Impact of RFID Technology on Supply Chain Management Systems

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Abstract

This paper deals with the impact of radio frequency identification (RFID) technology on supply chain management systems in order to give an insight into the current issues and status of the technology. It examines five RFID projects carried out by companies operating in different industries. The presentation and discussion of the results will help to better understand what RFID can deliver, what deficiencies companies have identified and where its application in supply chain operations is sensible and likely to occur.

Keywords: radio frequency, identification, supply chain management

1 Introduction

Even though radio frequency identification (RFID) as a technology was developed during the 1940s, the first industry uses occurred during the 1980s in tracking and access applications. Due to the relatively high costs of the RFID tags (> 50 US cents per tag) compared to widely used bar codes, the use of the technology was rather limited. Additionally, there was no unified standard, which resulted in incompatible vendor-specific solutions. However, recent industry initiatives, e.g. by the world's biggest retail company WalMart, have resulted in decreased production prices (~ 20 US cent per tag in orders of 1 million) and due to learning curve effects they are likely to decrease further. Thus, the use of RFID in supply chain operations becomes more attractive.

The market research firm IDC projects the spending on RFID in US retail supply chain companies to exceed one billion dollars by 2007 (Rockwell Automation, 2004). The increased use of this technology will have impacts on the supply chain management (SCM) systems which must adapt to the new possibilities offered. New possibilities offered by RFID include the automation of the scanning processes, the possibility to track location of items, and the storage, transmission, and use of more data about the item than just an identification number, e.g. temperature history, best-before-date.

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As can be seen by the results of the EPC Forum Survey conducted by IBM business consulting services, the majority of the participants plan to integrate RFID solutions with existing systems (Gramling, Bigornia, & Gilliam, 2003). With RFID the emergence of more data and the real time use of such data have impacts on the existing SCM systems. This paper examines the impacts of RFID introduction on SCM systems by trying to answer the following research questions:

- How is RFID technology currently used in supply chain operations?
- How are SCM systems impacted by this use?

2 Literature Review

An overview of the historical developments in SCM systems is given by Busch, Dangelmaier, Pape, and Rüther (2003). They outline the evolution of planning systems from the beginnings in the 1960s with the concept of Material Requirements Planning (MRP) and explain the development of Enterprise Resource Planning (ERP) systems, which are based mainly on the concept of Manufacturing Resource Planning (MRP II). Furthermore they introduce current functionalities and particularities of Advanced Planning and Scheduling (APS) systems and how these systems can be extended to collaborative SCM systems.

Finkenzeller (2003) gives a general introduction to RFID as an automated ID technology as well as sample applications such as container identification for the chemicals industry and tool identification in industrial automation. Also, McFarlane and Sheffi (2003) list advantages of RFID systems over barcode systems in supply chain operations (pp. 4-5):

- Speed – many tags can be read simultaneously into a computer, rather than reading a single tag at a time.
- The content of various conveyances (such as trailers, cases, pallets, shopping carts) can be read automatically without opening and sorting the conveyance.
- Bar codes do not work well when exposed to weather elements, when dirty, or if damaged in a way that interferes with clear line-of-sight reading.
- Location – RFID readers can provide rough location information, particularly when the goods being scanned are moving relative to the reader.

Sheffi (2004) states the RFID systems typically consist of the following four elements:

1. a unique standard identification number assigned to a particular item,
2. low cost identity tag which is attached to the item,

3. networked RFID readers and data processing systems, and
4. networked data bases that store the information and enable information exchange.

Davenport and Brooks (2004) argue that there are two factors which currently limit the use of RFID technology throughout supply chains, namely the price compared to bar codes and the incompatibility of RFID systems which means that companies across a supply chain cannot separately select a technology vendor. Additionally, they argue that "Software vendors must first create interfaces to access the distributed data network and will need to develop applications that can use the individual item data to its fullest potential".

Heinrich (2005) claims that RFID systems will improve flows in supply chains and points out that the benefits are heavily dependent on the system integration and how the automatically collected data is used by the SCM systems. He argues that before implementing RFID technology, a company must be aware of its business goals and then should map RFID technology onto these goals. To facilitate implementation success, top management commitment and a clearly defined scope are needed.

Angeles (2005) presents cases of RFID applications and information which support the adoption of RFID technology. She states that RFID enables supply chain visibility and that further research should be undertaken to evaluate if the technology lives up to the high expectations and find out which factors make implementation strategies effective.

