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A SIMULATION APPROACH TO EVALUATE THE IMPACT OF INTRODUCING RFID TECHNOLOGIES IN A THREE-LEVEL SUPPLY CHAIN

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ABSTRACT

The aim of this paper is to analyze the impacts of RFID technologies on supply chain performances, in particular to evaluate their economical impacts and to conduct ROI (Return-On-Investment) analyses. We simulate a three-level supply chain in which thefts, misplacements and unavailable items for sale cause inventory inaccuracies that decrease the supply chain performance. We compare the effects of different RFID technologies and with different tagging levels for different product types. The main originality of our research is that we are considering that there are various possible RFID systems of different costs and potential profits. The results indicate that different technologies can improve the supply chain performance at different ratios. The economical impacts depend on the chosen technology, the tagging level and the product. Our analyses thus show that the ROI of RFID applications strongly depends on the settings.

1 INTRODUCTION

Strong competition forces companies to ensure that customer demands are satisfied as well as possible (dependability) and at the lowest possible cost. Thus, companies try to find new solutions to improve the quality of their supply chains and to reduce their operational costs. In the past few years, RFID technologies, one of these solutions, have drawn considerable interests. Although it is not a new technology (it was used in World War II to differentiate friendly planes from enemy planes), recent advances in microelectronics make RFID technologies more efficient and cheaper, enabling more and more applications in various types of supply chains.

RFID is an automatic identification and data capture technology that uses radio waves to provide real-time communication with objects at a distance, without contact or direct line of sight. An RFID system is composed of three main elements; a transponder, an interrogator and a middleware. The transponder, also called tag, is made of a chip and an antenna. It contains a unique code that provides the unique identification of each object. According to EPC-Global standards, an Electronic Product Code (EPC) can be stored in the chip of the tag. There are three formats of EPC; 64, 96 and 128 bits. An EPC of 96 bits can identify more than 268 million manufacturers and almost 69 billion articles for each manufacturer (Brock 2001). The interrogator (reader) has an antenna. It emits radio signals and receives in return responses from tags. The distance of the reading range depends on multiple factors; the frequency that is used, the orientation and polarization of the reader, the environment, etc. Finally the middleware bridges RFID hardware and applications.

RFID technologies can contribute in different ways to supply chains through their advanced unique identification and real-time communication properties. Through the unique code of each tag and the easiness of scanning, RFID can improve the accuracy and speed of processes and the traceability and the visibility of products throughout supply chains. It can also reduce handling and distribution costs and increase sales by reducing stock-outs (Li et al. 2006). RFID can ameliorate the efficiency of current supply chains, but also may support the reorganization of supply chains to drastically enhance their overall performances.

RFID applications in supply chains have increased in recent years. Current applications can mainly be found in inventory management, asset tracking and object location, transportation and environment sensors in the sectors of logistics, retail, healthcare, automotive and textile. Wal-Mart, the US Department of Defense, the Food and Drug Administration, Marks and Spencer, Tesco and Gillette are some of the first pioneers. In 2005, Wal-Mart required its top 100 suppliers to put RFID tags on shipping crates and pallets (Roberti 2003). Through this mandate, RFID applications in supply chains increased considerably. Bagchi et al. (2007) reported the forecast of the increase of RFID applications from $1 billion in 2003 to $4 billion in 2008 to $20 billion in 2013.

The literature on RFID applications in supply chain is limited. The number of papers on this subject has increased in the last years with the increase of actual applications. Most of the studies are practical papers (white papers, technical reports, etc). The authors are interested in the results of pilot projects and case studies. In a white paper of IBM, Alexander et al. (2003) analyzed the contributions of Auto-ID technologies on the retail supply chain and the difficulties of the adoption in these companies. Similar papers dealing with the impact of RFID in supply chains can be found in Kambil and Brooks (2002), Chappell et al. (2003), Tellkamp (2006), etc.

