RFID IN THE SUPPLY CHAIN

*Design of an RFID Information System
to improve Supply Chain Performance*

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Preface

This Master Thesis is the conclusion of my study System Engineering and Policy Analysis at the Technical University Delft. The subject of this thesis, RFID in the Supply Chain, combines two fields of my interest, ICT and Logistics. I conducted my research at KPN, a large Dutch Telecommunications Provider, which enabled me to participate in two advanced and award winning RFID pilots, TelliTrace and Vers Schakel.

Special thanks go to my internal and external supervisors who kept supporting me, despite the uncommon and lengthy route followed: Jan van den Berg (Chair, TUDelft), Jos Vrancken (1st supervisor, TUDelft), Ron van Duin (2nd supervisor, TUDelft), and Jan Kroon (KPN)

Also I want to thank the RFID team of the KPN, especially Jan Kroon, Menno Witteveen and Ivo Carton.

My deepest gratitude goes to my sister Nicole for giving me moral support and by providing me a comfort shelter to finish my thesis; Wiebe Wiechers for giving his advice and pulling me through some though moments; and my parents for their support and their endless believe in me.

Finally, I want to thank all my friends and family for your support and confidence in me.

Xander van Hoff,

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Executive Summary

The performance of today's company is becoming more and more dependent on the performance of the supply chain the company is part of. To improve supply chain performance, through supply chain management, information is key. RFID, an upcoming information technology, has the potential to provide information to optimize supply chain performance.

The goal of this research was to design an RFID Information System (IS) that enables optimization in supply chain performance. For this purpose, literature studies on SCM and RFID were done to determine the requirements for such an RFID IS. Based on the requirements an RFID IS was built. Finally, this RFID IS was put into practice in two pilot Projects, TelliTrace and Vers Schakel, to test and validate the design of the RFID IS.

The literature studies show that to optimize the performance of the Supply Chain, the flow of information within Supply Chains can be improved. Product Visibility and Information Sharing are two key areas of improvement. The studies further showed that, when breaking down these two areas, RFID has inherent characteristics that improve some, but not all issues. To improve all areas an RFID Information System should:

- Improve Product Visibility
- Create efficient technical interfaces for sharing information
- Deliver a trusted platform for supply chain actors to share their information
- Foster understanding by Managers for the need for information sharing

These requirements lead to the design of an RFID IS consisting of the components in Table 1.

Table 1: RFID Information System Components

Requirement	RFID IS component
Improve Product Visibility	Real time Registration and Processing
Create efficient technical interfaces for sharing information	Technical standard for information exchange
Deliver a trusted platform for supply chain actors to share their information	Sophisticated role based management system
	Trusted Third Party Trusted to provide a platform for information Sharing
Foster understanding by Managers for the need for information sharing	Management Dashboard, visualizing chain/supply chain KPI's
	Improved Service Level Agreements between Supply Chain Partner

From the implementation of the RFID IS in the pilot cases several conclusions can be drawn. In the first place, the TelliTrace pilot showed that, without appropriate supply chain (re)design, the implementation of RFID does not necessarily lead to direct improvements in business processes. In Vers Schakel, the implementation of RFID did lead to improvements in supply chain wide business processes, resulting in improved Product Quality and improved Shelf Availability.

Both pilots had problems with RFID tag read rates, but in the end both approached near 100% readability. In Vers Schakel a sophisticated role based management system was implemented successfully, providing an external party (Container Centralen) only with information about the crates themselves and not about the content. As per the RFID IS, both pilots used a

telecommunications provider as third trusted party to provide the information sharing platform. The Vers Schakel pilot proved that a management dashboard could be implemented based on supply chain wide KPI's. These supply chain wide KPI's illustrate the potential to improve SLA's between supply chain partners.

Based on the experiences from these pilots, two refinements to the design of the RFID can be done. First, there should be a concerted effort on product visibility during implementation, since both pilots show that 100% readability is still not guaranteed. And secondly, the information sharing platform should provide stakeholders in the supply chain with information, because stakeholders can also benefit from the supply chain information.

The pilots showed that the design of the RFID IS is feasible in practice and is capable of improving supply chain performance. The final design of the RFID IS is illustrated in Figure 1. It should be noted that theoretical benefits to product visibility of RFID cannot (as yet) be completely realized in practice (e.g. achieving 100% readability), and that to fully realize supply chain benefits requires the RFID enhanced supply chain to be reorganized. However, in the context of this RFID IS design, RFID is a means to provide product visibility; it also contains several elements that are not limited to RFID.
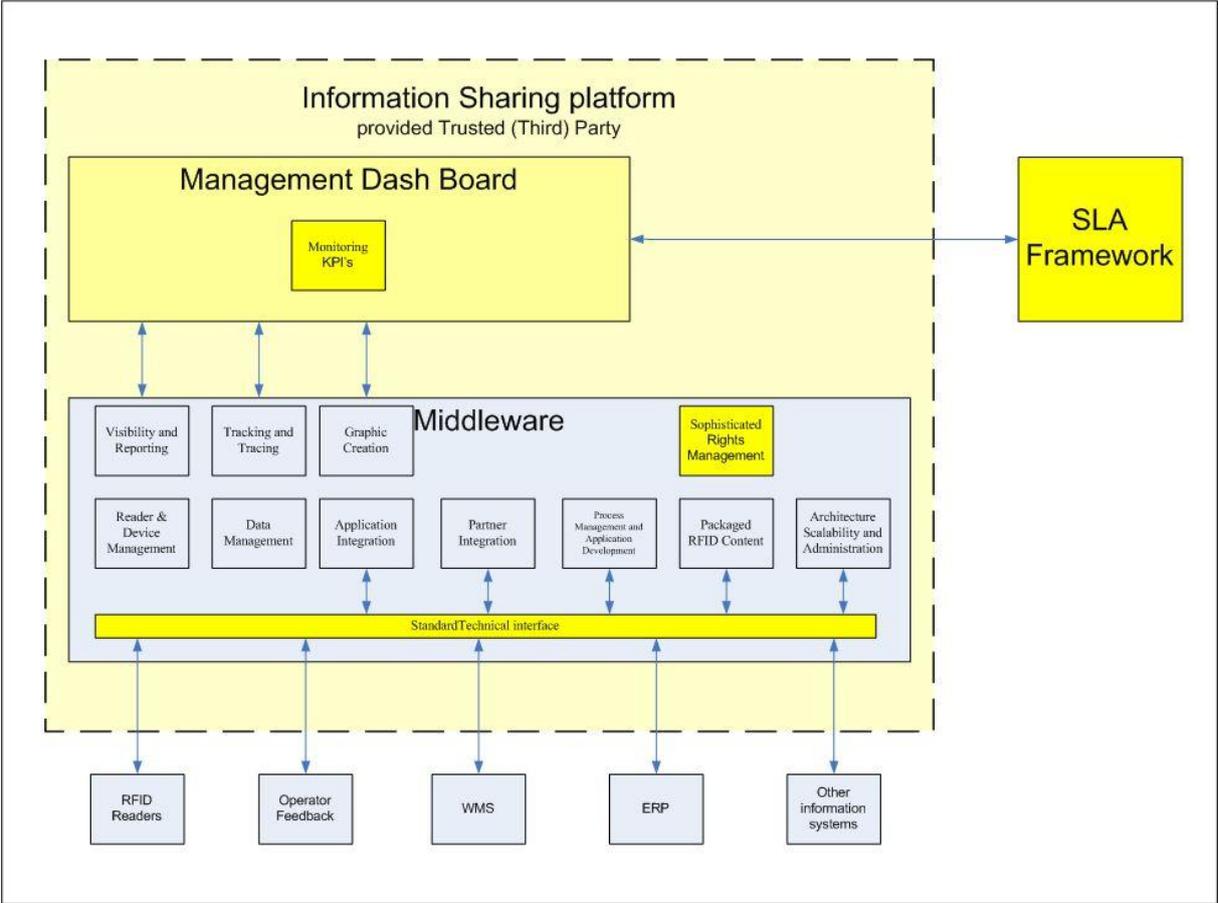

Figure 1: Design of RFID Information System

Interesting areas to explore in further research are the supply chain wide KPI's, the impact of these KPI's on SLA's between supply chain partners, and the reorganization needed to optimize supply chain benefits of the RFID enhanced supply chain.

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Chapter 1 Introduction

In the first part of this introduction (§1.1), a high level outline of the context, in which the research is conducted, is given. In §1.2, the research objective is described, §1.3 elaborates the scope of the thesis. The methods used to perform the research are clarified in §1.4. In the last section, §1.5 of this chapter a brief overview is given of the outline of the thesis.

1.1 Context

In order to be competitive in today's business environment, companies must focus on optimizing business processes along the entire supply chain. To achieve this, the function of Supply Chain Management (SCM) has emerged to manage the processes, assets, and flows of material within and among companies. Businesses have recognized the ability of supply chain management to deliver significant savings and continue to search for new ways to achieve competitive advantages through supply chain optimization. One of the key elements to further optimize the supply chain performance is information: The right information for decision making must be available at the right place, at the right time, throughout the entire supply chain.

The flow of information throughout a Supply Chain can be greatly improved by a new technology: **R**adio **F**requency **Id**entification. RFID makes it possible to track items in real time (Glover and Bhatt 2006) as they move along the supply chain. Linking a digital ID to a physical object makes its location and other important information instantly accessible to all parties in the supply chain. However, despite its potential, few examples of successful supply chain wide introductions of RFID exist today. Apparently the introduction of RFID by itself is not the universal antidote that resolves all issues complicating the flow of information through the Supply Chain.

This thesis takes a bottom up approach by looking at the key bottlenecks to the flow of information that diminish Supply Chain Performance and the characteristics of RFID. A concept of an improved RFID information system is proposed for a supply chain wide introduction of RFID which addresses all these bottlenecks. This design is tested and validated to two pilots, *TelliTrace* (KPN; TNT Logistics; Symbol; Zebra; 2006)*,* a project to track mobile phones with RFID moving trough an internal supply chain from warehouse to retailer; and *Vers Schakel* (KPN; Capgemini; Schuitema 2007) , a multi actor RFID project in a fresh vegetables supply chain, from supplier to retailer.

1.2 Research Objective

Based on the few numbers of successful implementation of a supply chain wide introduction of RFID, the objective for this research is:

> *Design an RFID Information System to improve Supply Chain Performance*

In order to reach this objective, the research is split up in three parts. The first part of the research addresses the requirements for the supply chain wide RFID Information System (IS). The second part presents a design for a RFID IS across the Supply Chain. In the Third part this design is tested in practice to find out whether it is feasible or not. Each part has its own accompanying research question.

> 1. *What are the requirements for an RFID Information System to improve Supply Chain Performance?*
>
> 2. *What does a design of an RFID Information System across the Supply Chain look like?*
>
> 3. *Is the design of an RFID Information System implementable in practice?*

1.3 Scope of Research

This research focuses on the way that RFID supports the flow of information through the Supply Chain. RFID is not only the interface between tag and reader, but also the RFID architecture, including the RFID middleware. In the context of this thesis the term RFID refers to the entire RFID system.

Supply chains come in different shapes and sizes, to reduce complexity this research is limited to linear supply chains.

1.4 Methodology

Different research methods are applied in the research.

First, a literature study was performed of Supply Chain Management (SCM) and of RFID. The literature study of SCM produced the benefits of SCM, the drivers of SCM, but also the barriers to effective SCM and the flow of information in particular. The RFID literature study, is oriented on RFID in the Supply Chain, and provides insight into the virtues and the shortcomings of RFID to support the flow of information across a supply chain.

From the two literature studies, four essential requirements are identified which an RFID system should satisfy to significantly improve the flow of information through the Supply Chain. Based upon these requirements a design of an RFID Information System is produced that is rolled out across the Supply Chain. The objective for this design is to overcome the barriers to the flow of information through the Supply Chain.

To test the design in practice two case studies are performed. In these case studies, TelliTrace and Vers Schakel, parts of the design are tested and validated. The thesis finalizes with a conclusion and recommendations for further research.
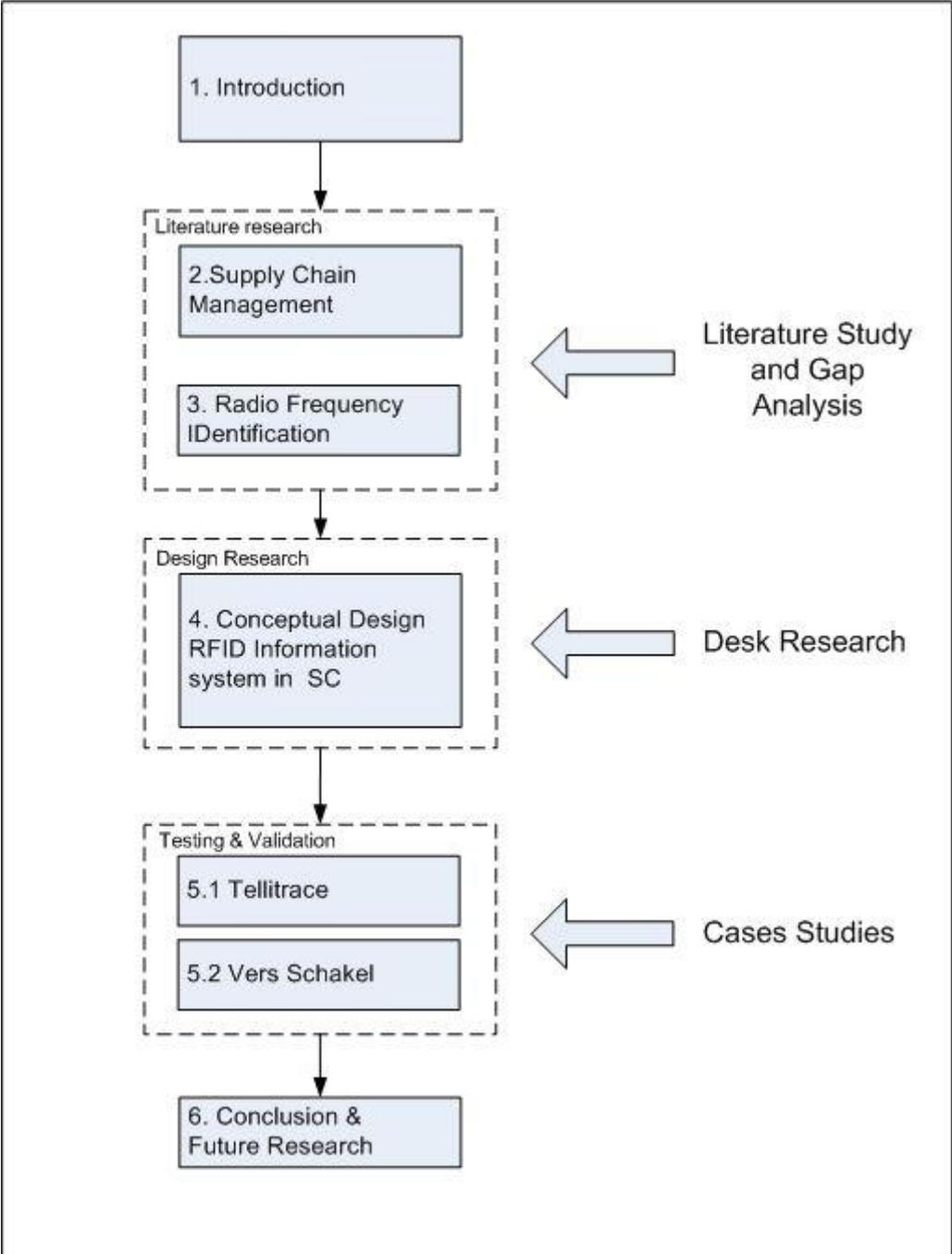
Figure 2: Research Approach

1.5 Thesis Outline

In this section an outline of the thesis is given. A brief overview of each chapter and its content is given.