Flint (2005) reports on current legal issues discussed by a British working party established to address RFID privacy guidelines. He comes to the conclusion that informed consent for now is a practicable way for RFID applications but that the privacy standards in the European Union are far more developed than in other parts of the world where the customers may suffer from exploitation by the companies.

Edmonson (2005) reports on the current issues and attitudes of the two competing standardisation bodies, the EPCGlobal incorporation, an organisation formed by technology vendors as well as RFID-deploying companies, and the International Standards Organization (ISO). He concludes that both standardisation bodies are trying to reach a common goal but the users of the technology fear that competition between the standardisation bodies may increase and ultimately result in two incompatible standards.

As can be seen, there are several issues related to RFID technology and SCM systems being discussed and almost daily new articles are being published. However, the discussion takes place rather on a theoretical level, not taking into account current issues experienced in practice. In order to close this missing link, this research will contribute to the discussion by providing knowledge about the current use of RFID technology and impacts of its introduction on existing SCM systems.

3 Methodology

Due to the fact that the use of RFID technology in supply chain operations is a rather new application it became clear in the planning process that the research methodology must be suitable for the analysis of qualitative data as it could not be expected to find a representative sample of participants for a quantitative analysis. Accordingly, case study methodology was used for the empirical part of this research project. Also, the nature of the research questions demanded that they were answered through multiple case studies in order to be more representative than one single detailed case study (Yin, 2003). Therefore, the goal was to find, analyse and compare current cases of RFID technology in several companies and to study the impacts on SCM systems. For this reason, a survey and interview were conducted and analysed by the means of thematic analysis. The results are presented and discussed in sections 4 to 7.

4 Case Studies

4.1 Heathcare Company

A leading logistics service provider was chosen by a healthcare company and Germany's largest retail company Metro to test RFID deployment in the context of Metro's Future Store Initiative. The task was to tag pallets for shipments bound from the healthcare company warehouse (which is operated by the logistics service provider) to certain Metro distribution centres. The anticipated benefits of this RFID pilot were an enhanced supply chain visibility, more accurate and efficient scanning processes and thus cost reductions

In Germany, the logistics service provider operates a central warehouse for the healthcare company with room for 33,000 pallets. In this warehouse, outbound pallets are picked individually per order. In case a shipment is bound for a Metro distribution centre a smart label is printed. On the front the smart label contains the number of the shipping unit in plain writing as well as in bar code form and on the back of the label an RFID transponder is located. This smart label is then attached to the pallet during inspection of completeness. Before the pallet is loaded on trucks it passes an RFID reader attached to the gate. As soon as all pallets are loaded and therefore scanned, the logistics service provider sends a despatch advice electronically to Metro, informing about the readiness of the shipment, its contents, and expected arrival time. On arrival of the shipment at a Metro distribution centre, the shipment again passes an RFID-enabled gate and the pallet's Electronic Product Code (EPC) is collected.

4.2 Fashion Company

Another RFID pilot project was conducted in Germany by a global fashion and lifestyle company together with its logistics partner and a retail company. Its goal was to test current technology, examine possible applications for RFID deployment, and to identify both costs and benefits of RFID solutions in the textile trade.

Logistic units as well as the items are tagged at the logistics service provider during the control of goods received. These tags are then read (bulk reading) before as well as after the order picking process at the logistics service provider. When arriving at the retail stores the control of goods received is done by scanning the goods when they pass RFID-enabled gates.

Apart from these logistical functions, additional functions in the retail stores are tested. For instance, the stocktaking for RFID-enabled goods is simplified and improved because of bulk reading and RFID-enabled shelves which recognize if goods are taken from them. Thus, errors resulting from manual data entry are minimised. In order to prevent theft, the RFID tags are used for article surveillance as well. The latest transaction in this supply chain, being the check out process for these products, is streamlined because RFID readers are used at the check out counters allowing for faster and simultaneous reads. Because this RFID system works as a closed loop system, the transponders are removed at the check out counters and sent back to the logistics service provider for reuse.

4.3 Mailorder and Online Retailer

In order to test practicability of RFID technology and to prevent theft of its high value electronic goods during shipment, a major German mail-order and online retailer opted for an RFID solution. In the central warehouse RFID transponders are attached to the packaging of high value goods like jewellery, digital cameras or cellular phones. The passive smart label transponders, working in the 13.56 MHz frequency band, contain a unique article number, the shipment code, as well as a number used for returned goods. Therefore, the goods arrive at the end customers with the transponder. In order to anticipate any privacy concerns, the packages comprise an informative letter about the technology and the confirmation that no personal data is stored on the transponder.