There are also several academic papers concerning potential benefits of RFID technologies in supply chains. Inventory inaccuracy, replenishment policies, bullwhip effect are some of the main problems of supply chains which could be tackled using RFID technologies. Inventory inaccuracy is the mismatch between the inventory levels in information systems and the real physical inventory levels. There are several factors leading to inventory inaccuracy such as thefts, shipment errors, delivery errors, scanning errors and misplacements. Kang and Gershwin (2004), Atali et al. (2005) and Fleisch and Tellkamp (2005) are some of the authors who focused on impact of RFID on the inventory inaccuracy. Replenishment policies are inventory management methods that aim at optimizing the timing and the quantity of orders so that the various costs (holding, ordering and stock-out costs) are minimized. Kok and Shang (2004) and Lee et al. (2004) are interested in the effect of RFID technologies on replenishment policies. The bullwhip effect is a well-known and important phenomenon in supply chain management. It is the fluctuation of customer demands from the downstream to the upstream of the supply chain because of the lack of information sharing among the entire chain. Joshi (2000), Lee et al. (2005) and Fleisch and Tellkamp (2005) are some of the authors who dealt with the contributions of RFID technologies on the reduction of the bullwhip effect. These studies are generally based on analytical methods (Lee and Ozer (2007), Rekik et al. (2008)) or simulation methods (Brown et al. (2001), Leung et al. (2007)).

Some practical and academic papers contain Return On Investment (ROI) analyses to quantify the economical impacts RFID technologies on supply chains. RFID technologies may lead to numerous benefits for supply chains such as revenue increase or inventory cost reduction. However, the costs related to implementing these technologies are still larger than most current identification technologies. Thus, several authors have dealt with ROI analyses to evaluate whether RFID applications are profitable on a given period of time. Tellkamp (2003), Lee et al. (2004) and Kang and Koh (2002) are some of them.

In our study, we simulate a three-level supply chain which contains a producer, a distribution center and a retailer under a reorder point (s) and Economic Order Quantity (EOQ) inventory replenishment policy for three different products. In particular, we focus on the inventory inaccuracy that occurs along the chain because of thefts, misplacements or unavailable items for sale and which leads to stock-outs, lost sales, long delivery times, poor customer satisfaction, etc. Our aim is to compare the introduction of different RFID technologies with different tagging levels and for three products which have different prices and customer demands. We use a discrete-event simulation to get the ROI for each case.

The remainder of the paper is organized as follows. In Section 2, a brief survey of simulation studies and ROI analyses on the impact of RFID technologies on supply chains is performed. Section 3 describes our problem. The simulation approach and the results on the different scenarios are presented in Section 4. Finally, in the last section, some concluding remarks and research perspectives are discussed.

2 LITERATURE REVIEW

In this paper, the literature review focuses on simulation studies on the impact of RFID technologies on supply chains and ROI analyses of RFID deployments.

2.1 Simulation studies on the impact of RFID technologies on supply chains

Simulation methods are developed in order to observe the dynamic behavior of a system and to optimize its performances. One of the first simulations on supply chain is performed by Krajewski et al. (1987). They analyze the factors of the inventory management performance through an MRP based production simulation. Inventory level, percentage of late orders are some of these performance factors. Brown et al. (2001) also simulated an MRP environment in order to analyze the impact of inventory inaccuracy. They showed that the frequency of errors (the number of time periods of inaccuracy) is the main supply chain performance factor, followed by the magnitude (the percentage of inaccuracy) and the location of errors (the processes where inaccuracy occurs).

Joshi (2000) simulates a simple supply chain in order to evaluate the value of information visibility in the supply chain through RFID. He focused on the bullwhip effect. He tested different scenarios by varying the degree of information visibility and supply chain actors' collaboration through RFID technologies. The results showed that, in supply chains, information visibility and actors' collaboration can provide 40-70% reduction in inventory cost. He also concluded that the reduction in lost sales by timely deliveries or orders, real-time traceability and more confidential supply chain management improve the customer service.