Chapter 2 Role of Information in SCM

In this chapter an introduction to SCM is given and the role information in SCM is elaborated. Subsequently, the key enablers for improvement in SCM are identified. Finally the challenges towards realizing these key enablers are elaborated.

Chapter 3 Radio Frequency Identification

First, this chapter provides an introduction to RFID followed by a more in depth description of RFID. Subsequently, the benefits of RFID are evaluated to which extend they address the SCM challenges identified in chapter 2.

Chapter 4 Design of a RFID Information System

Based on the analyses performed in the end of chapter 3, the requirements for a design of an RFID Information System (IS) that enables improvement of supply chain performance are identified. Subsequently, according to these requirements a design for an RFID IS is developed.

Chapter 5 RFID Cases

The design of an RFID IS is tested and validate into practice in two RFID pilot cases, TelliTrace and Vers Schakel. This chapter discusses the Pilot cases in detail and provides the results of the testing and validation of the design of the RFID IS in practice.

Chapter 6 Conclusions and Future Research

In this final chapter, the conclusions of the research are presented and recommendations to possible further research based on these findings are done.

Chapter 2 Role of information in SCM

In this chapter the areas of SCM are identified that can potentially be improved by RFID. The first part introduces SCM; it identifies the need for and definition of SCM and defines the type of supply chain central in this research. In the second part the critical role of information in SCM is analyzed and illustrated by one of the key processes within SCM inventory management, and by one of the negative effects that occur when information is not properly used. In the third part the two key enablers to ensure an efficient flow of information throughout the supply chain are highlighted: Product Visibility and Information Sharing. Finally, in the fourth part the challenges towards realizing these key enablers are identified. The chapter is concluded by an overview of the requirements which a potential supply chain wide RFID solution should satisfy to improve the flow of information across the supply chain

2.1 Introduction to Supply Chain Management

In this section SCM is introduced, starting with the subject of SCM, the supply chain. The need for SCM is discussed in the second part, followed by the definition of SCM. In the fourth part the supply chain central in this thesis is shown.

2.1.1 Supply Chain

A supply chain is the total system that produces goods from raw materials and delivers them to the end customer. It consists of organizations, equipment, processes, activities, and people (Brown 2007). The supply chain is a multi-actor environment as it consists of multiple participants. Supply chains have evolved to complex entangled networks of suppliers, distributors, and customers (Figure 3).
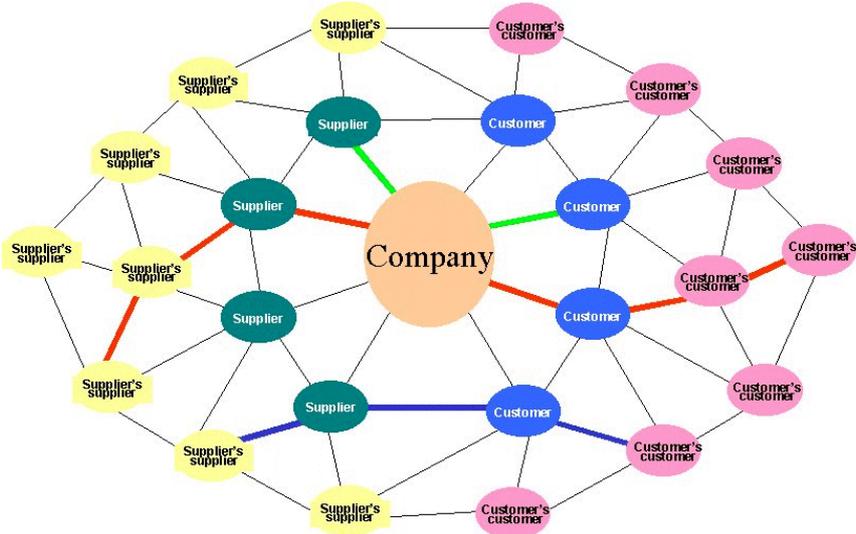
Figure 3: Networked Supply Chain

2.1.2 The need for SCM

There have been major changes in the business landscape over the years. Among the forces that caused these changes are *Globalization, Deregulation, Power shift in the supply chain,* and *the Empowerment of the customer* (Coyle, Bardi and Langley 2003).

Companies have become like spiders in a supply chain web (Figure 3). At present, while competition has evolved to competition between supply chains rather than between firms (Jespersen and Skjott-Larsen 2005) (Lambert and Cooper 2000), a manager should look beyond the boundaries of the firm, while making decisions, to create maximal value for the company. In other words, managers should not only do what is best for their company, but also what is best for the entire supply chain. This means that sub optimization within the supply chain should be avoided. In a collaborative supply chain, companies should strive to a 'win-win' situation (Coyle, Bardi and Langley 2003). In order to do so the supply chain participants should coordinated and eventually integrated their businesses to a certain level. The practice of improving and coordinating the supply chain is called Supply Chain Management (**SCM**).

2.1.3 Definition of SCM

One unique definition for SCM does not exist and the boundaries of SCM, in literature and practice, are vague (Croom, Romano and Giannakis 2000). The definition of SCM that will be used in this research is formulated by (Jespersen and Skjott-Larsen 2005). This definition is used because it is compact, yet covers "all" processes involved in supply chain management, which is more than only logistics.

> *SCM is the management of relations and integrated business processes across the supply chain that produces products, services and information that add value for the end customer*.

This thesis is about SCM enabled by RFID; therefore the focus is more on product visibility and information sharing across the supply chain to optimize business processes in order to add value to the customer than on relationship management. Yet, relations between companies are also important for the trust needed to cooperate and share information.

2.1.4 The Linear Supply Chain

The Supply Chain put central in this research is confined to a linear Supply Chain. Figure 4 depicts the supply chain that is used as a model of a supply chain in this thesis. It consists of a supplier, manufacturer, distributor, retailer and consumer. Goods move downstream from supplier to customer. (Brown 2007) identifies three flows that move upstream: cash, information and reverse logistics. The latter is out of scope of this thesis, so it is left out, but information doesn't exclusively run upstream, therefore Figure 4 shows an information flow that runs downstream as well as upstream.
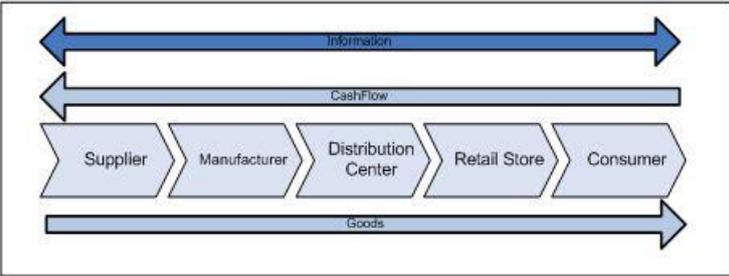
Figure 4: Linear Supply Chain

2.2 Role of information in SCM

In this section the importance of information in SCM is highlighted. First, the critical position of information in SCM analyzed. Subsequently, the potential for improving supply chain performance by information sharing and improved information quality is illustrated by a key SCM process. In the third part, an example is given what happens if information is mismanaged.

2.2.1 Information: the link between all SC elements

In their work (Hugos 2006) and (Brown 2007) have indentified five key drivers for the supply chain. These five drivers are: *Production, Inventory, Location, Transportation,* and *Information.* The decisions and control in these five areas determine the supply chain's throughput, operating expense and inventory level. Figure 5 depicts the five drivers. In the *production* area the production and production capacity is managed. The production manages the what, how and when to produce. The *Inventory* driver deals with how much to make and how much to store. The *Transportation* driver copes with how and when to move a product. The *Location* driver deals with the best location for each activity. However the most important driver is *Information.* Based upon the available information the activities of the other four drivers are managed.
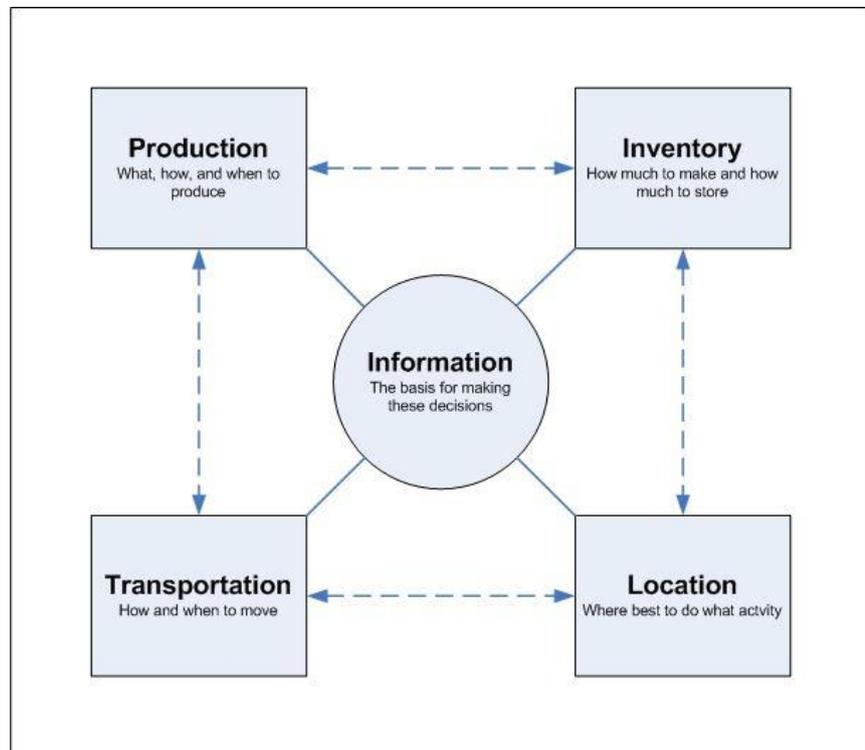
Figure 5: Five Key Drivers of SCM (Hugos 2006)

A few examples of information that is needed by the different drivers are the following. To produce the right products *production* needs to have information about customers' product requirements. For *Inventory* to know how much to make and how much to store, information about production capacity, customer demand, lead times, and inventory stock levels is needed. For *transportation* information about costs and lead times of different transport methods is needed to determine right moment and means of transportation. If *Location* determines the best place for each activity involved, it needs information about production capacity, production costs, and transportation costs. The more sophisticated methods become to manage the supply chain the more information they need (Pramatari 2007).

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2.2.2 Inventory Management

To keep inventory is important for a company in order to satisfy customer demand. Not to sell a product to a customer because of an out-of-stock situation is a loss of revenue, thus a company is benefited with a well stocked inventory. On the other side, to keep inventory brings costs, this can be up to 25% of total assets (Vollman, et al. 2005). These inventory carrying costs are build up from *Capital costs,* the value of using the capital for inventory instead of other investments, *Storage Space Cost,* the costs of the storage space and the inventory handling costs, *Inventory service cost,* the costs of insurance and taxes of the inventory, and *Inventory Risk Costs*, the risk costs of devaluation of the inventory (Coyle, Bardi and Langley 2003).

Therefore the volume of inventory is a tradeoff between product availability and the inventory carrying costs.

With good inventory management the product is always available for the customer (customer satisfaction) and the inventory is at a minimum (cost reduction). However inventories are never to the idle minimum because of transit, cycle, safety, and anticipation stock (Lambert and Cooper 2000) (Coyle, Bardi and Langley 2003). Where *transit stock* covers the time to transport goods; *cycle stock* is caused by economy of scale in acquisition, production and/or transport; *safety stock* exists because of uncertainty in forecasting, lead times, and transportation; and *anticipation stock* covers the risks of unusual events like strikes, political unrest, etc. The volume of transit, cycle, and anticipation stock is a corporate decision. However the volume of safety stock is caused by uncertainty in supply and demand.

By collaborating with supply chain partners, SCM aims to reduce uncertainty in the supply chain and thereby enable a reduction in inventory, especially safety stock, without decreasing the availability of the product to the customer. Partly due to advancements in Information Technology, several collaborative inventory management techniques have been developed to improve inventory management across the supply chain. Examples are *Vendor Management Inventory(VMI)*, the supplier has the responsibility of replenishing the inventory of the customer, *Continuous Replenishment Program (CRP),* VMI extended with customers' sales forecast, and *Collaborative Planning, Forecasting and Replenishment (CPFR)*, not only replenishment, but also joint planning, promotions, forecasting based on extended information sharing between supply chain partners (Pramatari 2007).

These inventory management techniques reduce uncertainty in the supply chain by improving *Inventory Visibility* across the supply chain. Inventory Visibility is more than providing information about where and how much inventory is in the supply chain on a real-time basis (product visibility). It also includes providing information about the products itself, shipments, orders, order fulfillment, notifications of failures and potential delays (Coyle, Bardi and Langley 2003).

The performance of the inventory management techniques is dependent on the quality of the information that is shared. (Sahin, Dallery and Gershwin 2002) stated that a research performed in 2001 at stores of a large retail chain showed that 65 % of the inventory records

had data inaccuracy. They identified that the data inaccuracy in the warehouses and stores with the use of barcodes was caused by 'item identification/counting and keypunching errors during daily operations or during inventory counting processes; misplaced or misdirected items; broken/damaged/perished items; inappropriate management of returned goods; pilferage and time lags between the flow of material and information. By improving the quality of the information shared the performance of inventory management will increase. The quality of information is defined by the degree to which the information represents the reality with real time information being the ambition.

2.2.3 Bullwhip Effect

As shown in the previous sections the availability of information across the supply chain is key within SCM. But at the moment still most of the supply chains fail to get the right information at the right time at the right place.