Along their way through the central warehouse the transponders are read at certain points such as the picking or packaging stations to identify the products which are then shipped to the distribution centres of the logistics service provider. During the processing in the distribution centres, the items are also identified by RFID readers. The data collected along the shipment route is combined with local data from each read activity. Thus, in case of theft or loss, the last location where the product was identified can be found but also improved tracking for customers increases the service level.

According to the company, the benefits of this RFID system for theft reduction alone outweigh the costs by more than 20 percent. Therefore, the RFID solution is used in practice but because of the costs of the transponders is restricted to high value goods only.

4.4 Supplier of Industrial Printers

In cooperation with a freight forwarder and an airfreight carrier, a supplier of industrial printers tracks shipments from its Germany based warehouse alongside the route to American customers. With the intention of providing better customer service, the printer supplier needed to track shipments at shorter intervals and to gain better visibility of the shipments during the time they were handled by the freight forwarder and the airfreight carrier.

The goal was to provide more timely and accurate information which could allow for a comparison of the planned execution plan with the actual shipment execution. For that reason, in the German warehouse the printers together with spare parts and supplies are picked and tagged at case level with 96 bit UHF transponders and then loaded onto pallets. Before the shipment leaves the warehouse, it passes an RFID-enabled gate which is activated manually and indicates shipment conformance with expected values with a traffic light signal. On arrival at the freight forwarder's warehouse the shipment again passes an RFID-enabled gate with traffic light signal and the same happens when the shipment leave the warehouse and is loaded onto the plane of the airfreight carrier. After being shipped to North America, the shipment is read again in the loading dock when it is loaded onto trucks bound either for the last part of the journey to the customers or for a warehouse of the printer company.

Conducting the project provided the company with insights in how to integrate RFID solutions by different vendors deployed on two continents, increase supply chain visibility and deploy real-time SCM.

4.5 Semiconductor Company

A semiconductor company simplified its supply chain processes using an RFID solution between its manufacturing plant and a distribution centre. The main purpose of the pilot project was to present a valid business case for RFID deployment. The pilot serves as reference project for other company locations and also as a showcase for customers since the company produces RFID transponders.

In the manufacturing plant RFID transponders are used at three levels. Every pallet, carton box and individual packaging unit is tagged with passive smart labels and scanned before shipment to the distribution centre. On arrival at the distribution centre, the receiving process is largely automated. Previously every carton and packaging unit had to be opened to tally the shipment. Now, the shipment passes an RFID-enabled gate and information of a shipment is collected and the receipt process is shortened to a quarter of the previously needed time. Costs savings result from the reduced redistribution time.

One of the main efforts of the project was the process re-engineering. In order to allow for very high reading rates with products and packaging containing aluminium the location of the transponder on the packaging was critical. Also the stacking provides a source for error as transponders put too close together can block each other. The integration into the IT environment was mainly concentrated on changes in the warehouse management system. Because of the internal business benefits, the company plans to extend the scope of the project to include customers as well.

5 Analysis

5.1 The RFID Projects

All of the examined RFID projects were carried out as pilot schemes. In the survey, questions were asked about the motivation and drivers of the projects as well as what the participants expected as business benefits. The prime reason to start the projects was to test the technology and to experiment with it:

> *"Test for cost reduction, theft reduction, more accurate and efficient scanning processes, and item-level information."*

> *"Gain insight into shipment status and location of goods while in transit to provide better customer service with better forecasts and test the possibility to deploy a solution in different standard-regions".*

The main testing theme mentioned by the participants was the improvement in scanning processes which goes along with the findings in previous research (McFarlane & Sheffi, 2003; Kambil & Brooks, 2002) regarding the expected automation in the process in comparison to manual barcode scanning. Also, cost reduction is stated as a motivational factor for the use of RFID technology as well as the enhanced supply chain visibility mentioned by Joshi (2000). In two cases RFID technology was tested for theft reduction based on item-level solutions. The possibility to store and use more data on an RFID transponder than with a conventional barcode was only mentioned once.

The companies were mainly trying to introduce RFID technology on a small scale in order to be better prepared for possible global rollouts. The semiconductor company wanted to "showcase the benefits of RFID and generate a positive business case" for possible RFID customers. In all RFID projects, the numbering scheme of the Electronic Product Code developed by the Auto-ID Center was used. Only in one case was additional information stored in the memory of the transponder. It also contained the shipment number and a return identification number only used internally.