Several authors used simulations in order to analyze the impact of RFID technologies on inventory inaccuracy due to shrinkage errors. Kang and Koh (2002) simulate a retailer inventory system with an automatic reorder point replenishment policy and random demand. They showed that a 2.5% increase of shrinkage can augment stock-out rate by about 50%. He also concluded that the indirect cost of stock-outs due to uncounted shrinkage errors is 30 times greater than the direct cost of shrinkage errors. Kang and Gershwin (2004) simulate a single-item inventory model with a periodic review system under a (Q, R) policy. They observed that even a 1% of shrinkage error can cause an out-of-stock level of 17% of the total lost demand, and that 2.4% of shrinkage error can increase this value up to 50%. They also examined and analyzed several inventory management methods, in order to eliminate inaccuracy, such as safety stock, manual inventory verification, manual reset of the inventory record, constant decrement of the inventory record and Auto-ID technologies. Lee et al. (2004) perform a quantitative simulation under a reorder point and order-up-to level inventory replenishment policy (s,S). They compare different models with or without RFID, with different values of s and S. The results show that RFID implementation can reduce the distribution center inventory level by 23%, eliminate completely backorders and also that RFID can provide a reduction in order quantity that can reduce the distribution center inventory level by up to 47%. Fleisch and Tellkamp (2005) simulate a one-product three-level supply chain. They detail shrinkage errors as low process quality, theft, and items becoming unavailable for sale. They compared two models with and without an inventory level alignment. The results showed that the elimination of inventory inaccuracy, even a small initial level as 2%, can reduce out of stock level and supply chain costs. Basinger (2006) develop a simulation model for a single-item three-level supply chain. He believes the main factors of inventory inaccuracy are the order policy, stock-out/backlog policy, theft and supply chain synchronization. His results showed that the stock-out/backlog policy is the dominant factor, followed by the order policy. He concluded that physical inventory counting is a current, frequently used method to align physical and information system inventory levels while RFID is a new method that can facilitate this alignment. Leung et al. (2007) simulate a three-echelon supply chain under the (s,S) replenishment policy. Three scenarios were tested. In the first scenario, RFID technology does not exist. Physical inventory counting is done in the store once every three months. In the second scenario, RFID is integrated in order to provide inventory accuracy in real time and better replenishment decisions. They considered that RFID technology provides 100% accurate inventory levels. The results show that the back-order quantity decreases by 1%, the average inventory level increases by 20% and the fluctuation of the inventory is much smaller in the second scenario. In the third scenario, they decrease the reorder point and order-up-to level inventory, respectively from 36 to 26 and from 48 to 38. The results show that the back-order quantity becomes 22% lower from the first scenario, and the average inventory level is reduced by 16%.

Our paper is close to these contributions. We simulate a three-level supply chain for three different products. The inventory information becomes inaccurate along the chain due to errors such as thefts, misplacements and unavailable items for sale. We use several inventory management methods such as a reorder point and Economic Order Quantity (EOQ) replenishment policy, safety stock (ss), manual inventory verification. We compare the effects of different RFID technologies and with multiple tagging levels for different product types. The main originality of our paper is that we are considering that different RFID systems can be obtained by combining different tags, readers, frequencies, tagging levels, etc and that the cost and potential profit of each system differ in a wide range.

2.2 ROI analyses of RFID implementation in supply chains

RFID technologies can provide several benefits for supply chains. However, an RFID technology can be more efficient for one company than another RFID technology and/or for another company. Furthermore, RFID implementations still require significant investments. Thus, in order to decide to integrate these technologies in their supply chain processes, companies have to carefully analyze the economical impacts of RFID. Fleisch and Tellkamp (2005) report that companies have to seriously investigate the feasibility of applying RFID technologies in their processes. ROI (Return On Investment) analyses should be performed to evaluate the economical impact of RFID implementations, as a rate of the efficiency of investments in a given period of time. Goel (2007) reports that, in order to successfully calculate a ROI, companies must first understand RFID technologies, then analyze different implementation approaches and their potential impacts on the company's complete IT infrastructure. Leung et al. (2007) and Lee et al. (2004) reported that classical ROI analyses which only consider direct benefits are not sufficient to evaluate RFID economical impacts on supply chains. Direct benefits such as increase in sales and decrease in losses can easily be quantified. However, indirect benefits such as the increase of customer satisfaction and decrease in customer response time cannot be quantified but they can increase direct benefits on the long run.