One of the effects that occurs due to dissimilarity of information across the supply chain is the Bullwhip Effect. The Bullwhip effect is an amplification of the demand order variability as it moves up the supply chain (Lee, Padmanabhan and Whan 1997) (Jespersen and Skjott-Larsen 2005). A company makes a production forecast based on the order history of its direct customer which leads to the following example: The manufacturer makes a forecast based on the order of the wholesaler which in turn makes a forecast based on the order of the retailer
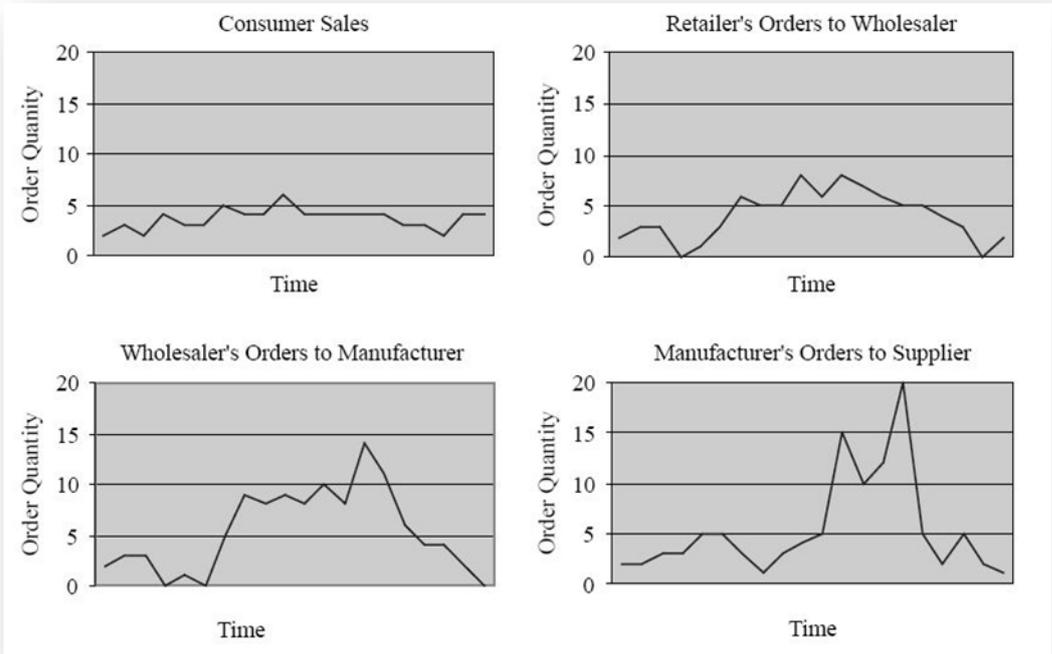
Figure 6: The Bullwhip Effect (Paik and Bagchi 2007)

which makes a forecast on customer demand, making the forecast of the manufacturer a forecast of a forecast of a forecast. With every step added to the supply chain the forecasts become more dissimilar from actual demand. This can eventually lead to excessive inventory, poor customer service, lost revenues, misguided capacity planning, ineffective transportation,

and missed production schedules, in short an inefficient supply chain (Lee, Padmanabhan and Whan 1997).

Supply chain participants can prevent the bullwhip effect in their supply chain by sharing usefull information across the supply chain and make products visible in the supply chain, thus enabling high-quality Supply Chain Management.

The conclusion that can be drawn from this section 2.2 is that without the right information at the right place at the right moment, the right decisions, effecting supply chain performance, cannot be made.

2.3 Product Visibility & Information Sharing

The previous section stated that without the right information at the right time at the right place the supply chain can not be effectively managed. In practice this means that products must be visible throughout the SC and that useful information needs to be shared between supply chain actors. Hence, in a Supply Chain context an efficient flow of information requires two key enablers: Product Visibility and Information Sharing. These two enablers are discussed in the first two sections. If the right information is at the right time at the right moment several benefits can materialize which are demonstrated in the third part.

2.3.1 Product Visibility

Product visibility is to know which product is where at what time. This is done by registering a product when it passes a certain point. By registering the products at several points an overview is created where products are. This information, in combination with a company's perspective of customer demand, forecasting and planning, is used to manage the company in the areas of *Production, Inventory, Transportation,* and *Location*, see § 2.2.1. However the product visibility information, and more important the history of this data, is also used to improve a company's forecasts and planning that are used in decision making.

There are different ways to register the products at a certain point and over time these methods have evolved. First the information was recorded on paper. With the advance of the computer, the information was stored on computers. Advances in Information Technology enabled more efficient ways to register products, such as barcode and RFID.

Once the information was stored electronically, the evolution of information systems started. Starting with a small tracking log of inventory to company wide Enterprise Resource Planning (ERP) systems, companies nowadays have several different information systems (Sridharan, Caines and Patterson 2005). These systems enable thorough analysis of recorded data and facilitate the development of even more sophisticated forecasting, planning and decision models.

However, all these sophisticated information systems and models are for a big part dependent on one simple thing, the registration of a product at a certain point. If this is not correct, it will decrease the quality of information systems and models. Product Visibility is the

accumulation of registration of all products. Thus, Product Visibility should be of good quality to have high quality information and forecasts.

The quality of Product Visibility is defined by the degree it represents reality. I.e. product registration is accurate, when that specific item is indeed at that specific place at that specific time. Hence, the quality of Product Visibility can be broken down by the accuracy of the Item, Place, and Time.

- The quality of Item depends on the unique identification of the product.
- The quality of Place depends on the registration of correct location of the product
- The quality of Time depends on how close the time of registration is to 'Real Time'.

2.3.2 Information Sharing

Even optimal Product Visibility, does not guarantee that information is available at the right place, at the right time in a larger Supply Chain context. Product Visibility as describe in the previous section is only available to the party that does the registration. As products flow through a Supply Chain and are transformed from raw materials, to intermediates to final product information must travel with them
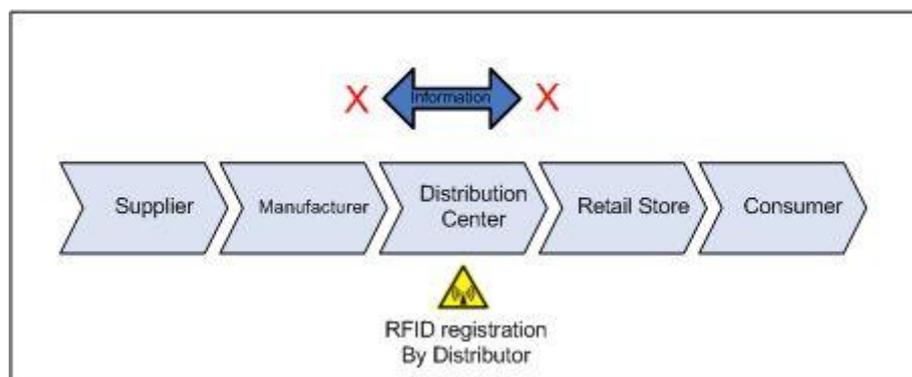
Figure 7: Product Visibility without Information Sharing

In the example of the Lineair Supply Chain a product registered by a distributor does not provide any information to the supplier, manufacurer, or retailer, if the distributor does not share that information with its Supply Chain partners. This information sharing is critical for a Supply Chain to function effectively.

The concept of information sharing is not limited to product visibility information alone. Other information such as stock levels, customer demand information, etc. ,must flow through the supply chain to manage it effectively. E.g. if the Retail Store sees new trends in customer demands which will create product shifts and communicates that through the supply chain the suppliers and manufacturers can react, if not they will continue to produce the "old" product mix untill actual orders from the distribution center change. By now, inventories of unwanted products have built up in the supply chain, leading to high levels of working capital and high levels of discarded products.

In short, information is essential for a company to satisfy customer demand. Companies cannot "register" all this information themselves. Therefore the spread product visibility and other information across the supply chain, information must be dispersed to the other supply chain participants.

2.3.3. Benefits by Product Visibility and Information Sharing

When the right information is known at the right time at the right place several SCM benefits, identified by (Jespersen and Skjott-Larsen 2005), can be realized.

If information about product visibility and information sharing are high in a supply chain than *products can be delivered more precise and quicker*, resulting in shorter lead times. With shorter lead times less safety inventory is needed, in case of perishable products this means less risk on decay.

The shorter lead times in combination with the sharing of demand forecasts and transparency of inventory levels in all stages of the supply chain, can lead to *fewer back orders or sold out situations*. By sharing information throughout the supply chain participants can plan their activities based on real information and are less dependant on forecasts, reducing uncertainty. Hence, they can react better on demand changes, making the supply chain more reliable.

With less inventory and fewer back orders already *total costs are reduced.* Another reduction in costs can be realized by eliminating redundant processes. An example of a redundant process is quality control. Most suppliers perform a quality check on their products before delivery, and receiving customers also do a quality check on the products upon arrival. If the information about the quality check is shared than the second quality check becomes superfluous. This requires a considerable level of trust between the companies, built up through sharing of product visibility and information and an effectively functioning supply chain. The supplier has incentive not to corrupt the quality check information in order not to harm the existing level of trust, which enables cost savings in all areas of the supply chain, lowering the total costs

By sharing customers feed back, or even customer preferences in case of mass customization, the supply chain can *increase flexibility towards the customer' wishes.* The supply chain can produce products tailored to the customer preferences. By offering products more in compliance with the customer's wishes, the total supply chain becomes more competitive.
Benefits are value of cooperation throughout the whole supply chain. It creates stable and strong relations among the supply chain participants.

2.4 Challenges to Product Visibility and Information Sharing

Unfortunately, at most supply chains product visibility and information sharing are not used to their full potential, resulting in effects which suppress the performance of the supply chain, such as the bullwhip effect. In this section, first, the challenges to product visibility are discussed and in the second part the challenges to information sharing.

2.4.1 Challenges to Product Visibility

Product visibility was defined by three key components, Item (Product Identification), Place (Location) and time. The challenges to product visibility are arranged according to these three key components: Product Identification (Item), Location Registration (Place), and Real Time (Time)

Product Identification

A challenge to product identification is to make a distinction between two different items of the same product group. Today's common used identification techniques use product level differentiation, i.e. solely based on bar code there is no difference between two milk cartons of the same type. But what if one of the two milk cartons is past the due date, how is that one identified based on product level identification? There is a need to identify products uniquely, on item level.

Another challenge to product identification is to cover every item that passes a registration point. Most registrations, even bar code, are still done by hand. This makes the process vulnerable for errors, such as misalignment of products to be read resulting in a bad registration, or even items that are forgotten to be read, e.g. the product was packed in a box with other products and forgotten to be taken out while the box moved passed the read point..

Location Registration

Even within one company there are a lot of places were a product could be located. Because of the costs and effort involved, registration moments are kept to a minimum. With little registration moments it becomes hard to exactly pinpoint the location of product. E.g. if a company only has registration moments upon receiving and sending, one can tell the product is at the company, but not it which storage facility.

Real Time

Another challenge to product visibility is to keep information up to date to reality. Time lags exist between material flows and the information flow. E.g. Information from common hand held barcode scanners is uploaded to the central information system after it is placed back in its cradle. So if an employee uses the hand held barcode scanner all day, only at the end of the day the information is updated and can be already out of date.

2.4.2 Barriers to Information sharing

As with product visibility, there are also several barriers that prevent sufficient information sharing between companies to realize the benefits of SCM (Fawcett, et al. 2007) (Sridharan, Caines and Patterson 2005):

- Cost and complexity of implementing advanced ICT systems
- Systems incompatibility
- Different levels of connectivity exist up and down the chain
- Managers do not understand the willingness dimension of information sharing

Cost & Complexity of implementing advanced ICT Systems
Implementing "enterprise" systems is considered by most companies as a difficult and painful route, with time and costs often exceed by 50 to 100 percent (Fawcett, et al. 2007). The costs and complexity of extending their systems discourage companies to implement advanced ICT systems that enable information sharing across the supply chain.

System incompatibility
Companies have often not one but several ICT systems, -Enterprise Resource Planning systems, Warehouse Management Systems, Advanced Planning and Scheduling systems. Integrating these systems within a company already offers many challenges (Sridharan, Caines and Patterson 2005), integrating all systems across a supply chain is even more complicated, time consuming and most of all costly. Smaller companies in the supply chain lack the resources to invest in multiple connectivity systems (Fawcett, et al. 2007).

Different Level of Connectivity
Another barrier for information sharing is different levels of connectivity across the supply chain. A company is less willing to share and invest in sharing capabilities, if it receives orders electronically, but has to send its orders to its suppliers by fax or telephone. Companies will wait until the key players across supply chains are able to share or willing to invest in sharing capabilities (Fawcett, et al. 2007)

Unwillingness to Share Information
In present business culture, it's not accustomed to share information, as information is considered by most companies as power, providing a competitive edge, and is therefore controlled carefully (Fawcett, et al. 2007) (Coyle, Bardi and Langley 2003). To enable information sharing across the supply chain, first of all the business culture has to change to a more pro sharing information attitude, starting with the managers willing to invest in a conductive to information sharing (Fawcett, et al. 2007).

2.5 Conclusions

To improve the performance of the supply chain, information of sufficient quality needs to flow freely through the supply chain and be available at the right place at the right time. In practice this means that products must be visible throughout the SC and that useful information needs to be shared between supply chain actors. Conversely, if information is lacking or misaligned negative effects, like the Bullwhip effect, can diminish the performance of the supply chain.

Creating product visibility has several barriers, such as product identification, accurately pinpointing products and keeping information up to date.

Information sharing has both technical (systems incompatibility, different levels of connectivity) and cultural challenges (companies' unwillingness to share information) that need to be addressed.

In the following chapter the RFID technique is assessed to determine to what extent the RFID technology can address these challenges.

Chapter 3 Radio Frequency Identification

In this chapter the RFID technology is introduced to explore its potential for facilitating the flow of information throughout the Supply Chain and thereby improving supply chain Performance. First the concept of RFID is introduced §3.1, followed by a more in depth description of the RFID technology in §3.2. In the third paragraph, the benefits that RFID can bring towards the flow of information in the supply chain are evaluated.

3.1 RFID in the Supply Chain

3.1.1 RFID in the supply chain

With RFID it becomes possible to make uniquely identified products visible in the supply chain. If a product equipped with an RFID tag passes an RFID reader, the RFID reader registers the tag's unique ID. The combination of a unique ID and its location and time makes the product visible in the supply chain. Readers placed tactically can provide visibility of products across the supply chain. These read events can be used by the information systems to automate several processes, such as inventory management, sending and receiving, and billing.