The wish for a better supply chain visibility was not only expected to be solved through the use of more check points but also by identifying entities at a lower data collection level. The extension of unique identification numbers of the Electronic Product Code compared to the barcode was used in four of the five examined cases. In these cases, the older data collection level was still used but additionally lower levels came into operation. In three cases item-level information was employed and in one project individual cases were identified. Only in one project, which was initiated because it was mandated by a customer, was the data collection level not affected.

Only passive transponders without their own power source were in operation. Because the systems were set up mainly to facilitate the shipping processes of receiving, picking and loading, distances between reading devices and transponders were rather short so that the passive transponders were sufficient. In four cases, the RFID systems were deployed in open loop systems, meaning that the transponders were disposed of and only in the case of the fashion and lifestyle company were the transponders removed from the clothing at the point of sale and then sent back to the manufacturer's warehouse.

This layout of the systems also determined the form of the transponders. In the closed loop system, robust plastic cases like the widespread but less sophisticated tags of the older article surveillance systems were used, whereas in the open loop systems smart labels were in operation. The limited use of memory and the fact that the smart labels are printed and written to just once did not make it necessary to use more complex and expensive transponders. Another of the mentioned reasons why smart labels were used is the fact that the front side of the smart labels still contain the traditional barcode symbols and numbers. In the interaction with the participants it became clear that the barcode on the labels was still needed as it provided a twofold backup in case the transponder did not work. The barcode could be scanned or the numbers could be entered manually.

The use of real time data which is collected via RFID technology and is one of the proposed benefits (McFarlane & Sheffi, 2003; Sheffi, 2004) was only implemented and tested in two of the five projects. In the fashion and lifestyle case the stock keeping data is permanently gathered at the retail store with RFID-enabled smart shelves and monitored by the SCM systems to avoid out-of-stock situations. The company expects to benefit from more sales through the improved customer service. In the transatlantic RFID deployment of the printer supplier, "RFID event information is combined with route maps which are updated immediately to reflect the time differences between plan and actual execution." Therefore, the company can provide more timely information about the location of products and the forecasts of arrival time are more accurate. Additionally, costs savings due to less express charges and contractual penalties are expected.

Regarding the scope of the pilot schemes, the companies were mainly involving other supply chain members as well. Only the semiconductor company build the entire business case internally. This was necessary due to the fact that it wanted to provide the customers with reliable and uncensored data from within the company. The other projects involved all logistics service providers as well. This finding refutes the expectation of Kambil and Brooks (2002) who argued that most early RFID deployments would not be of collaborative nature. But it also indicates that the companies are aware that the greatest benefits of RFID solutions lie in a cooperative use of the technology by several supply chain members (see McFarlane & Sheffi, 2003; Sheffi, 2004).

5.2 Evaluations of RFID use in SCM

Because the nature of the examined projects was experimental due to the testing purpose, the given answers also contain a certain degree of criticism which results from the testing issues discovered in the pilots. These issues represent flaws in the technology from a user perspective. Interestingly, these shortcomings were

addressed by four participants but not the participant from the semiconductor company which also produces integrated circuits (IC) for RFID transponders. Among the detected weaknesses, the technical barriers for the use with products containing metal or liquids and problems with reading rates during bulk reading procedures were mentioned. Also the different standards used on different continents were brought up as a disadvantage leading to higher costs.

Nevertheless, the participants revealed mainly two groups of advantages of RFID technology compared to barcodes. They often mentioned the increased efficiency in scanning, identification and receipt processes and that the time savings enabled better inventory turns. The other main group relates to the increased supply chain visibility which resulted from more checkpoints and better tracking and inventory control. Additionally, the participants appraised RFID as a more robust technology that can be used in counterfeit protection and become a standard which has coverage of more than one industry.

The participants expect to convert these advantages into business benefits. Better customer service with a higher supply chain transparency, less out-of-stock, increased sales, theft reduction, higher delivery reliability, increased inventory turns, and improved warehouse performance are expected to accrue in the examined industries. These findings resemble the benefits expected by McFarlane and Sheffi (2003). Interestingly, the stated benefits can be classified into two different themes. Benefits accruing to companies due to improved supply chain performance play the major role, whereas only the participant of the fashion and lifestyle company talks about improved sales performance due to less out-of-stock problems.