There are several factors that may contribute to a positive ROI; improvements on processes, prices of RFID technology (tags, readers, middleware, implementation, maintenance, etc.), tagging levels, needs of companies, needs of the environment of companies, cost sharing of RFID implementation between all actors of a supply chain, etc. Doerr et al. (2006)

report that a positive ROI depends on process improvements. Gaukler and Seifert (2007) report that item level tagging can provide a positive ROI for retailers while a positive ROI is almost impossible for manufacturers. Tagging cases or pallets is less expensive but the traceability possible through item level tagging in stores brings more benefits through more accurate stock information. Tajima (2007) reports that, in manufacturing and asset management, closed loop RFID applications have recorded positive ROI in recent years. Tags can be used several times in a closed loop. However, in an open loop, tags can only be used once. So the tag cost is more important in open loops than in closed loops (Barbier and Lecosse 2007). Thus, choosing the right technology is very important for companies. Angeles (2005) reports that choosing the right RFID technology is one of the main factors of a positive ROI. He concluded that, in order to choose the right RFID technology, we have to consider the needs of the environment of companies and the needs of their partners and the needs of the industry. Gaukler et al. (2005) reports that sharing the cost of RFID between manufacturers and retailers can maximize the total supply chain profit. As in the example of Wal-Mart in 2005, by asking its top 100 suppliers to use RFID at the pallet and case levels, Wal-Mart decreased its RFID deployment cost by sharing it with its suppliers (Wang et al. 2008).

In spite of their importance, ROI analyses are still limited. IBM and Accenture developed an ROI calculator for a multi-level supply chain (manufacturer, distributor, retailer) (Angeles 2005). Companies can use this calculator by filling a list of parameters and variables such as tagging level, difference in labor cost, difference in inventory level, etc. Twenty-five companies have tested and validated this calculator. Since supply chain processes vary a lot within each company, this calculator can only measure basic effects of the introduction of RFID technologies, thus leading to underestimated ROI results.

By surveying the literature, we observed that ROI analyses of RFID deployments are limited. In this paper, we aim at providing an approach that supports the analysis of the economical impacts of different RFID technologies for different products. This approach helps to calculate the ROI of introducing RFID in various supply chain for different RFID systems for different classes of products (different prices, different customer demand levels) and for different time horizons. It is thus possible to find the critical cost for RFID technologies in each case.

3 PROBLEM DESCRIPTION

In this paper we consider a three-level supply chain with one manufacturer, one distributor and one retailer for three different products.

We chose three products with different prices and different customer demands, as shown in Figure 1.

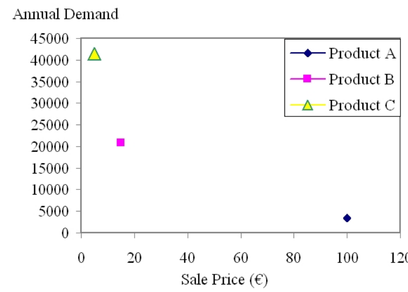

Figure 1: Demands and prices of products A, B and C

In order to analyze their importance, we used the ABC classification method. The classification of items is performed on their annual dollar value (Stevenson 2007). There are three groups of items; A (very important), B (moderately important) and C (less important). The number of products in each category varies from one company to another. In what follows, the studied products are in the second group, i.e. moderately important.

Figure 2 represents the supply chain that we study. End customers take a certain quantity of products from the shelves of the retailer. The retailer orders and receives the products from a distributor and stores them in its back store. The retailer can satisfy customer demands as long as items are available on the shelves. The inventory capacity of shelves is limited. Shelves are replenished under a reorder level policy or using the information of customers in out-of-stock situations. The distributor supplies the products from the manufacturer in order to satisfy the retailer demands. We assume that the manufacturer does not have any product capacity constraint, and thus can always satisfy the distributor orders.

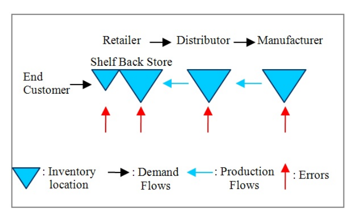

Figure 2: The studied supply chain

The retailer and the distributor use a reorder point (s) and EOQ replenishment policy in order to satisfy end customer demands with a minimum holding and transportation costs. The reorder level consists of the average demand during the lead time (average daily demand multiplied by the lead time) plus the safety stock. The EOQ depends on the setup cost, the demand and the inventory carrying cost. The values chosen for the various parameters of our case study are presented in Table 1.