Figure 8 illustrates an RFID application that is used by multiple supply chain partners.
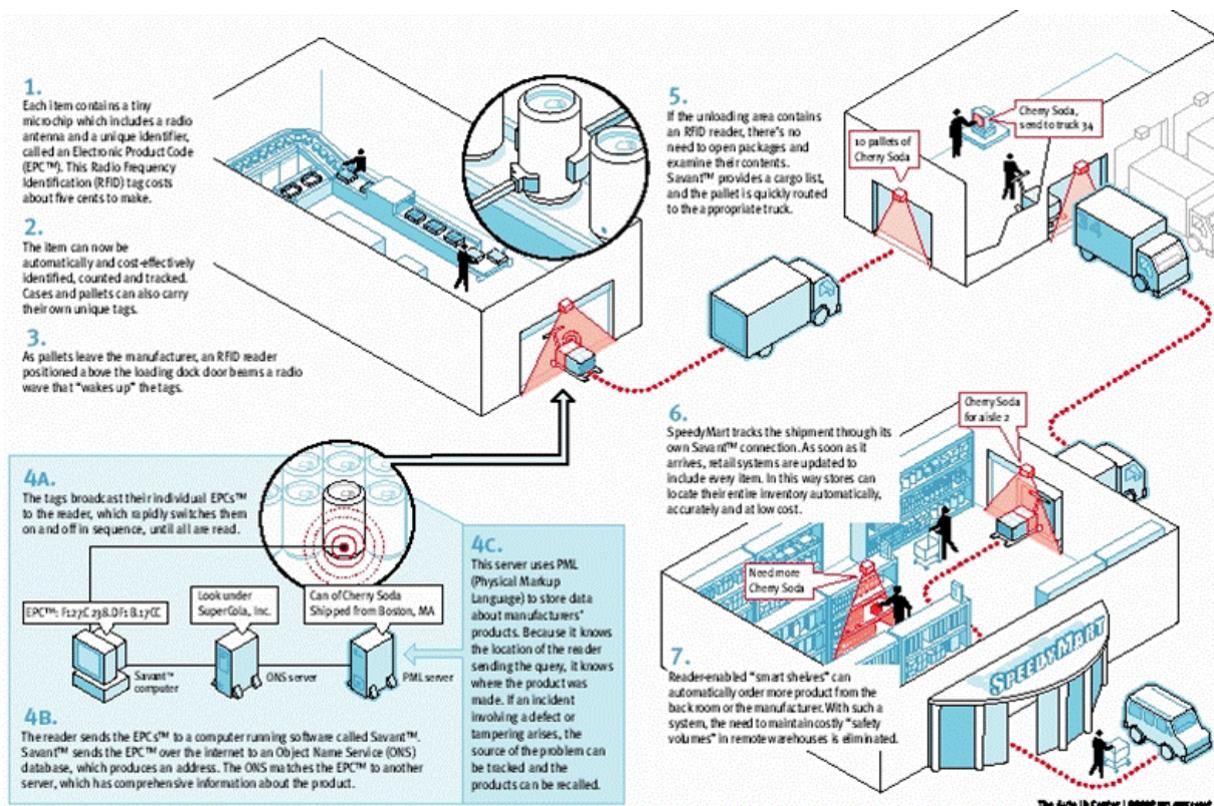
Figure 8: RFID in the SC (Global Commerce Initiative/IBM 2003)

3.1.2 Benefits of the RFID Technology

The characteristics of the RFID technology, such as the use of radio waves and tags with a chip, provide RFID with certain qualities that can be valuable for SCM. These qualities are: *unique product code, no line of sight necessary, bulk reading, more robustness*, and *greater read distance in comparison with other technologies.*

This are the main benefits of RFID compared to other techniques like barcode within the scope of this thesis. Yet RFID can provide more benefits, e.g. programmable tags have the advantage that the information can be changed or the tags can even be programmed to execute small actions such as calculations, record sensor readings, and logical operations (Brown 2007). However, these are beyond the scope of this research.

Unique product code

One of the foremost advantages of RFID is the unique product code. The chip, present on a RFID tag, provided the tag with extended data storage capacity. Because of this extended data storage capacity, it is possible to provide every tag with its own unique identification code. At the moment the RFID tag with a 96-bit data storage capacity is the most used (Brown 2007) (Glover and Bhatt 2006) providing capacity to identify 268 million manufacturers, with each 16 million different products, and 68 billion different items in each product (Srivastava 2004). Therefore, RFID makes it possible to assign every product with its own unique identification code on item level (See EPC, § 3.2.7).

This unique identification number per item makes it possible to track and trace items on item level providing better visibility throughout the supply chain improving inventory management.

No line of sight necessary

RFID tags can be read by readers through material, if the material is radio frequency lucent for the specific frequency used (Lahiri 2005). This makes it possible to read packed products with out opening them. This reduces the time needed to register the product, leading to improvement in efficiency of processes involving receiving, checking, loading and unloading of the products (Srivastava 2004).

Bulk reading

By using an anti-collision algorithm, it's possible for a RFID reader to read several tags in a short period of time (Lahiri 2005). Readings up to a 1,600 tags per minute in US and due to legislation on power restrains 600 reads per minute in the EU can be accomplished (Glover and Bhatt 2006). Reading multiple products at once, instead of one by one speeds up the total registration time for bulk of the products, also leading to improvement in efficiency with receiving, checking, loading and unloading processes, like *no line of sight necessary.*

More robust

The no-need-for-line-of-sight feature of RFID makes it more robust then other systems. E.g. it doesn't matter if a tag is covered in paint, dirt or a material as long as the material is radio frequency lucent. It even becomes possible to incorporate tags into products, e.g. mould a tag

into a plastic product. Tags can also be designed such that they can survive in hostile environments (Brown 2007).

Greater read distance

RFID makes it possible to read tags for a distance varying from less than 1 cm to over 100 metres for active tags depending on the frequency of the radio waves used. E.g. the read range of EPC UHF Gen 2 tags is up to 10 meters.

3.2 RFID Explained

In this paragraph more in depth knowledge of RFID is acquired. First, the principal of RFID is explained in §3.2.1. An implementation of RFID consists of a RFID system (§3.2.2) with an architecture (§3.2.3). Subsequently, the key components of a RFID system, the tag (§3.2.4), the reader (§3.2.5), and the middleware (§3.2.6) are discussed. Standardization of RFID is addressed in §3.2.7.

If the reader wishes to obtain more technical information on RFID after reading this paragraph, it is recommended to read (Finkenzeller and Waddington 2003), (Shepard 2005), (Glover and Bhatt 2006), and/or (Brown 2007).

3.2.1 The Technology behind RFID

As the term already indicates, **R**adio **F**requency **Id**entification (RFID) is the identification of objects using of the Radio Frequency spectrum, radio waves. In essence the technique works as follows; a reader (interrogator) sends out a signal, radio waves. The antenna of a tag (transponder) picks up the signal. This signal is then used to power a microchip. The data in the microchip is read and broadcasted back. The reader receives the signal and can then inform other systems about the reading. This is the initial concept of RFID, Figure 9.

Figure 9: The Workings RFID Technology (Glover and Bhatt 2006)

3.2.2 RFID System

In the previous paragraph, the basic principle of RFID is explained. Yet, a RFID system is broader then just the air interface between tags and readers. The main goal of a RFID System is to convert raw reading events to useful business data.

The following calculation shows that raw reading events need to be processed before other business systems, like ERP, WMS, and CRM systems can use the data as appropriate business information. (Glover and Bhatt 2006) show with an example in inventories of an electronics

retailer consisting of 10 stores that the numbers of observations per day, thus data, are numerous, in the order of 240.000.000 observations per day as seen in Table 2.

Table 2: Example: Volume of Read Events (Glover and Bhatt 2006)

Location	Average inventory	Location	Number of Observations
1 shelf	25	1 rack per minute	1.000
1 rack (4 shelves)	100	1 store per minute	400.000
1 store (400 racks)	40.000	1 store per day	24.000.000
All 10 stores	**400.000**	All stores per day	**240.000.000**

If these observations are simply passed on to business applications, it's not impossible to imaging that these applications will be overwhelmed. And then are stresses in networks and infrastructures that support these applications not even taking in consideration. To process raw reading events into useful business information that can be used by business applications, an extra layer is introduced called middleware.

3.2.3 RFID Architecture

The example in previous paragraph indicates that a RFID system consists of more then just tags and readers. It includes tags, readers and a middleware layer. These components together will be called the RFID System. Eventually, the RFID System presents useful business information to the Business Applications. A simple schematic illustration of the overall architecture of a RFID system is shown in Figure 10.

The tag layer consists mostly of hardware; if necessary little software could be installed in the chip for security protocols. Via the air interface the tag layer communicates with the reader layer which consists for the greater part of hardware. The reader has to some extent software installed for controlling and managing the reader. After collecting the signal from the tags, the reader passes the signal on to the middleware layer. The middleware processes the signal to meaningful data. The
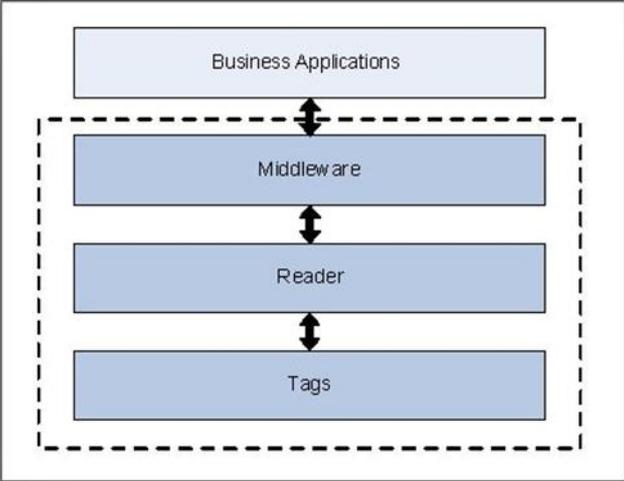
Figure 10: RFID Architecture

ratio of software/hardware depends on the preferences of the middleware manufacturer. Some manufacturers prefer to have a more hardware based solution, like (CISCO 2006) and (REVASystems 2006), while others like to use a more software oriented resolution, examples are VI SixD for Viagents (Viagents 2006) and (Globeranger 2006). More insight in RFID middleware is given in §3.2.6. Eventually, the data produced by the middleware is forwarded to Business Applications via an interface. A Business Application primarily consists of

software and is outside the scope of this thesis, although sometimes Business Application will be referred to while it is connected to the RFID systems.

3.2.4 RFID tags

Tags are a crucial part of an RFID System. The tags contain the unique identification number that is eventually read via Radio Frequency. Coupled to a database, this unique number can provide lots of details about the product. The tags are the bridge between the physical world – atoms- and the information world -bits and bytes-.

Tags can be distinguished in several ways. The general features on which tags can differ are physical characteristics, such as *Size and Shape, Power Source, Air Interface, Information Storage,* and *Processing Capacity* (Finkenzeller and Waddington 2003) (Glover and Bhatt 2006) (Brown 2007). The purpose and environment of a proposed RFID system strongly influence the requirements and performance of a tag. Therefore tag selection shouldn't be taken lightly.

3.2.5 RFID Reader

For the tag and reader to be able to communicate, it is essential that the use the same kind of air interface. The air interface consists of *Operating frequency, Communication Mode, Keying, Encoding* and *Coupling* (Finkenzeller and Waddington 2003) (Glover and Bhatt 2006) (Brown 2007). During the designing phase of a RFID system good attention has to be paid to this vital part, as it is of great influence on the performance of the RFID system.

RFID readers can be divided in two crucial parts, the reader itself and the antennas. The reader controls the communication with the tags according to the specifications of the used air interface. It collects information from the tags in its read range. It then forwards that information, if relevant, to the middleware. In this way the reader is involved in communication with middleware.

The reader sends electrical signals to the antennas which in their turn convert these electrical signals into radio waves and vice versa. Most readers use multiple antennas. An antenna is dedicated to one purpose only; sending or transmitting radio waves. Each frequency has its own optimum requirements for the shape and size of the antenna which in turn has influence on the bandwidth of an antenna and thus of the RFID system (Brown 2007).

3.2.6 RFID Middleware

As the mathematical example of Table 2, shows, the data created by read events and performed by the readers can be significant. The middleware layer is introduced to extract meaningful business information from the stream of raw reading events. A standard definition for RFID Middleware is not yet agreed upon. Many suppliers of RFID middleware have their own different vision on middleware. E.g. as said, some belief in a solely software solution, like GlobeRanger (Globeranger 2006), while others tend to belief in a more hardware approach, such as REVA systems (REVASystems 2006). However, despite the several visions on middleware, there are seven functionalities that RFID Middleware should provided (Leaver 2004). Through these functionalities a general impression is given of what the requirements to RFID middleware are.

Table 3: Seven RFID middleware functionalities (Leaver 2004)

Reader and Device Management	RFID Middleware should allow users to configure, monitor, deploy, and issue commands through common interfaces to readers, but not only to reader but also other devices such as typical I/O devices
Data Management	After collecting data from the readers, the middleware should be able to filter and route the data to the appropriate destinations. This should minimal include low level filtering of duplicates, but also can be filtering based on more complex algorithms. More comprehensive RFID Middleware could have tools to aggregate and manage data in a federated or central data source
Application Integration	For integration with application the Middleware should support messaging, routing, and other connectivity features to existing applications of SCM, ERP, WMS or CRM systems. Also adapters to common standards like JMS, XML and SOAP should be provided
Partner Integration	Expected from RFID is that it will provided significant surplus value by improving collaborative processes like forecasting and inventory management. This can be done by sharing information with RFID partners. B2B partner integration is crucial for RFID
Process Management and Application Development	More sophisticated RFID middleware will do more than just route the data to applications. It will manage RFID end-to-end processes that involve multiple applications; this enables more efficient automated systems, like inventory replenishment
Packaged RFID Content	RFID middleware platforms that include packaged routing logic, product data schemas, and integration with typical RFID-related applications and processes like shipping , receiving, and asset tracking
Architecture Scalability and Administration	Read events will produce a lot of data. RFID middleware is the first line of defence for reliable processing that data. RFID middleware should balance processing loads and reroute data upon server failure

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These seven functionalities were drawn in 2004. After some years of experience with RFID systems and RFID Middleware, three more functionalities can be added (Brown 2007).

Table 4: Three extra RFID middleware Functionalities (Brown 2007)

Visibility and Reporting	One of the main motives for RFID is the enabling of the real time business. For management to act quickly to changing events information needs to be presented in a swift and actionable way. As stated above in *Process management and application development* RFID middleware has the total overview and access to the information and applications, and is therefore the most suitable instance to make a swift and actionable report. It is also the responsibility of the middleware to monitor the performance of the systems. RFID middleware is like a giant spider in the RFID web
Track and Trace Applications	In *Packaged RFID content* already a hint to track and trace applications is made, but only as historic data to an item, if one receives an item one could track its history. This track and trace application implies the track and trace ability throughout the supply chain. Where is the item at this moment, where has it been, and where should it be? This is an essential feature of RFID
Graphic creation	*Graphic creation* follows from *Visibility and Reporting*. For a manager to make quick and right decisions, the management data produced by RFID Middleware should be presented in a comprehensible clarifying way, in the form of graphics and messages

A distinction can be made between the different functionalities, functionality is more technical or business orientated. By technical orientated the functionality is intended to process the data stream in order for the rest of the RFID system to understand and be able to further process the data, like *data management* and *Architecture Scalability and administration*. The functionalities that are more business orientated give meaning to the data, like *Packaged RFID content* and *Visibility and Reporting*.

3.2.7 Standardization

EPCGlobal is an organization that wants to develop open, voluntary global standards to provide companies with complete visibility in their standards-based, integrated supply chains at any time in any country in the world (Global Commerce Initiative/IBM 2003). EPCglobal has developed amongst others a standard for the unique identification code for items and a standard for information sharing. Both standards are discussed below.

Electronic Product Code (EPC)

The EPC provides a product with an unique identification code on item level, while other (barcode) identification codes only differentiate on product level (Brown 2007) E.g. with EPC a milk carton has its own unique number, while with the other codes every milk carton

has the same number. The EPC makes it possible to track and trace every product individually.