Estimations about the future relationship of barcodes and RFID technology were rather consistent among the participants, even across the different industries. They expect a co-existence of the two for the following reasons:

- bar codes have broad coverage today,
- bar codes are still cheaper and more reliable,
- investments are required to switch to RFID,
- RFID is only sensible for high value goods due to low prices of bar codes,
- RFID is not mature enough, and
- barcodes are needed in order to provide a human-readable code in case the tag is damaged.

Nonetheless, the outlook given on the longer term (more than five years) of the barcode and RFID relationship is in favour of a substitution as RFID is expected to provide more benefits and the possibility of value added services. However, most participants do not expect a complete substitution to happen within the next ten years.

When comparing the RFID deployments in the different industries, the price of the products is associated with the data collection level. In general, it can be said that the more expensive the product, the lower the data collection level is. Whereas the item-level information of single wafer cartons justifies the price of a smart label, information about single shampoo bottles with small margins is not economic but information on pallet level serves its purpose. Currently, the mail-order and online retailer makes use of RFID labels only on high valued goods but plans to extend the use to cheaper goods as soon as the prices for transponders fall below certain price levels.

Concerning the barriers of widespread RFID technology integration, the participants mentioned different themes. Some stated that the technology is not mature enough and made reference to problems with bulk reading procedures, one of the main benefits which accelerates warehousing and loading processes. Here the required reading rates are seldom reached. But also the costs of the transponders and reading devices compared to barcode solutions are seen as a hindrance for fast large scale RFID applications.

The participants also stated that the inconsistencies in the RFID standards both in frequencies and protocols were posing problems because global standards would be needed. Davenport and Brooks (2004) found that a single supply chain member cannot individually decide on a technology vendor, which is a reason for hesitation. Nevertheless, the printer supplier and its two partners proved that the technology from different suppliers deployed in different standards locations worked along the supply chain. Only the costs due to the different standards requirements were mentioned as a barrier. But the participants also see other hindrances, for instance that current systems do not reflect RFID processes, and that there is lack of professional knowledge in the companies which could deploy RFID technology. Also, the participants are aware that privacy issues for end-consumers need to be addressed by government regulations before open loop RFID systems can be securely deployed in retail stores.

Unfortunately, none of the examined projects dealt with more sophisticated types of RFID technology. This is probably related to the analysed industries. The business scenarios did not require sensors to be deployed. Such systems can be expected to be used for instance in the food section of the consumer packaged goods industry or along the pharmaceuticals supply chain.

5.3 Impacts of RFID on SCM

With the intention of gaining a better understanding of the current supply chain integration efforts and to situate the RFID technology introduction in a superior SCM strategy, questions were asked about the current supply chain integration efforts of the companies. The answers revealed two distinguishable themes. The participant from the logistics service provider explained the goal of becoming the market leader in the segment of lead logistics providers, which means that the company consults, plans, and controls entire supply chains of other companies with their own logistics capacities. Therefore, the company's integration focus lies in the external supply chain. Also, the participants from the fashion and lifestyle, mail order, and printer supplier companies stated that they were concentrating their efforts on external supply chain integration.

"external integration in order to boost supply chain efficiency and shorten time to market"

"external; to develop better relationships with supply chain partners for better customer service"

"external integration; link systems and provide and use real time data for plan updates and corrections; to provide more accurate information for the customers"

These comments indicate that the introduction of RFID technology is part of a larger systems' integration intention among supply chain members. However this was not the case with the semiconductor producer participant who stated that the RFID project was only used for the internal integration efforts, he added that it was also planned to integrate external systems in the pilot scheme in order to "to leverage the potential with customers as well". So in the long term RFID technology fits into or facilitates the external system integration reflected by the SCM system development.

Concerning the experienced and expected impacts of RFID technology on SCM systems in the industries, the participants' statements are aligned with the projections found in literature (see McFarlane & Sheffi, 2003; Davenport & Brooks, 2004; Sheffi 2004; Angeles, 2005). From a bottom-up perspective, the mentioned impacts start with redesigned, faster scanning processes which lead to improved stacked lead time. Because the data collection level mainly shifted to lower levels and even towards item-level in three cases, the systems are provided with a higher granularity of data. Additionally to the higher granularity, the more efficient scanning processes allow for more check points which can be integrated along the supply chain. The previous labour- and time-intensive barcode scanning processes forbid a higher number of check points. Therefore, the occurring data volume is increased by the shifted data collection level and the higher number of check points.