Table 1: Reorder points (s) and Economic Order Quantities (EOQ) of products A, B, C

Products	A	B	C
s for the shelves	1	2	4
EOQ for the shelves	6	20	50
s for the back store	4	20	50
EOQ for the back store	120	800	2000
s for the Distribution Center	12	40	150
EOQ for the Distribution Center	400	2000	8000

Several inventory errors may occur along the supply chain. In this paper, we are mainly interested in thefts, misplacements and unavailable items for sale. These errors induce inaccurate inventory information that influence supply chain performances by increasing stock-outs, lost sales, delivery times and decreasing customer satisfaction, etc. Each actor controls its inventory levels by physical inventory counting to align physical and information system inventory levels.

4 SIMULATION APPROACH

In order to analyze the effects of RFID technologies on supply chain performances and to evaluate their economical impacts on supply chains, we simulate the above mentioned problem using the Arena Modelling Software (Version 11).

4.1 Model description

The retailer is open 288 days per year from 9 AM to 9 PM. Customers arrive at the store to pick products A, B or C during the working time of the store. The time between arrivals are exponentially distributed with means of respectively 5 min., 10 min. and 60 min.

Figure 3 presents the customer buying process in the store. The customer who arrives at the store goes to the shelves to search for the product. If the customer finds the product on the shelves, he gets the product and then can act in three ways. He can go to the cashier to buy the product, he can change his mind while shopping and put the product on another shelf in the store or he can steal the product.

The physical (PH) inventory levels on the shelves decrease when the customer gets the product, or when an item becomes unavailable for sale. But the Information System (IS) inventory levels on the shelves decrease only when the customer pays at the cashier. Thus, because of stolen, misplaced and unavailable items, inventory information becomes inaccurate.

The retailer automatically replenishes the shelves according to the IS inventory levels. The retailer cannot automatically detect the errors and products may be lacking on the shelves. When stock-outs occur on shelves, the customers cannot find the product and either leave the store without buying the product or search for an employee to ask for shelf replenishment. The shelves can thus be replenished through the information given by the customers to the employees. Customers can either wait until the shelves are replenished or give up after waiting a certain time.

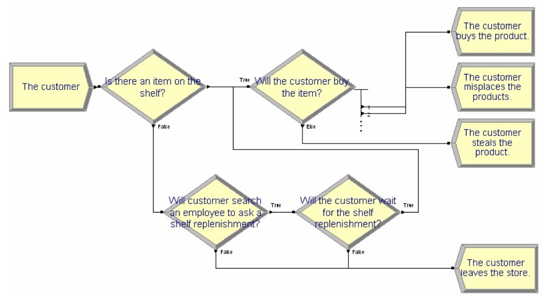

Figure 3: Customer buying simulation process

The shelves can be replenished as long as the items are available in the back store. Replenishment time is normally distributed with a mean of 11 minutes and a standard deviation of 2. After each shelf replenishment, the retailer decides to order products under a (s, Q) inventory policy using the IS inventory levels. However, the same errors also occur in the back store. In this case, products can be misplaced or stolen by employees. Hence, there may be stock-outs in the back store, which can increase the shelf replenishment delay and lead to the loss of customer sales.

The procedure in the distribution center is similar to the one in the back store, where the same errors can occur. These errors are generally caused by the distributor employees. Products are automatically ordered from the manufacturer under a (s, Q) replenishment policy in order to satisfy the retailer orders. Again, stock-outs may happen because of the potential errors.

We assume that the manufacturer has no production constraints, and thus that he can always deliver the products to the distribution center. The delivery time is normally distributed with a mean of 0.5 day and a standard deviation of 0.01.

The retailer and the distributor update their IS inventory levels when they encounter stock-outs or through a physical inventory control that they perform every period of a given duration.