EPC is able to coop with existing coding schemes already used, like barcode standards such as Global Trade Item Number (GTIN), Global Location Number (GLN), Global Returnable Asset Identifier (GRAI), Global Individual Asset Identifier (GIAI), Global Service Relation Number (GSRN), Serial Shipping Container Code (SSCC) (Brown 2007) (Thiesse, et al. 2009). The ability of EPC to use existing code schemes makes RFID suitable to replace barcode.

Only minimum information, the ECPS code, is stored on the tag. More information about the product is retrieved from the EPC Information System (EPCIS).

EPC IS

The EPC Information System (EPCIS) provides a standard interface for information sharing between different partners (Thiesse, et al. 2009) (KPN; Capgemini; Schuitema 2007). EPCIS stores information about products in the supply chain providing a repository of historical data and related information (Brown 2007) (Thiesse, et al. 2009). EPC makes use of Physical Markup Language (PML), standardizing the way data is stored and can be read by different kinds of systems (Brown 2007).

3.3 Optimizing the flow of information in the SC through RFID

RFID's ability to track products as they move through production facilities, warehouses, etc, makes it an interesting technique for improving information flows within the SC. Chapter 2 concluded with the key challenges to creating product visibility and facilitating information sharing. In this section, the extent to which RFID addresses these challenges is evaluated.

3.3.1 Improving Product Visibility

The challenges to product visibility are addressed according to the three key components, Product Identification, Location and Real Time.

Product Identification

The challenges posed to product identification are the unique identification of a product and to register every item that passes the registration point.

One of the foremost features of RFID is the ability to identify products on item level. This ability is made possible by the data capacity on the tag that is used to identify the product. RFID can overcome the challenge of unique product identification.

The RFID features of no line of sight to register tags, bulk reading and a greater read distance attend to the challenge of covering every item that passes a registration point. These features

decrease the change of products slipping past the registration point without being read. E.g. if a closed box carrying several RFID fitted products passes a registration point all products get registered, because there is no need to have line of sight and the ability of multiple reads. The greater read distance increases the area were products can get registered.

Location Registration

RFID drastically reduces labour costs and effort to register products at a registration point, because of bulk reading, no line of sight and a greater read distance. Therefore installing more registration points is worthwhile. If more registration points are present then the ability to better pinpoint the location of a product increases.

Real Time

For registration with RFID no human intervention is needed, because there is no line of sight needed, multiple tags can be read and RFID has a great read distance. Products moving past a registration point, a RFID reader, are automatically read. Assuming the reader is always operational; all products passing the reader are registered instantaneously. If the reader is connected to the company's information system, the company's information system is directly provided with the registration information. Thus, RFID can enable 'real time' registration information.

Besides the RFID features discussed above two middleware features, *Reader and Device Management* and *Data Management* support Product Visibility. Reader and Device Management sees to the proper working of the RFID readers which do the registration. Data Management eventually makes the registration of an item known with the companies information systems, i.e. Data management makes the registration 'visible' for the company.

3.3.2 Facilitating Information Sharing

An individual company implementation of RFID will not significantly improve some of the challenges to information sharing. However, when RFID is rolled out across the SC, it can address some of those challenges, as discussed below:

Cost and complexity of implementing advanced ICT systems

It is not said that an implementation of a RFID system is not costly and complex. But when a RFID system is rolled out across the whole supply chain, the implementation is done in cooperation with supply chain partners, therefore a company can share the investments costs and experience in unrolling a RFID system.

For smaller companies in the supply chain that do not have advanced ' information systems to provide insight into company processes, the RFID system can be used as a 'light' version of such information systems. Features provided by RFID middleware such as *Tracking and Tracing, Visibility & Reporting, Graphic Creation, Process Management and Application Development*, and *Packaged RFID Content* make this possible.

Systems Incompatibility

RFID can play a role in the integration of ICT systems for a company, internally and externally. RFID middleware provides features, such as Application Integration and Partner Integration (Table 3) that enable integration with different kinds of applications. This facilitates middleware to have interfaces to the other systems present; a system only needs an interface to the RFID system. This principle is based on the bus system in network topology (Stallings and van Slyke 1998), see Figure 11. The integration does not stop at the boundaries of a company. Providing the RFID system is rolled out to all the supply chain participants the information available in the RFID system can be made available to all supply chain participants, contributing to information sharing across the supply chain. EPCglobal made an effort to make a standard interface for companies to share information with the development of EPC IS.
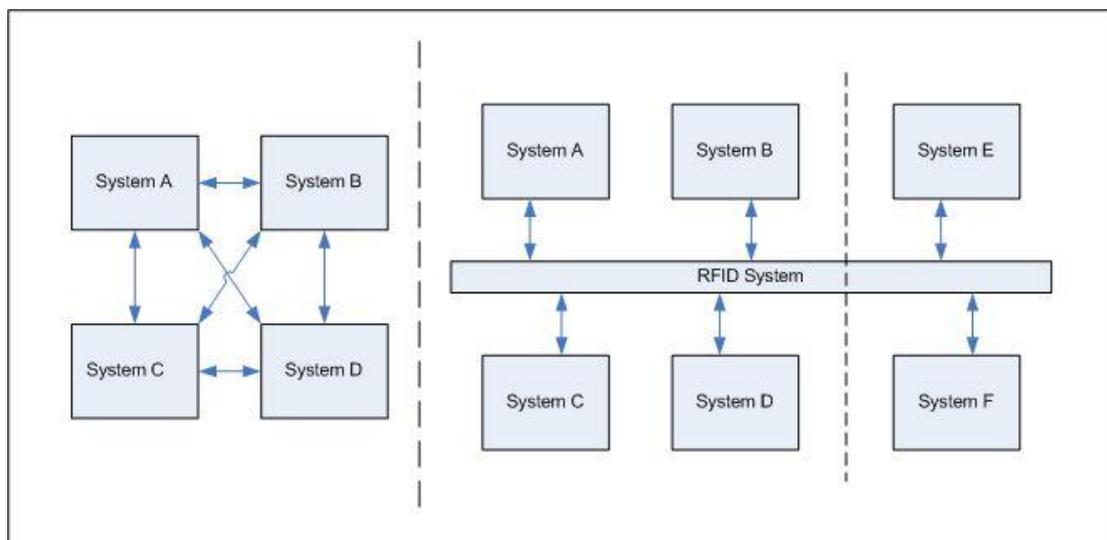
Figure 11: Technical interface

Different levels of connectivity exist up and down the supply chain

Assuming the RFID system is rolled out to all of the supply chain participants everyone uses the same level of connectivity. The middleware features, *Process management & application development* and *Packaged RFID Content* help to orchestrate and optimize the level of connectivity across the supply chain.

Companies' unwillingness to share information

Companies do not want to share information, because they see information as competitive advantage. In order to create willingness by companies to share information, the managers need to be convinced with the benefits of information sharing in order for them to invest in culture change towards information sharing by companies(Fawcett, et al. 2007). However, only RFID technique and an RFID system cannot convince managers to share information. The manager needs to be trained and made accustomed to the potential benefits of using the RFID system and sharing of information. In the middleware features Visibility & Reporting and Graphic Creation are hints that can support in the education of managers to turn information sharing in their advantage. These hints are access to 'Real Time' supply chain information and a graphical reportage of this information.

3.4 Conclusion

Can RFID resolve issues around visibility and information sharing and thereby improve the, for supply chain performance so vital, availability of information? The inherent qualities of RFID enable the improvement of Product Visibility. However, the barriers to information sharing are only partially overcome. When rolled out across the supply chain, a RFID system provides solutions to *system incompatibility* and the *different levels of connectivity*. Yet, *the cost and the complexity of implementation advanced ICT systems* are only partially resolved, the cost and complexity are shared among the supply chain participants, but still remain. *The willingness of companies to share information* is not resolved by implementing a RFID system. Managers need to be shown and educated in the potential yield of information sharing in order for them to start changes in business cultures towards information sharing.

Thus can a supply chain wide RFID implementation resolve the barriers of the availability of information? In part it can; it creates product visibility and is able to provide efficient technical interfaces for sharing information. But to convince companies to willingly share information across the supply chain, something more has to be done other than simply roll out a RFID system.

Chapter 4 Design of an RFID Information System

Chapter 3 concluded that to create product visibility and an effective flow of information through the Supply Chain a plain implementation of RFID is not enough. In this chapter a design of an extended RFID implementation is developed that addresses all the challenges to product visibility and effective flow of information through the Supply Chain. In § 4.1, the requirements to the design are determined and in § 4,2 a design of the extended RFID implementation is developed, based on those requirements.

4.1 Requirements Design of an RFID IS

In Chapter 3, the extent to which RFID addresses the challenges to the flow of information and product visibility were addressed. As highlighted below, RFID addresses some but not all of those challenges:

Table 5: RFID and Challenges SCM

	RFID	Supply Chain Wide RFID	Conceptual Design Objectives
Improving Product Visibility			
Product identification	●	●	●
Location Registration	●	●	●
Real time	●	●	●
Facilitating Information Sharing			
Cost and complexity of implementing advanced ICT systems	○	◐	●
Systems incompatibility	○	●	●
Different levels of connectivity exist up and down the chain	○	●	●
Managers do not understand the willingness dimension of information sharing	○	○	●

● *Challenge overcome*   ◐ *Challenge partly overcome*   ○ *Challenge not addressed*

As shown, the objective for the design is to develop a comprehensive framework of how to deliver all the benefits of Supply Chain wide RFID, but also how to address the challenges that Supply Chain Wide RFID does not inherently address.

From this, four key requirements for the RFID IS that provides Supply Chain Wide RFID implementation have been defined:

- *Improve Product Visibility*
- *Create efficient technical interfaces for sharing information*
- *Deliver a trusted platform for supply chain actors to share their information*
- *Foster understanding by Managers for the need for information sharing*

The four key requirements are elaborated below. All these challenges will need to be delivered with the cost dimension in mind, to also address the challenge: cost and complexity of implementing advanced ICT systems.

4.1.1 Improve Product Visibility

As shown in §2.3.1, it can be said that product visibility is the foundation of the operational management within companies. Based upon this information, in combination with different kinds of planning and forecast, operational decisions are made. This forecast and planning are also derived, via sophisticated tools, from (historic) product visibility.

Thus improved product visibility improves better decision making in two ways; first directly and secondly indirectly through improved forecasts and planning. As defined in §2.3.1, the quality of product visibility is determined by the degree it represents reality, making 'real time' product visibility the highest quality and a requirement for an RFID IS.

4.1.2 Creating efficient Technical Interfaces

In order for information to flow free across the supply chain there is a need for a technical architecture to make that possible. Two types of information flows are identified. First, there is an information flow from one information system to another within companies. The second type of information flow is between companies. The problem with information sharing between systems is system incompatibility. The different systems use different ways of presenting information making exchange of that information difficult. The flow of information between companies is troubled, besides systems incompatibility, by the different level of connectivity between companies. E.g. a company uses email to communicate its order to suppliers while the company's customer uses the phone to place orders. This difference in connectivity level creates inefficiencies. In addition, in the example there is still manual labour, email and telephone, involved to exchange data from one company to the other making the information flow vulnerable for human errors, such as typos.

In order to create efficient technical interfaces the RFID IS must address system incompatibility and the different levels of connectivity. Thus, the design needs to create one technical standard that enables automatic information sharing between systems and between companies.

4.1.3 Deliver a trusted platform for Information Sharing

To enable information flow across the supply chain, the RFID IS should not only enable information sharing in a technical sense but needs to "convince" companies to share information as well. No manager will share information without being convinced that it is "safe", because the company's information can be used by suppliers, customers and competitors as competitive advantage. Before companies are willing to share business sensitive information across the supply chain, they need the trust this information will not be misused.

Therefore, the RFID IS should provide the ability to share information in such a way that decisions in line with the supply chain can be made, but suppliers and customers do not get

competitive advantages over each other. The RFID IS should not only provide a "technical" trusted platform, but also facilitate and enhance the perception of trustworthiness.

4.1.4 Foster understanding by Managers for the need of information sharing

Even if there is a trusted platform in place, companies will not automatically start sharing information. This is partly because the company may not be accustomed to it, i.e. information sharing is not part of the business culture, and in part because they do not see the benefits of information sharing. For a business culture to change towards information sharing, a manager needs to proactively invest in changes of the business culture towards information sharing (Fawcett, et al. 2007).

Thus, in order to get managers to invest in a business culture of information sharing across the supply chain, the RFID IS needs to convince company managers that sharing information provides the company with overall supply chain benefits. To ensure that managers become convinced of the benefits of information sharing, the RFID IS must make these benefits transparent.

4.2 The Design

In this paragraph the design of an RFID IS is worked out. The goal of RFID IS is to provide an information system that is shared by supply chain partners to improve supply chain management by improving product visibility (§4.2.1), creating efficient technical interfaces (§4.2.2), providing a trusted information sharing platform (§4.2.3) and fostering understanding for the need to share information (§4.2.4).

4.2.1 Improve Product Visibility

'Real time' product visibility is the highest quality of information available. To ensure optimum decision making in the Supply Chain the objective for the RFID IS is to provide that.

Real time Registration and Processing

As shown in Table 5 product visibility was already improved by RFID itself, §3.3.1. Product Identification and Time are improved by the features -unique identification, no line of sight, and greater read distance- provided by RFID.

Location Registration is improved because RFID enables cost efficient installation of multiple registration points (compared to other registration techniques, e.g. barcode).

Real time Registration and Processing can include direct feedback to an operator that monitors the registration process, if applicable. E.g. in case an order needs an operator's clearance to be send, the operator must have feedback of the registration directly before he can approve the order.

The middleware feature *Reader & Device Management* manages the readers and *Data Management* sees to *it that* the registration becomes known by the company's information system; both these factors contribute to Product Visibility.

- *Reader and Device Management* configures, monitors, deploys, and issues commands to the readers
- *Data Management* filters and routes data to the appropriate destinations

Real time registration and processing is a key element, but to what extent a real time flow of information is realized depends on how fast a product registration is shared with /known by other supply chain participants. To ensure a rapid flow of information the other requirements to the RFID IS must be addressed as well.

4.2.2 Creating efficient Technical Interfaces

To overcome system incompatibility and achieve the same level of connectivity across the supply chain, the RFID IS should provide one technical standard that enables automatic information sharing between systems and between companies.

One technical standard for information exchange

To be able to share information across systems and automate processes across supply chain information systems must be capable of communicating with each other. Technical interfaces enable different information systems to exchange information. RFID middleware is capable to offer such technical interfaces through the features *Application Integration, Partner Integration, Process Management and Application Development,* and *Packaged RFID Content.* These features enable different applications from different supply chain partners to exchange information.

> - *Application integration* provides interfaces to existing applications based on JMS, XML and SOAP.
> - *Partner Integration* provides B2B integration, e.g. it provides B2B transport protocols.
> - *Process Management and Application Development* orchestrates end-to-end processes enabling automated processes such as inventory replenishment
> - *Packaged RFID Contents* provides standard platforms for routing and integration of typical RFID related processes.