The faster and higher information availability allows the SCM systems to conduct real time data processing. However, as already stated, only two of the participants stated that they were actually using real time data. Faster data processing in turn leads to "increased information visibility" and "better supply chain visibility" together with greater system integration. In terms of the impacts on business performance, one of the participants reported "increased inventory turns", "better delivery reliability and warehouse performance". Other participants stated they could provide better customer service because of fewer out-of-stock situations which also lead to higher sales. Therefore, RFID is seen as serving the main goal of SCM, namely increased customer service.

As the literature review has indicated, the extent to which SCM systems are thought to be impacted by RFID technology introduction varies greatly. Nevertheless, the participants showed a more uniform assessment of the impact. They found that in each case, the hardware, software, processes as well as the workforce were affected. Additionally, the RFID technology introduction affected infrastructure (for instance warehouse design) in four cases and middleware was impacted in three cases.

These findings oppose Morán, Ayub, and McFarlane (2003) but support the methodologies for system integration presented by Chang, MacFarlane, Koh, Floerkmeier and Putta (2002). They also show that disregarding required modifications of business information systems as found by Morán, MacFarlane and Milne (2003) was not the case with the participants' pilot schemes.

Regarding the main integration efforts which were encountered in the SCM systems integration, the cooperation of all supply chain partners was especially mentioned. Four of the five participants stated that the alignment of the partners' systems or the cooperation between the partners was the critical integration effort:

"standardize the data management between the supply chain partners"

"cooperation of all supply chain partners"

"integration of the partners' SCM systems and providing an open platform".

It seems that one of the most crucial aspects of external supply chain integration in RFID projects is not of technical nature but rather a question of how supply chain members are able to cooperate. But the comments also highlight the importance of a standardised data structure and a harmonised system landscape between the supply chain members.

The participants also stated that the integration of new hardware and software, warehouse management system adaptations, and process re-engineering were among the main integration efforts. The latter required intensive testing because the location of transponders on packaging must be considered as well as the direction of the products on the pallets to allow for bulk reading.

6 Discussion

The examined cases of RFID deployment in supply chain operations show that companies are already using the technology. Nevertheless, the limited extent to which they deploy RFID solutions shows that they are still hesitating to use it on a full scale. Because of the lack of knowledge in companies and because of problems of technical nature, mainly pilot schemes are conducted. The participants stated that there are still technological barriers which need to be overcome. These include faultless reading processes with products and packaging containing metals and liquids. But also the performance of RFID hardware in bulk reading processes needs to be addressed by the producers of RFID systems and components. Not until these deficiencies are overcome, are widespread global and industry crossing RFID deployments likely to be seen. These are the main reasons for better performance and more efficient processes compared to barcode solutions. As long as the technology is not mature enough to deliver these promises, companies will keep on hesitating to deploy it.

Apart from the technical advantage and its availability, costs still represent a major hindrance in mass deployment. Whereas high value goods can already be

tagged economically on item level, lower value goods with small margins (as can be found in the fast moving consumer goods industry) are still far from being individually identified at reasonable costs. But despite the costs for such item-level identification possibilities, the benefits must be considered. Is it sensible to individually identify for instance every yoghurt pot? From the perspective of one producer it means that out of stock situations are likely to be avoided and thus sales increased. But when every yoghurt producer makes use of such RFID solutions, is it likely that people consume more yoghurt and the total yoghurt market expands? Only the early adopters in such a scenario can leverage RFID technology and expand their market share at the expense of the (late) followers.

Often producers claim that RFID item-level identification will reduce costs for recalls. The logic in such a scenario may be clear, as affected products can be uniquely identified. But should companies not focus on preventing the sources for failures rather than curing the symptoms? With regard to item-level identification, the end customer plays an important role even for supply chain operations. As stated by the research participants, the acceptance of item-level RFID solutions by the end-customer is ultimately needed because of privacy issues. The companies deploying item-level RFID solutions where the transponders are not deactivated during the transfer of risk are very careful not to violate privacy rights but still have to fight accusations from consumer rights groups. These groups oppose the technology in a fashion similar to those who opposed the emergence of cellular phones in fear of being monitored and eavesdropped. The advantages of item-level tagging for consumers are still far from being available. Therefore, companies have to consider privacy issues very carefully especially as there are no regulations governing the use of RFID solutions.