4.2 Scenarios

We propose 5 scenarios to simulate this supply chain. In order to analyze the performances of each scenario, we measured the key performance factors such as the number of sales and lost sales (unhappy customers who leave the store without buying a product). In order to compare the economical impact of each scenario, we observed the number of lost products, the number of deliveries between the retailer, the distributor and the manufacturer, and the retailer and the distributor inventory levels.

We first simulate a base model in order to analyze the dynamic and stochastic behaviors of the supply chain in which inventory inaccuracy occurs and a classical identification technology (bar coding) is used.

In the second model, we integrate an RFID technology at case level tagging. Cases are prepared at the manufacturer and each case contains 100 products. The technology in this scenario can improve the visibility and traceability of cases from the manufacturer to the retailer. It can decrease supply chain errors in the back store and the distribution center. However, the visibility of items in the store does not change. Cases are opened in the back store to replenish shelves. The RFID technology cannot identify products outside cases. So, the retailer still gets the same errors in the store. However, since RFID technologies accelerate the physical inventory control; supply chain actors can increase the frequency of physical inventory controls to adjust inventories in the back store and the distribution center.

In the third model, we integrate an RFID technology at the item level. The visibility of items also improves in the store, where the number of errors is reduced and inventory levels can be checked frequently in the supply chain.

As mentioned before, various RFID systems can be obtained by combining different tags, readers, frequencies and level of tagging The cost and the potential profit of each system change in a wide range. In the fourth model, we consider a more efficient RFID technology at the item level that enhances the supply chain performances more than in the previous scenario.

In the final model, we use a RFID technology that includes smart shelves which can frequently (e.g. every minute) control inventories on the shelves. This technology provides real-time information in the store.

RFID technology integration has two cost components; unit cost of RFID tags and fixed cost for technology implementation (antennas, manual readers, fixed readers, smart shelves, middleware, etc.). The costs that we use are shown in Table 2. Variable costs of RFID technologies depend on unit cost of RFID tags (C_t) and the number of tagged products (Q_{total}). In our model we assume that we use the same tag in each scenario. The unit cost of RFID tags is fixed as 0.1 Euros for the three products.

Table 2: RFID variable and fixed costs

	Variable cost (Euros)	Fixed cost (Euros)
Scenario 1	0	0
Scenario 2	$C_t * Q_{total}/100$	5000
Scenario 3	$C_t * Q_{total}$	12500
Scenario 4	$C_t * Q_{total}$	20000
Scenario 5	$C_t * Q_{total}$	40000

We simulated five scenarios, separately for each product for 3 years, 2 years and 1 year and the simulations are replicated 100 times. Table 3 presents the simulation parameters of each scenario for product B. Thefts and misplacements in the store are respectively the percentages of the customers who steal or move products. The values of thefts and misplacements have been chosen referred to Fleisch and Tellkamp (2005). We consider that the number of stolen products decreases step by step from the first scenario to the last one. The misplacement in the store does not change because technologies cannot prevent customers to move items in the store. However, misplacements induced by employees in the back store and the distribution center, which follow a poisson distribution, can decrease because RFID readers can guide employees to position products in the right place. Stock control processes at each inventory location are realized periodically. Stock control times are normally distributed. Since inventory controls take less time using RFID technologies than bar-coding identification technologies, supply chain actors can check their inventory more frequently. Payment time also follows a normal-distribution and can also be decreased using RFID technologies through its communication at a distance.

Table 3: Some of the simulation parameters for product B

Scenarios	**1**	**2**	**3**	**4**	**5**
Theft in the store (%)	2	2	1	0.5	0.5
Misplacement in the store (%)	1	1	1	1	1
Stock control period in the store (days)	24	24	4	2	1/1440
Mean of the stock control time in the store (hours)	48	48	12	12	1/2160
Mean of the theft period in the back-store (days)	1.5	2	2	3	3
Mean of the misplacement period in the back-store (days)	1.5	3	3	4.5	4.5
Stock control period in the back-store (days)	48	8	8	4	4
Mean of the stock control time in the back-store (hours)	48	8.4	8.4	4.32	4.32
Mean of payment time (minutes)	5	5	2	2	2

5 SIMULATION RESULTS

We analyzed the simulation results to answer two questions. How do RFID technologies affect supply chain performances and what are their economical impacts?