Data flow is expected to expand with the number of supply chain partners and applications connected to the supply chain wide RFID system. *Architecture, Scalability and Administration* of the middleware balances processing loads and reroutes data upon server failure to cope with the increase of data volumes.

These features enable the RFID middleware to have interfaces to the other systems present. A system only needs to interface with the RFID middleware, as shown in Figure 11 (p. 34), to be able to exchange information with all other systems. The integration does not stop at the boundaries of a company, provided that the RFID system is rolled out to all the supply chain participant's information exchange is made available across the supply chain, contributing to information sharing across the supply chain.

EPCglobal has made an effort to make one standard interface for companies to share RFID information with the development of EPC IS. The design leverages EPC IS to ensure one common standard for information exchange between the Supply Chain partners

4.2.3 Deliver a trusted platform for Information Sharing

The information sharing platform should provide the supply chain participants with a feeling of trust in order for them to share their delicate business information. Crucial for supply chain participants to share information is that their information is not misused or used by parties that should not have accesses to that information. To provide the supply chain partners with control over who sees their information improves the trust in the information sharing platform. This can be achieved through *a role based management system*.

Sophisticated role based management system (not everybody can see everything)

Supply chain partners do not want certain delicate business information to be known with certain supply chain partners, e.g. if a company uses a returnable transport item to transport their product, there is no need for a company to share information of the product with their provider of returnable transport item, only information about the returnable transport item, such as location.

With a role based management system supply chain participants can define to what detail level information is shared with a certain supply chain partner. It becomes possible for supply chain participants to indicate which information is accessible by which party and to which level of detail (Thiesse, et al. 2009). This creates a sense of control over their own data, improving the trust in the information sharing platform of the supply chain. In the design, EPCIS provides this functionality. With EPCIS, supply chain participants are able to share their data with those they choose and determine the detail level of that information (Thiesse, et al. 2009).

However, even with a role based management system in place, the owner/manager of the middleware has access to the information shared. If the manager is a supply chain participant this can be an obstacle for other supply chain participants to share information, still the information is accessible by a member of the supply chain. By introducing *a trusted third party* who does not participate in the supply chain to manage the middleware, and thus the information sharing platform, trust in the platform is improved.

Trusted platform for information Sharing offered by a Trusted Third Party

To improve trust in the platform of information sharing the management is given into the hands of a trusted third party. Since the trusted third party is no beneficiary to the supply chain, the information shared on the platform is of no interest to the trusted third party. To know for supply chain participants that their information is managed by a trusted third party that has no interest for that information improves trust and the willingness to share information. Figure 12 illustrates the information sharing platform managed by a trusted third party. Information still flows across the supply chain (virtual information flow), but via the trusted party (Actual information Flow).

By outsourcing the management of the information sharing platform to a trusted third party, additional advantages arise. On the assumption that data exchange and management is the core business of the trusted third party. In that case, the trusted third party will have the infrastructure and experience to leverage economies of scale when implementing trusted platform. This will reduce complexity and costs for the supply chain partners during implementation, one of the challenges to information sharing §2.4.2.
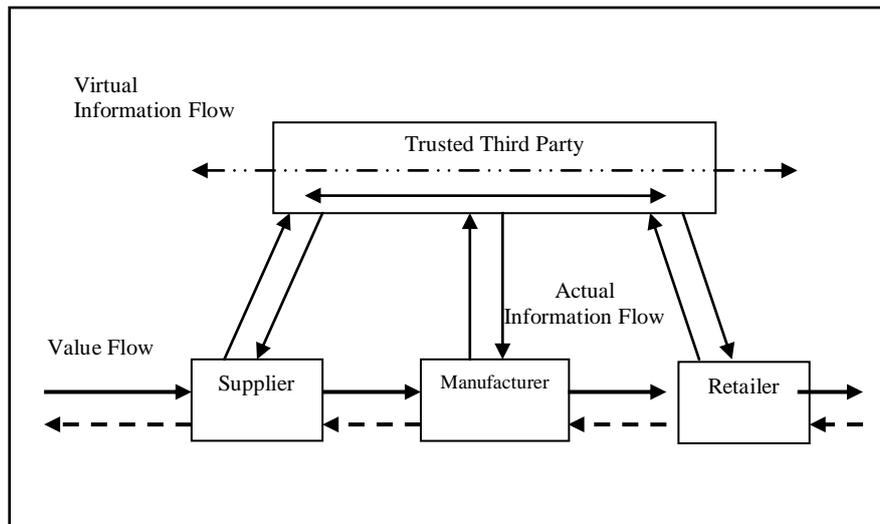
Figure 12: Platform for information Sharing provided by trusted third party

A telecommunications provider as trusted third party

Within this design of an RFID IS, a telecommunications provider is proposed as a trusted third party to implement the trusted platform for information sharing. It is a telecommunications provider's core business to deal with business sensitive information, ranging from payment traffic and business traffic to private phone calls. In a sense a telecommunications provider is already entrusted with the data exchange of business sensitive information. They have secured their trusted position and probably have a track record with all supply chain participants. Therefore most supply chain participants will not likely object to a telecommunications provider as trusted third party. Besides the trusted status and the experience with data exchange and management, a telecommunications provider has the infrastructure for data exchange and management.

4.2.4 Foster understanding by Managers for the need for information sharing

To convince company managers to share information across the supply chain the benefits in doing so have to be made transparent. The RFID IS makes the overall supply chain benefits visible by providing *a management dashboard*

Management Dashboard, with value chain/supply chain KPI's

This management dash board provides managers with an overview of information across the supply chain in order to take right decisions, with a balanced view of what is right for the company and for the supply chain. The management dashboard provides an overview of important Key Performance Indicators (KPI) across the supply chain, such as lead times, inventories, best before dates (if relevant). Other features that can be added to the management dashboard are tracking and tracing, (error) notification, device management (integrity). The middleware features that enable the development of such a management dashboard are: *Visibility and Reporting, Track and Trace Applications* and *Graphical creation*

- *Visibility and Reporting* provides the possibility to present information on changing events
- *Track and Trace Applications* provides the ability to track and trace an item's history or its present location
- *Graphical creation* enables reporting in a graphical manner

Figure 13 provides a graphical example of a management dashboard:

Figure 13: Example of Management Dashboard

The management dashboard provides the supply chain participants with Key Performance Indicators. Via the KPIs the performance of the supply chain and certain parts of the supply chain can be measured. This enables the agreement on performance of certain parts of the supply chain by supply chain partners. Agreements on performances are drawn up in so called *Service Level Agreements (SLA)*. A company benefits of an SLA framework because agreements are made on minimal levels of provided services, making information sharing worthwhile.

Improved Service Level Agreements between Supply Chain Partners
SLAs can be more specific in an RFID enabled supply chain. Improved monitoring allows stricter agreements with bonuses and penalties more in line with value creation. Performance

can be measured of the whole, or parts of the supply chain. The performance of not only direct suppliers and customers becomes visible but also from indirect suppliers and customers. Hence, service level agreements can be made, not only with direct suppliers and customers, but also with indirect supply chain partners or to parts of the supply chain. In this way an SLA framework emerges that covers the whole supply chain, guaranteeing at least a minimal of service quality.

4.3 Conclusion

From the previous chapters, two key outcomes were concluded. There are several challenges to achieving an efficient flow of information throughout the supply chain and RFID can contribute to addressing those but cannot alleviate them completely. To address the remaining challenges of efficient information exchange, a design of an RFID IS for implementing RFID across the supply chain is developed along four key requirements.

Improve Product Visibility: the RFID IS improves product visibility through *Real time Registration and Processing* of product type, location and time. Registration events are processed through RFID middleware and routed to the appropriate destination

Create efficient technical interfaces for sharing information: the RFID IS creates an efficient interface through a *technical standard for information exchange.* It leverages characteristics of RFID middleware to provide connectivity and EPC IS to insure data compatibility

Deliver a trusted platform for supply chain actors to share their information: the RFID IS delivers a trusted platform through a *sophisticated role based management system* and by introducing a *Trusted Third Party Trusted to provide a platform for information Sharing.* Furthermore, the design proposes a *telecommunications provider as trusted third party* as a starting point.

Foster understanding by Managers for the need for information sharing: the last requirement is delivered by the RFID IS by making benefits transparent through a *Management Dashboard, with value chain/supply chain KPI's.* Visibility of the performance of the supply chain is further enhanced through *Improved Service Level Agreements between Supply Chain Partners.*

This holistic design of an RFID IS, addressing all four key requirements is illustrated in the figure below (Figure 14). The areas highlighted in yellow show the main characteristics of the RFID IS addressing the key requirements.
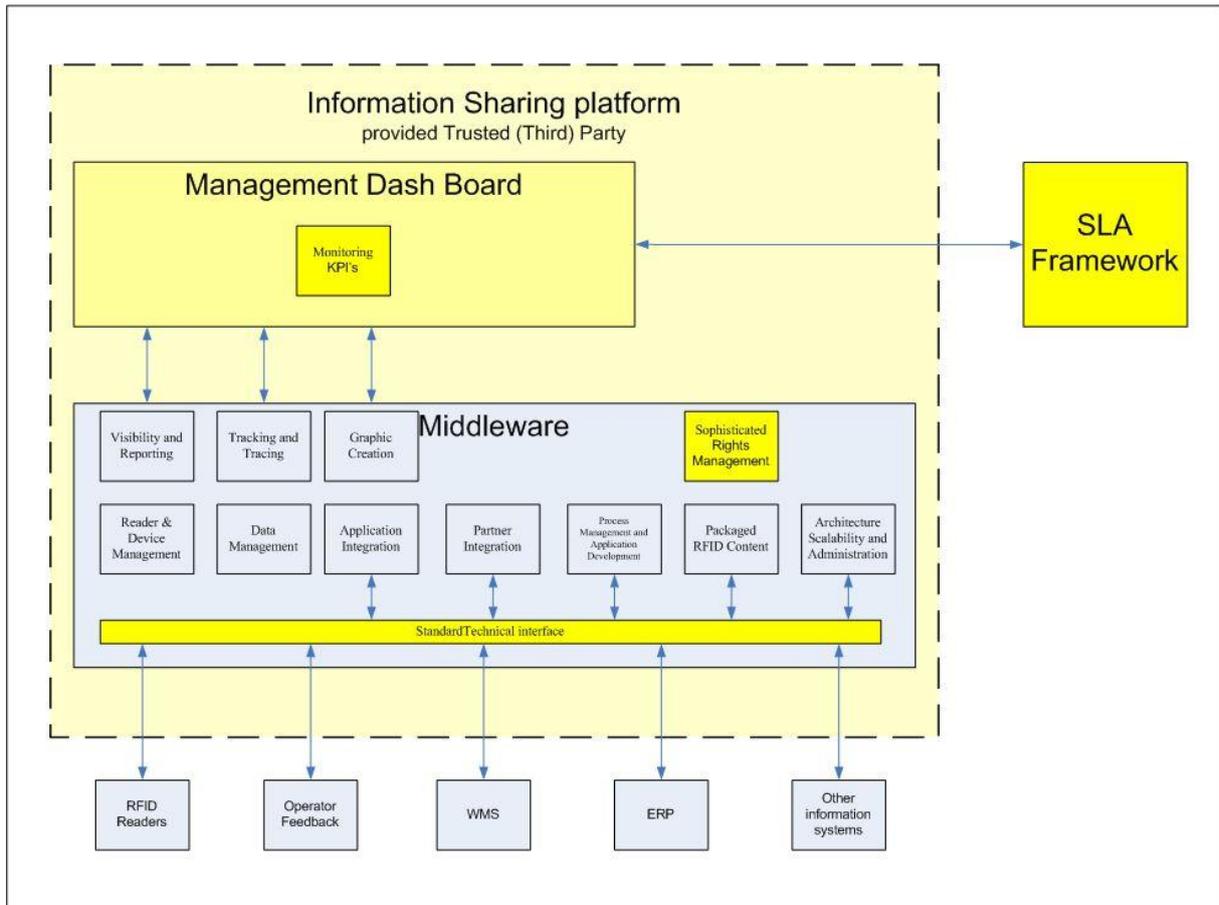
Figure 14: Design of RFID Information System

With the design of an RFID IS thoroughly established, it will be subject to testing in Chapter 5 in two pilot cases, to provide proof of concept and further refinements

Chapter 5 RFID Cases

In this chapter the RFID IS defined in Chapter 4 is put into practice and refined through two practical RFID pilot cases performed by KPN, TelliTrace and Vers Schakel. The writer of this thesis actively participated in the two pilot projects, from operational implementation to report writing. First, in §5.1, the overall objectives for the two pilot projects in the context of this thesis are determined. Subsequently each pilot case is discussed in detail. In the TelliTrace pilot (§5.2), mobile phones were traced from a distribution centre to two retail stores (KPN; TNT Logistics; Symbol; Zebra; 2006). The Vers Schakel project (§5.3) encompassed the tracing of crates of fresh cut and packed vegetables from the manufacturer via a distributor to a retail store (KPN; Capgemini; Schuitema 2007). For each of the cases the performance of and potential improvements to the RFID IS is evaluated.

5.1 Objectives

In this chapter the RFID IS is put to the test in two pilot cases. For the purpose of this master's thesis the objective is not to provide a full scale validation of the design of the RFID IS, but to provide a "proof of concept". With that in mind, three objectives were defined during these pilot projects:

- To confirm the benefits of a supply chain wide RFID IS for supply chain performance
- To evaluate the performance of the proposed RFID IS
- To refine the design of the RFID IS through practical testing

Eventually the goal of the design of an RFID IS is to improve the performance of a supply chain. Therefore the first objective for the pilots was to focus on the implementation of an RFID IS to improve supply chain performance.

The second objective was to determine how different parts of the RFID is performed in practice. The focus was on different parts of the RFID IS for the two cases. With TelliTrace the emphasis lay primarily on getting hands experience with RFID. Only parts of the RFID IS are implemented in the pilot project. The focus was on two of the requirements for RFID IS, on *improving product visibility* and *creating efficient technical interfaces*. For the Vers Schakel pilot these requirements were also under scrutiny but expanded with an evaluation of *the role based rights management (trusted platform)* and *the management dashboard (fostering understanding of the need for information sharing)*.

During implementation and testing a lot of valuable experiences can be learned that lead to refinement of the design of the RFID IS. Therefore the third objective is added.