The price issue being currently debated takes the form of the chicken and egg problem. The users of RFID transponders claim that they will deploy systems with massive numbers of transponders as soon as the prices fall. And yet at the same time, the industry leaders producing RFID devices and transponders argue that the prices will fall as soon as more RFID mass deployments are in place. As the examined cases have shown, in most cases it takes more than one company to economically deploy RFID solutions. But along a supply chain, the costs as well as the financial benefits of RFID deployments vary for each supply chain member. One way out of this problem is the emergence of solution providers which supply the RFID systems for an entire supply chain and develop innovative concepts which allow for an equitable breakdown of costs according to benefits. Due to the complexity in business and supply chain operations this is hardly achievable. Nonetheless, RFID costing concepts in which supply chain members are charged according to the accessed information are already being developed.

However, the current RFID mandates by retail companies such as WalMart, Tesco, and Metro do not necessarily reflect this. The retailers' power over the end-customer is high enough that they can force their suppliers to meet their RFID requirements. However, it can be expected, that such forced mandates do not reap the benefits which accrue for RFID solutions where companies, on their free will, explore and apply the technology. This goes along with the findings of this study where the pilot project for such a mandate only used pallet-level tagging and tested automation of the previous barcode scanning processes.

The participants assess the coexistence of the barcode and RFID technology as the dominant form for automatic identification within the next five years. Because the system stability of sole RFID solutions is not high enough for supply chain operations, a combination of barcode and RFID will be used. This solution brings the advantage that exception handling with non-working RFID transponders can be solved with barcode scanning or manually entering the human readable numbers. Because reading errors are even likely to occur with more advanced RFID technology it is questionable whether a complete substitution will ever take place. However, the participants expected that the substitution will take place at some point in time, but that it will not happen within the next five years. One way out of this is the development of polymer ICs for transponders which can be printed directly on products. Together with human-readable numbers they might replace the currently deployed smart labels which are impractical on small products and packaging due to their size.

Also, as long as packaging and not the products are tagged, a solution along the entire supply chain is not possible as products are unpacked before they are processed. The data might be collected and available along the supply chain. But the transponders can only be used in the picking, loading, shipping, unloading and goods received processes. As soon as the product is taken from its tagged packaging, it is disconnected from the transponder and its data. Additionally, after it is processed, a new transponder must be attached. These solutions bear inconsistencies and are likely to drive costs. In order to provide the discussed and expected supply chain visibility it is necessary to directly equip the products with transponders. Otherwise, it is likely that the connection of the data with the product is unsustainable. Interestingly, none of the participants mentioned this problem and also the researched literature contained no discussion on that topic.

However, the examined cases showed the participants' views on standardisation issues. Even though EPCGlobal already developed global standards in form of the EPCGlobal Architecture Framework, which in its latest version is closely aligned with the ISO standards, the different frequency bands regulated by postal and telecommunication institutions of the countries pose problems. Even though one of the examined pilots schemes successfully integrates an inter-continental RFID solution with several technology vendors involved, the participant mentioned that this is a suboptimal solution due to the higher costs for devices which support the different standards involved.

Nonetheless, the integration of supply chain systems and the cooperation of the supply chain members is seen as one of the crucial factors in RFID technology

introduction projects. It seems that it is an organisational problem to gather all supply chain members together and get them pushing in the same direction. But, for instance, the standardisation of the data management and exchange between systems is taking efforts which the companies could have realised before the advent of RFID technology (since the data collection method does not determine how the data is exchanged between systems). Nevertheless, the participants' attitudes give the impression that they see RFID as a vehicle towards tighter system integration.

7 Conclusion

As an emerging technology, RFID is a currently often-discussed topic when process optimisation, efficiency gains and better supply chain visibility and integration are sought after. In the aftermath of large retail companies forcing their suppliers to use RFID technology, more and more companies consider RFID technology as a way to reach long term strategic objectives.

From the survey and interview, insight could be gained into the current use of RFID in supply chain operations and how this use impacts SCM systems and key findings were:

- The RFID projects surveyed are overwhelmingly carried out as pilot schemes deploying passive smart labels. The costs and associated risks of large-scale roll-outs are regarded as too high because knowledge in the companies about the technology and its deployment is not sufficient yet.
- Co-existence of barcodes and RFID (in form of smart labels) can be expected at least over the next five years because a backup for defective transponders is needed.
- The current use of RFID technology mainly serves as automation of previous processes whereas the promised extending advantages, for instance the possibility to store more data or to include sensors, are not exploited yet.
- RFID is used as a vehicle for tighter supply chain and systems integration between supply chain partners which theoretically could have taken place before and without the technology.
- The greatest barrier in RFID projects which include several supply chain members is the organisational task to align and coordinate the members towards the common goal and the synchronisation and standardisation of the various systems along the supply chain.