We can evaluate the impact of RFID technologies using a customer satisfaction measure. The customer satisfaction measure we use is the percentage of customers who actually purchase the product compared to the potential customers who want to purchase the product. Figure 4 reports the variation of customer satisfaction (for a three-year simulation) according to the 5 scenarios. This evolution is reported for products A, B and C. According to the simulation results, the number of sold products increase and the number of unhappy customers who leave the store without purchasing the product because of stock-outs decrease from the first to the fifth model. Figure 4 shows that the customer satisfaction for products A, B and C increases respectively from 93.4% to 95.5%, from 87.0% to 90.5% and from 90.7% to 94.3%. These results illustrate how RFID integration improves supply chain performances.

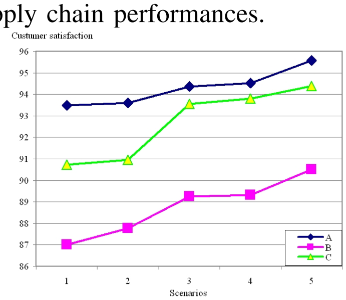

Figure 4: Customer satisfaction according to the 5 scenarios for products A, B and C

In order to analyze the economical impact of each technology, we can compare the profits along the supply chain. We can calculate profits according to sales, stolen items, unavailable items for sale, deliveries, inventory levels and technology costs. Figure 5 reports the evolution of profits (for a three-year simulation) according to the five scenarios for products A, B and C. In order to observe the impacts of each RFID technology, we consider profits of the first scenario as 100 %, and others scenarios profits as a percentage of the evolution compared to the first one.

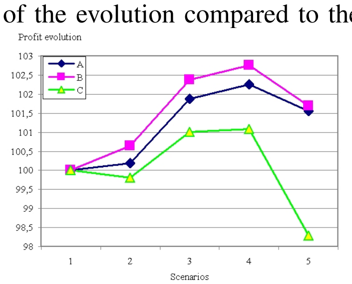

Figure 5: Profit evolution according to the 5 scenarios for products A, B and C

We observe that RFID technology integration at a case level (Scenario 2) increases the profit for product B more than the profit of product A. However, for product C, it is not more profitable than the initial system. Product C is demanded every 5 minutes and the errors in the store are proportional to the number of customer. So, the contribution of an RFID technology at the case level cannot compensate the costs of this technology for product C. Note also that, by integrating RFID at the item level (Scenario 3), the profits of all products increase considerably. Furthermore, the integration of a more efficient RFID technology (Scenario 4) increases the profits of each product. But, the increases are sharply smaller than the increases realized through the previous technology. Through the last scenario (5), we observe that, for Product C, the RFID technology with smart shelves is not profitable. However, as mentioned before and as shown in Figure 4, this technology increases the customer satisfaction through the increase of sales and the decrease of lost sales. Because of the high cost of smart shelves, the additional income does not compensate the technology costs. This technology is also less profitable than the other technologies for products A and B. In order to analyze the economical impacts of smart shelves, we consider a new product D with the same demand rate than product B (20,736 items/year) and which is more expensive than B (selling price is 30). According to the ABC classification, Product D is in the first group, i.e. very important. Figure 6 shows the profit evolution (for a three-year simulation) for all scenarios and for products B and D. Scenario 5 becomes profitable for product D. Hence, smart shelves can become relevant for expensive and highly demanded products.

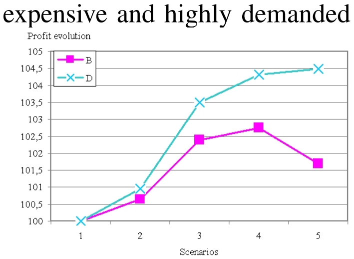

Figure 6: Profit evolution according to 5 scenarios for products B and D

We studied the economical impact of each technology in which the unit cost of RFID tags is fixed at 0.1 for the three products. For each scenario and for each product, a critical RFID tag cost exists. RFID technologies are profitable for all of the values below the critical costs. We calculated the critical costs for each technology and for each product, on a three-year horizon. The unit critical costs are shown in Table 4. They depend on incomes obtained through RFID technologies, the numbers of the used tags and prices of the products. It can be observed that the value of the second scenario for product C is zero because the associated technology cannot be profitable even if the unit tag costs is 0. The other values for the second scenario are very high because, in this scenario, we use a RFID technology at the case level and each case contains 100 products. The total number of necessary tags is considerably smaller than in the other scenarios. Note also that, in all scenarios, the critical tag costs for product B are lower than for product D.