5.2 TelliTrace

The TelliTrace RFID pilot project was a joint undertaking of KPN, TNT Logistics (later became CEVA logistics), Symbol, and Zebra. KPN was in the project two sided, one way as KPN retail/mobile as participant in the supply chain (retail stores) and one way as RFID service provider. TNT Logistics took care of the warehousing and distribution of KPN mobile phones to the retail stores. Symbol and Zebra are both hardware providers. Later a RFID integrator, Mieloo & Alexander, was asked to 'pre-activities'. The whole pilot from design to implementation and reporting took place from June 2005 and ended in September 2006.
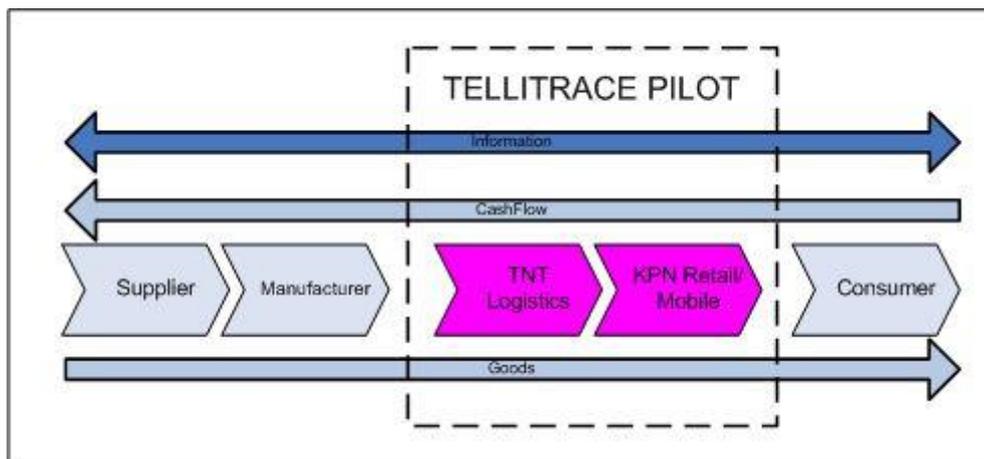

Figure 15: TelliTrace Pilot Supply Chain

5.2.1 Goal of TelliTrace

The main goals of the TelliTrace project, as formulated by the project team, were to:

- Gain hands on experience with RFID
- Create a RFID industry supply chain solution
- Stimulate and asses RFID market developments
- Asses the effect of RFID technology on business operations
- Indentify possible customers for joint commercial RFID proposition

For this thesis of importance are the development of a RFID industry supply chain solution, the effect of RFID technology on business operations, and the experience gained by doing a pilot project with RFID. From the implementation of a working supply chain solution improvements to the RFID IS can be derived. Positive effects on business operations will confirm the benefits of a supply chain wide RFID solution. The effect on business operations is measured in the time it takes to executed process handlings in seconds in the normal situation and the RFID enabled situation. For the improved RFID situation the times are estimated. During the pilot other several interesting and relevant experiences were learned, which impact the design of an RFID IS

5.2.2 Setup of TelliTrace

The setup of TelliTrace was to track and trace new mobile phones from the distribution centre to the retail store. Two retail stores were selected, the Primafoon in Leiden and the Business Centre in Rijswijk. The mobile phones ordered by these stores were to be fitted with a RFID tag at the distribution centre and to be traced though the warehouse operation, transport operation and eventually the receipt at the retail store. To be able to trace the products at these places the following read moments were suggested; In the distribution centre at the packing table, at the wrapping Machine, and the loading dock; at the business centre in Rijswijk in the corridor to the storage room; at the Primafoon in Leiden by the storage room door.

The system architecture was designed as an internet based information system to log all status changes and provide all relevant parties with this information. The information system was called SixD and was built according to the EPCIS standards (§3.2.7). The RFID readers at the retail stores were integrated to SixD while in the warehouse were integrated with the warehouse management system, UNAS, with the purpose not disrupt the warehouse operation UNAS provided SixD with the necessary reader information, see Figure 16.
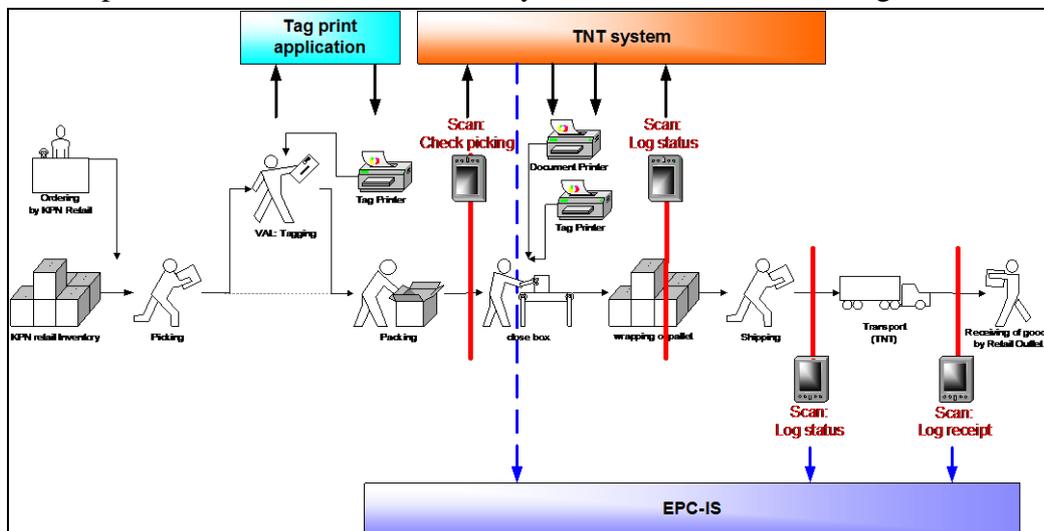

Figure 16: TelliTrace System Infrastructure

5.2.3 Execution of TelliTrace

The process used for the TelliTrace Pilot, from the distribution centre to the retail store, can be described as follows. TNT received orders from KPN retail. The items were picked per order. In this case the items were boxes of new mobiles phones. The items for the orders of the retail stores participating in the pilot were taken out of the process. These items were fitted with printed RFID tags. The tag was placed on the box of the new mobile phone. The items were packed, in a specific position, in boxes. At the picking table the first RFID scan took place by a RFID reader hanging over the picking table. Next delivery notes were printed and added to the box. Also a RFID tag was printed and attached to the box in order to identify the box carrying the items. Subsequently the boxes of the complete order were wrapped at the wrapping machine. Here the second read moment occurred by a RFID reader placed at the wrapping machine. During shipping the items were loaded through a loading dock that was equipped with a RFID reader, the last read moment at the distribution centre. After delivery at appropriate retail store the items were carried to the storage room. In the business centre in

Rijswijk the items are carried trough a corridor to the storage room, in this corridor the reader was placed and the items were read. At the Primafoon in Leiden the items were read upon entry to the storage room whilst the reader was placed at the door. The arriving at the storage room is the end of the process. The tags were removed by hand before the item was handed to the customer. Figure 17 shows the RFID process in comparison to the normal process.
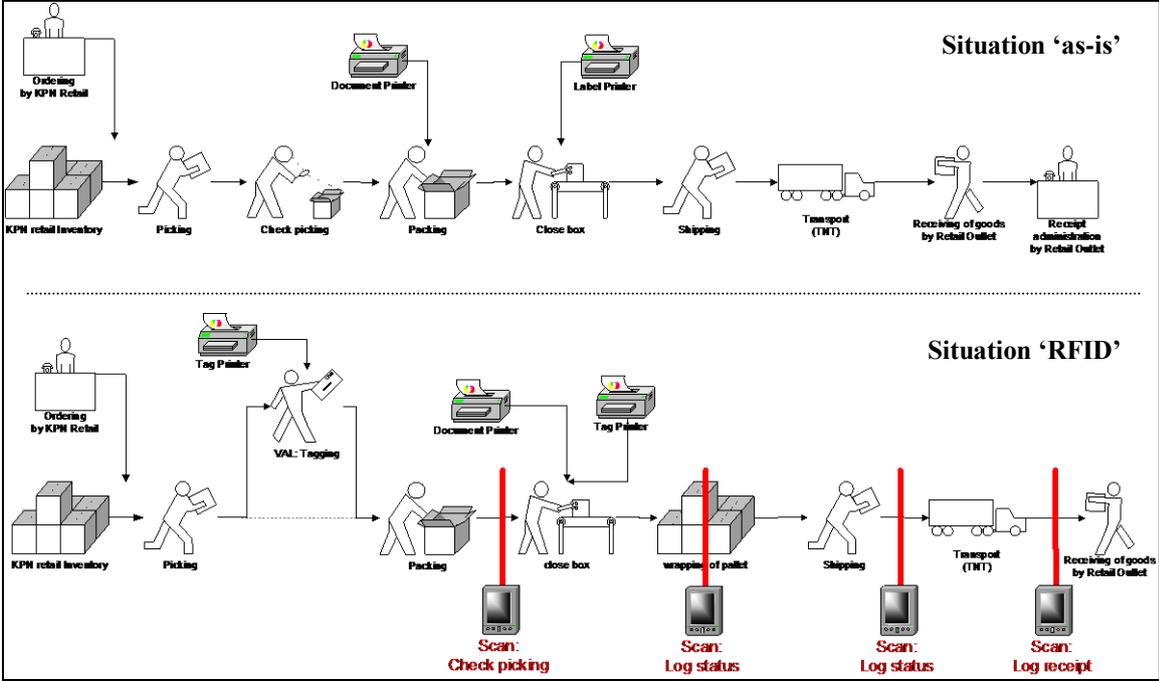

Figure 17: TelliTrace Business Processes

5.2.4 Relevant experiences learned from TelliTrace

Four valuable experiences can be learned from the TelliTrace project. The first three experiences are related to the read rate of the tags. The first experience shows that the quality of the tags in not 100%. The second experience is that a RFID implementation is not simply hook on RFID readers and all tags will be read. The third experience is that the specific placement of the tags on products (still) affects the read rate. The fourth experience, related to the impact of RFID on business processes, shows that just implementing RFID does not deliver instant increase in the performance of business processes.

Tag quality

In the TelliTrace pilot project, the tags delivered by the tag manufacturer had an underperformance rate of 9 %of which 5 % didn't work at all and 4 % underperformed, resulting in unreliable reading results. Even though the printable tags delivered were the first batch of a new design tags, an error rate of 9% in an environment that requires 100% performance is not acceptable. There is room for improvement on the quality of (printable) tags

RFID reader configuration

During the building and testing phase of the pilot it became clear that there was a significant lower read rate in the retail stores. To increase the read rate, the reader construction at the retail stores was reconfigured. An RFID reader consists of the reader itself and antennas

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(§3.2.5). In this case in both retail stores the power of the antennas had to be retuned in order to optimal cover the area the tags placed on the items would be passing, and thereby the read rate was increased.

The experienced learned is that RFID is (not yet) a plug and play solution. Proper effort should be invested in the design of the RFID configuration. The field of RFID reader implementation and configuration is a science at itself.

Tag Placement

In the 'pre-testing' by Mieloo & Alexander the readability of individual item, a box with a mobile phone, packed in a greater box with other tagged items, an order, was increased from 74% to 99.6% in laboratory conditions. This was done by placing the tag in a specific way and pack the individual items in a specific way in the box. The reasons for doing so are to prevent interference and aligning the tags to the antennas of the RFID reader. Interference occurred by installation CD included with the mobile phones and interference by other RFID tags. The 'obvious' improvement in product visibility by implementing RFID still needs attention before implementing RFID.

RFID's impact on business Processes

The impact of RFID on the business process was measured through the lead times of process handlings. The lead times of process handlings in the normal process without RFID and with RFID were measured, for measurement data see Appendix A. The RFID pilot as performed showed that there are no advantages in lead times. On the contrary, because the items had to be tagged within the pilot process and the products had to be packed in a specific manner, the lead time per shipment became 7 times longer. To give a realistic picture of a RFID enabled process an alternative scenario was developed (Figure 18) and lead times were estimated. In alternative scenario all item were already 'pre-tagged' by the manufacturer before entering the distribution centre, shipment documents were no longer needed due to replacement of RFID functionality (electronic information exchange), and no extra time was needed for wrapping a RFID shipment. Even with the 'realistic' RFID process the lead times exceed the normal process lead times.

However, while barcode scans have a major impact on the lead time, RFID scans add limited extra time to the total process lead time. The advantage of RFID on process handling times becomes visible when the required number of scan increases.
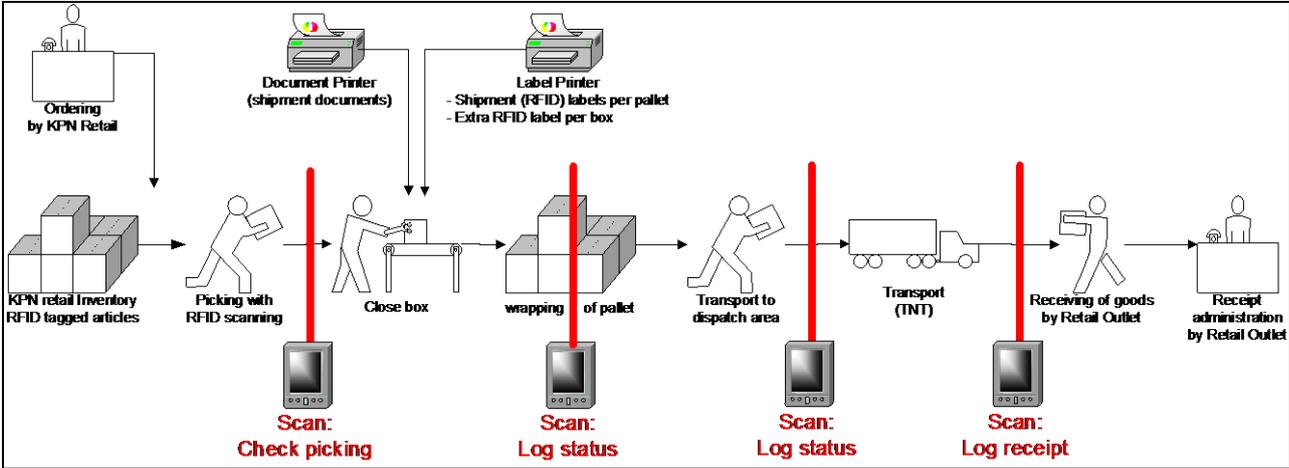

Figure 18: TelliTrace alternative RFID enhanced business Processes

5.2.5 Conclusions from TelliTrace

The main conclusions that can be drawn from TelliTrace according to this thesis are discussed below.

Benefits of a supply chain wide RFID solution

The pilot project proofed that a one on one replacement of barcode RFID does not make the supply chain faster, on the contrary the RFID supply chain design used in the pilot was significantly slower. Even the estimation of the lead times in the conceptual RFID design, where the tags would already be in place before entering the distribution centre, showed a slower supply chain. The reason for that there was no advantage by RFID was that the supply chain was designed and optimized for barcode. The effort to make product more visible was greater than the benefits of improved visibility, in this part of this supply chain.

The advantages of RFID should materialize when more scan moments are introduced, while RFID scans have less impact on lead times. This enables the redesign of supply chains.

Performance of the RFID IS

In the pilot a technical interface was provided between the WMS system of the distributor and the middleware based on the EPC IS standard. The interface made it possible to share information about registrations of products done at the distribution centre.