As this research has shown, RFID deployment in supply chain operations is not yet running routinely. Companies are mainly carrying out pilot schemes to evaluate business cases and test the technology. However, these pilot cases reveal weaknesses in the technology itself and flaws in the initially expected possibilities and business benefits. The identification of these deficiencies helps to improve the quality of offered systems, identify best practices and clarify what the technology is actually able to deliver. The recent hype about RFID has led to exaggerated assumptions and hopes among many companies which could not (yet) be met. But as expert knowledge about RFID is still rare in most companies, a more realistic assessment of the possibilities without pilot schemes cannot be expected in the near future.

The deployed solutions are based on passive smart labels, a combination of RFID transponder and printed bar code. In this way, problems with defective transponders can be anticipated with exception handling routines since the barcodes can still be scanned or the corresponding numbers can be entered manually into the systems. But still, bulk reading operations where entire pallets with tagged items should be read simultaneously are not working properly with the passive smart labels. Exact placement on the packaging and correct direction on the pallets may increase reading rates but need to be figured out beforehand and strictly maintained. Such routines demand training of the staff in order to deliver the required results.

Concerning the purpose of RFID technology and what it delivers, mainly an automation of previous scanning processes and operations such as picking, counting, stock keeping, loading and unloading can be seen. As budgets are small, positive business cases are strictly required which only leads to solutions on proven applications. Also, despite the efforts of the two large standardisation bodies, EPCGlobal and ISO, differences in regional standards represent a barrier in global RFID supply chain applications. Although one of the examined cases showed that the technology vendors developed devices which can deal with the different standards' requirements, this situation still means higher than necessary costs. Especially in industries with low value items and low margins per product, the current status remains prohibitive for global roll-outs.

Based on the sample taken, the development of new value-adding functionalities and services has not taken place yet. Neither the possibility to store more data on the transponders nor the combination with other technologies such as sensors is yet exploited to any great extent. Nevertheless, it can be expected that key players in the fast-moving consumer goods and pharmaceutical industries will experiment with and examine these. As some companies are forced by their customers to adopt RFID technology, their motivation differs from companies examining RFID which wish to use the technology to its benefits of their own free will. However, these differences should be further researched as insight can be expected to prevent suboptimal and costly RFID applications.

Concerning the role of RFID in SCM systems, the conducted research shows that RFID technology acts as a system enabler which delivers the needed granularity of item information and greater number of check points for higher supply chain visibility in real-time. Even though supply chain processes have been redesigned because of RFID introduction, the design of entire supply chains has not been affected yet. But RFID is used as a medium to integrate systems along the supply chain. Data structures are standardised in order to allow efficient data exchange among the supply chain members.

These efforts theoretically could have been realised before, as the data collection method does not determine

the data exchange. But when considering the advent of RFID technology and the development of business information and especially SCM systems, it becomes clear that the company internal integration of systems and data which was realised with the ERP systems in the 1990s preceded the external integration possible only since the development of APS and SCM systems. As discussed in the literature review, this order is widely regarded as superior. Therefore, RFID integration can be regarded as the logical next step in supply chain integration and SCM system development.

Still, the coordination of supply chain members proves to be a major factor influencing the progress speed and ease of the RFID introduction process. As the development of open systems and the sharing of crucial information along the supply chain require trust among the supply chain members and especially when companies simultaneously operate in several supply chains, standard procedures and regulations need to be in place. As current RFID applications do not yet span complete supply chains, the possible inconsistency along the supply chain when packages and not products are tagged has not emerged. Therefore, further research in the behavioural and organisational issues of the coordination and integration of supply chain members with regard to RFID applications should be conducted.

This study was conducted to provide information on the current use of RFID technology in supply chain operations and its impacts on SCM systems. As RFID technology can provide important business benefits, the results of this research deliver a better understanding of current problems and issues in the introduction of RFID technology and show which factors influence the level of success of such projects. As presented in the literature review, a better understanding of these issues will facilitate RFID technology introduction and further development of the technology itself. Also, the discovered impacts on SCM systems will enable decision makers of RFID projects to more quickly identify common problems before they occur. Hopefully this will lead to smoother and faster supply chain integration on the basis of RFID technology introduction in supply chain operations.

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