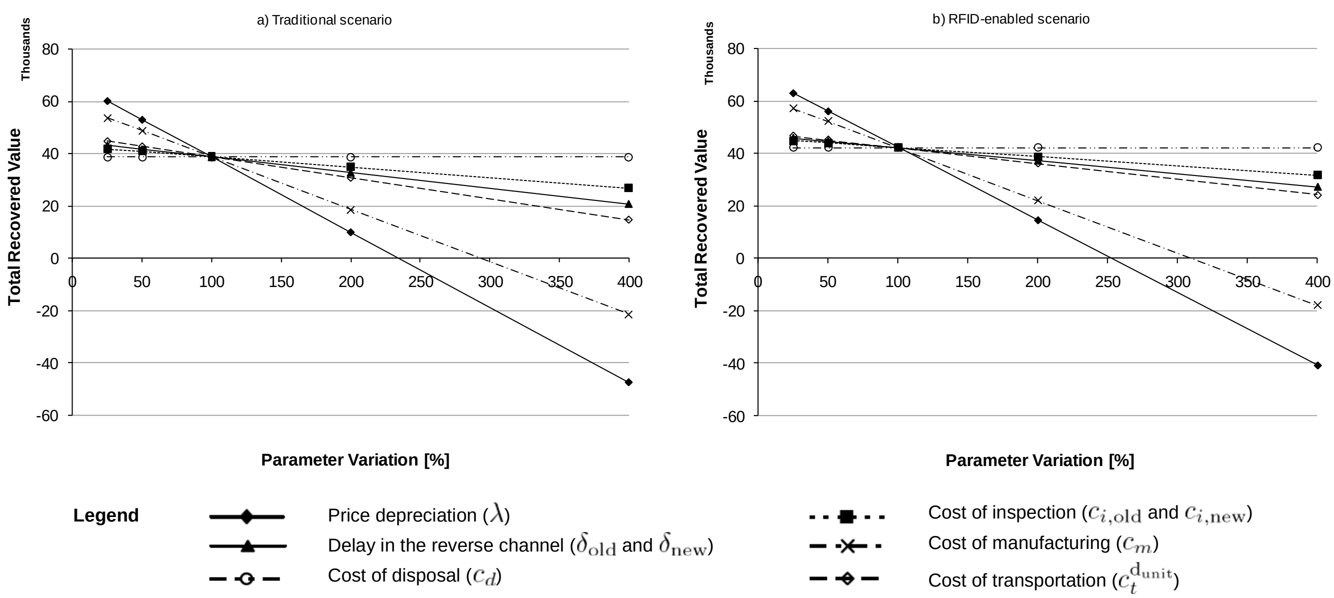

Figure 4. Sensitivity analysis for traditional and RFID-enabled scenario

SUMMARY AND OUTLOOK

The purpose of this study was to investigate the potential of RFID and sensor technology for improving the returns management process in the case of time-sensitive products. We presented a model in order to quantitatively assess the value of technology-enabled product differentiation and its impact on reverse logistics costs. Our contribution to the literature lies in the combined consideration of early product differentiation at the retailer and the role of inspection inaccuracies inherent to automatic data collection technologies. As we have shown, early differentiation using sensor-equipped RFID tags on returned products bears the potential to substantially improve total recovered value for the manufacturer. This result, however, strongly depends on the achievable accuracy level.

From a theoretical perspective, our research is limited to one specific kind of reverse supply chain based on our own experiences with a manufacturer of imaging and information technology solutions. Supply chains in other industries might be different in some respect, which could lead to varying findings. Transferability of our results into practice is currently limited due to technology costs, which most likely allows for implementing our approach only for high-value products. Against this background, we see a number of opportunities for further research. First, empirical research will be necessary to develop a better understanding of the reverse supply chain, relevant cost factors, drivers for process improvements, and so on. Based on these data, enhancements of our model might be proposed to increase the validity of our results. Not least, acceptance of RFID-based quality inspections on the part of consumers and retailers might also be an interesting issue waiting to be considered in more detail.

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