Table 4: Critical costs of RFID (Euros)

Products	A	B	C	D
Scenario 2	17.27	9.12	-	26.74
Scenario 3	1.83	0.43	0.15	1.06
Scenario 4	2.18	0.48	0.15	1.29
Scenario 5	1.52	0.33	0.23	1.32

5.1 ROI Analyses

RFID technologies provide several benefits for supply chains. However, actual RFID implementations require significant investments for companies because RFID systems are still considerably more expensive than current identification systems such as bar-coding. Hence, in order to decide to integrate these technologies in their systems, companies must perform relevant ROI analyses to evaluate whether RFID applications are profitable. We simulated each scenario separately for the three products for different lengths of the time horizon (3 years, 2 years and 1 year) in order to evaluate in which scenarios integrating RFID technologies become profitable.

Figures 7 and 8 present the profit evolution of products B and D for different horizon lengths and for the 5 scenarios. We observe that RFID applications in all scenarios cannot be profitable for product B in one year. Scenarios 2, 3 and 4 can be profitable in one year for product B. Scenario 5 can be profitable for product B in two years. Figure 8 shows that RFID technologies in Scenarios 2, 3 and 4 are profitable in two years for product D, while two years are necessary in scenario 5.

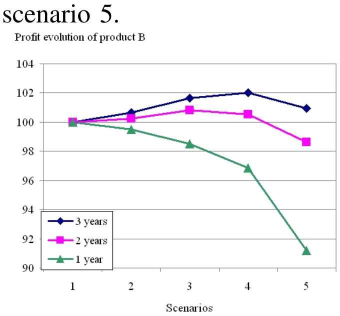

Figure 7: Profit evolution of product B according to 5 scenarios for 1, 2 and 3 year simulations

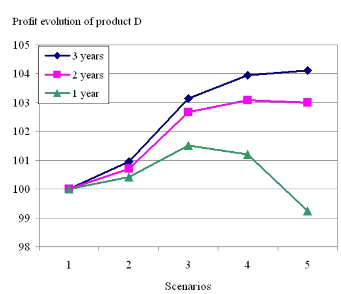

Figure 8: Profit evolution of product D according to 5 scenarios for 1, 2 and 3 year simulations

These ROI analyses show that each RFID application requires different time periods for different products to become profitable.

6 CONCLUSION AND FUTURE WORK

In this paper we simulated a three-level supply chain in which inventory inaccuracy occurs along the entire chain through errors such as stolen, misplaced or unavailable items. This inaccuracy can affect supply chain performances by increasing stock-outs, lost sales, and delivery times or by decreasing customer satisfaction.

We studied different RFID technologies with different tagging levels for three products which have different sale prices and different customer demands. The impacts of these RFID technologies on the supply chain performances were compared. Simulation results show that these different technologies improve the supply chain performance at different ratios. We also noticed that the economical impact depends on various factors such as the cost of the technology, the tagging level, the income realized using the new technology, the price of the product, etc. We also calculated the unit costs of the studied technologies that lead to increases of the profit.

Additionally, we focused on ROI (Return On Investment) in order to evaluate how long companies have to wait to gain following RFID technology implementations. Again, the simulation results indicate that the ROI of various RFID applications depends on multiple factors.

In this paper we studied a "simple" three-level supply chain. However, practical supply chains are more complicated. We believe it would be relevant to extend our work by integrating additional errors such as delivery and transportation errors. Furthermore, dealing with practical cases will give us more realistic data for our simulation approach; in particular on the unit and fixed costs of RFID technologies.

We are also currently investigating how supply chain processes can be reorganized using RFID technologies, thus leading to improved efficiency and additional benefits.

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