A trusted platform for information sharing was provided by a trusted third party, KPN. However, not the full potential of the information sharing platform was used. Only product registration information provided by the WMS and the readers at the retail stores was shared.

Interestingly, the most inherent RFID requirement of the RFID IS, improving product visibility, caused the most issues during implementation, under performing tags, special placement of tags, and retuning reader configurations. For business processes, such as logistic administration, to start using RFID, it is necessary that the RFID-information is reliable; this means at certain points in the supply chain 100% readability is required.

After correction for underperforming tags in two of the five places a 100% readability was measured of individual items. In the other three places the read rates measured were high (from 89% tot 98%). It is believed that with reconfiguration of the reader construction the read rates can be further improved. A readability of 100% of individual items is not yet met; however read rates are approaching that level. A readability level of 100% is within reach.

Improvements to the RFID IS

Two improvements of the RFID IS can be derived from the TelliTrace pilot, first of all product visibility cannot be taken for granted in a supply chain wide RFID implementation. There must be a concerted effort to achieve 100% readability in early stages of implementation.

The second improvement to the RFID IS lies in the driver for rolling it out in the first place. The main driver to implement RFID in a supply chain should not be to implement RFID in the supply chain, but to optimize the supply chain. RFID can be one of the (potential powerful) tools to improve (parts) of the supply chain. But as shown in the pilot, implementation of RFID does not guarantee instance improvement of the supply chain. Before implementing RFID much effort should be invested in the business case, the cost and benefits should be thoroughly considered.

5.3 Vers Schakel

Vers Schakel, translated Fresh Chain, was a RFID pilot Project in a fresh vegetables supply chain in the Netherlands. The pilot started in 2005 and would eventually last 2 years. The project was undertaken by Schuitema (Distributor), Heemskerk (manufacturer), C1000 Bergen op Zoom (Retailer, franchiser), CapGemini (IT consultant), KPN (Dutch Telecom Provider), Centraal Bureau Levensmiddelenhandel (Dutch Food Retail Association), Intel, NXP Semiconductors, the University of Wageningen and Research Centre (WUR), and Container Centralen (Manager of the crates used in the Supply chain).

5.3.1 Goal

The goals of the RFID pilot project were two folded. First part was to *improve the quality of the product offered to the customer*. The second goal was to *increase shelf availability*. To achieve these goals, RFID was used *to reduce decay* and *to improve transparency and logistical efficiency* in the supply chain. Meeting the two goals eventually should result in better customer service by the entire supply chain.

These goals are in line with objective of this thesis to confirm the benefits of a supply chain wide RFID solution. Other experiences gained from this project will support the other two objectives: evaluating the performance of the RFID IS and refining it further.

5.3.2 Design/Setup

To create transparency and logistical efficiency to improve shelf availability, products were to be followed with RFID throughout the Vers Schakel supply chain. The Vers Schakel supply chain consisted of the manufacturer, Heemskerk, the distributor, Schuitema, and C1000 retail stores. The manufacturer, Heemskerk situated at Rijnsburg, processes raw vegetables into cut and packed fresh vegetables. Heemskerk supplies different customers, one of which is Schuitema. Schuitema is the distributor of C1000 supermarkets, a retail branch in the Netherlands. For the pilot the fresh cut vegetables were track and traced with RFID which were delivered to one C1000 supermarket in Bergen op Zoom franchised by M. de Veij. The fresh vegetables were delivered by the Schuitema from the Distribution Centre located in Breda. Thus, the total tracked supply chain started at Heemskerk in Rijnsburg, subsequently transported to the Schuitema Distribution Centre in Breda. From there Schuitema transported the products to the retail store in Bergen op Zoom.
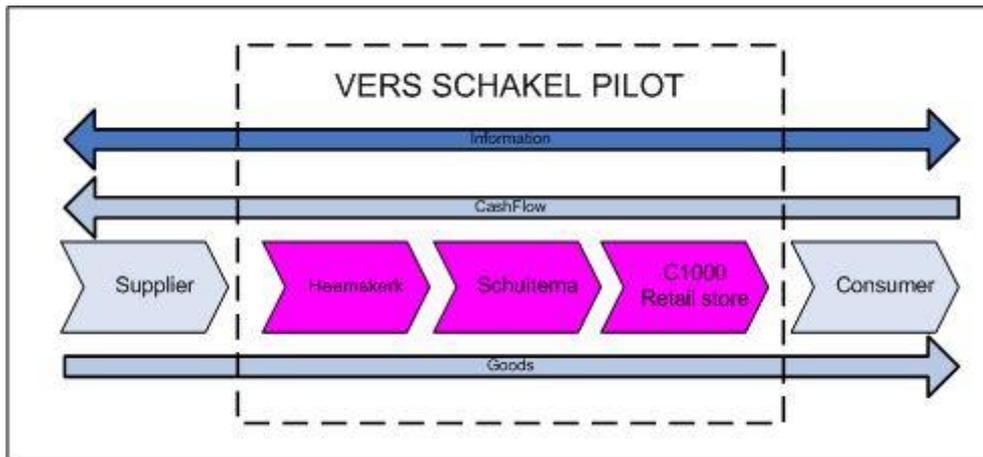
Figure 19: Vers Schakel Pilot Supply chain

The products that were followed with RFID were standard CBL-crates that are used to transport the packages of fresh cut vegetables. The crates were filled with one type of vegetables and a fixed quantity of packages. The crates were loaded onto roll containers in stacks between 80 and 120 crates

The Vers Schakel pilot project knew two phases. The first phase covered the supply chain from Heemskerk to the distribution centre. Two read moments were installed by the manufacturer, at the labelling line just after picking, and at the dock door, whilst loading. The read moment at the distribution centre was installed at the dock door, thus at the moment of unloading.

The second phase was an extension of the first phase with the supply chain extended from the distribution centre to the shelves in the C1000 retail store. At the distribution centre two read moments were added, picking and loading to the retail store. At the retail store the products were read upon delivery. Then products could go to the shelf or to the cooling cell. Upon entry and exit of the cooling cell the products got read. After the products were placed on the shelf, the content of the crate was set 'empty'.

Parallel to these two phases a sub project was done with Container Centralen, the manager of the crate pool. Container Centralen as provider of the crates is a beneficiary to the supply chain, but not a supply chain partner. Problem for Container Centralen at that moment was that they had no overview of the whereabouts of their crate pool and therefore had no good information for proper billing: Once a year their clients were asked to count the crates in their possession and based on that information the accounts were settled. Using RFID should bring a detailed overview of the crate pool and provide appropriate information for billing.

Technical Infrastructure
For the design of the technical infrastructure the EPCglobal standards were used, the EPC-IS interface and the EPC-Discovery interface. The Vers Schakel project was one of the first to use them. At the time of the Vers Schakel pilot the EPC-IS was still in a draft version. The EPC-Discovery interface can be seen as an application that can extract RFID data from databases. Examples of information that was retrieved for the pilot are Crate Identity, Time of

Crate Detection, etc. However, the level of detail of information that could be retrieved was adjustable to each participant. For example Container Centralen could retrieve information on a crate id's and crate locations, but not on its content.

Figure 20 gives an overview of the technical infrastructure used in the Vers Schakel pilot.
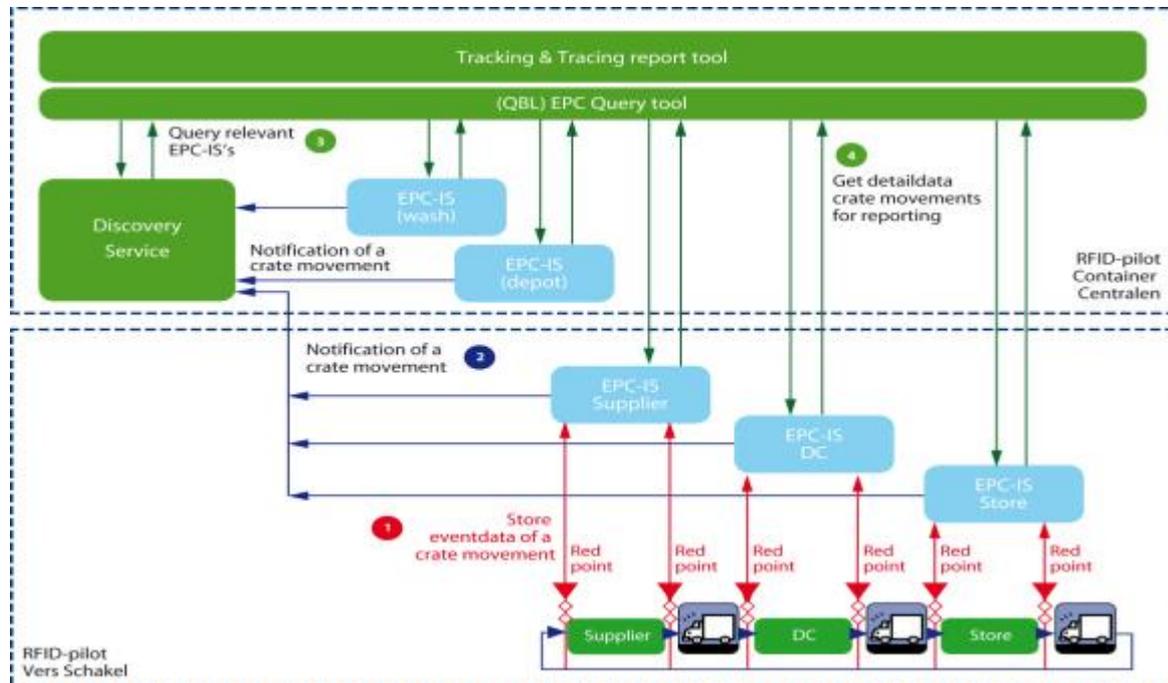
Figure 20: Vers Schakel Pilot System Infrastructure

5.3.3 Quality Improvement

To guarantee quality and reduce decay of the fresh products across the supply chain several methods were used. The unique ID provided by RFID to the crates made it possible to track and trace every crate as an individual item.

BBD Sequence

To prevent that fresher products were used before 'older' products, increasing the chance of on decay of the older products, control on Best-Before-Date (BBD) is required. Given the unique ID of the crates, enabled by RFID, it was possible to provide the crates of fresh vegetables with a BBD. This enabled steering on BBD. E.g. At the cooling cell, a signal was given if a product with a longer BBD was being transported to the shelves while a same product with a shorter BBD was still in the cooling cell.

Temperature Progress

Quality of fresh products, like vegetables, is subject to temperature conditions across the supply chain, too long outside a cooled area increases decay. To measure the temperatures the products were exposed to across the supply chain, temperature loggers were shipped with certain crates. This data, temperature, in combination with the RFID data, place and time, gave a picture of the product's temperature progress throughout the Supply Chain. In case of decay, this information also could play a role in the discussion about liability.

Warning outside cooled area

To avoid products being to long outside a cooled area, a timing mechanism was installed in the system at the retail shop that warned, via text message, when products were too long, longer than 15 minutes, out of the cooled area.

5.3.4 Experiences from Vers Schakel

Many experiences were learned during the Vers Schakel pilot which can be found in the report of the pilot (KPN; Capgemini; Schuitema 2007). The important experiences learned from the pilot for this thesis are the development of an operator console providing direct feedback, the development of a management dashboard with supply chain wide KPI's, and the development of a crates pool management tool for Container Centralen.

Operator Consoles

At the read portals a console was placed were the operator got direct feed back of a read event. This enabled a fast 100% control of every shipment passing the read portals. The shipments were checked on the right quantity and the BBDs. In case of an error the operator could act directly and correct the situation. The information was adjusted to the new situation providing the supply chain with up-to-date real time information. An example of possible feedback is shown in Figure 21.
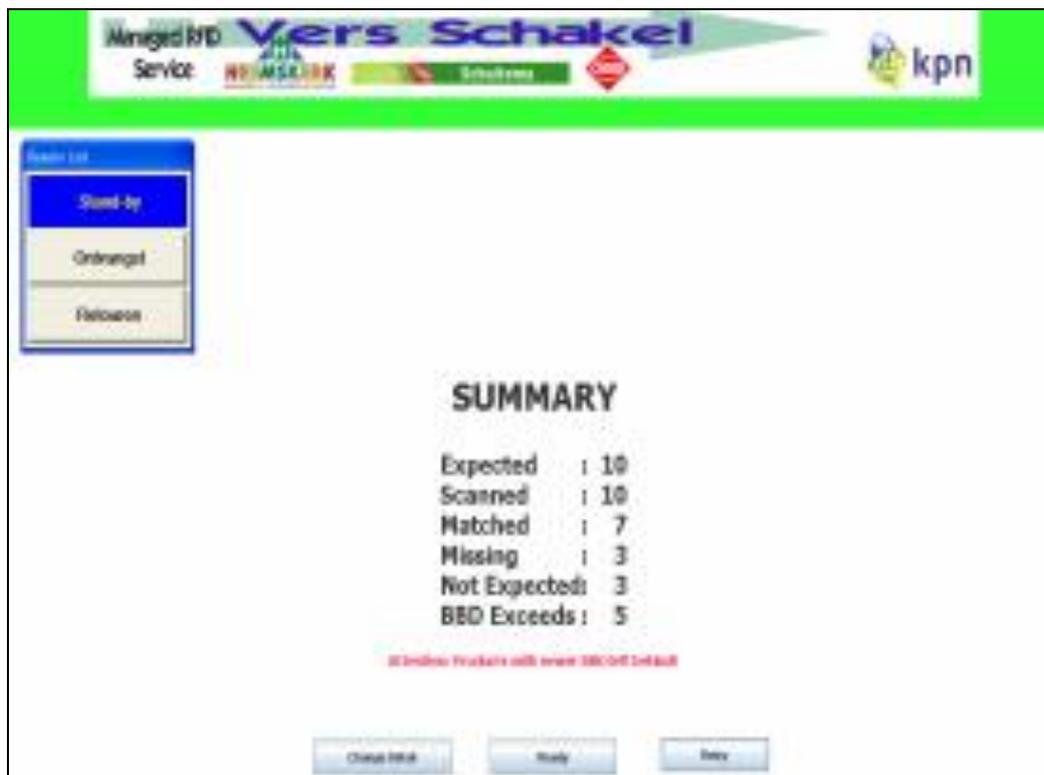
Figure 21: Operator Console

Management Dashboard

During the pilot also a management dashboard was developed. This management dashboard provided the supply chain partners with a clear overview of Key Performance Indictors

(KPI's) that cover the supply chain. The insight provided by the KPI's can help managers improve the logistical efficiency. For the Vers Schakel project the following KPI's were developed: *Tracking and Trace (individual item), Lead Times, Inventory Cold Store C1000, Inventory Supply Chain Wide, Reader Sanity* and *Overview of Exceptions* In Appendix B the KPI's provided by the management dashboard in Vers Schakel are elaborated.

An example of a KPI, in this case supply chain wide inventory, reported by the Management Dashboard can be seen in Figure 22. The example provides an overview of the supply chain wide inventory of French Beans (Snijbonen).With this information a manager can make righteous decision on production, ordering, shipping etc.
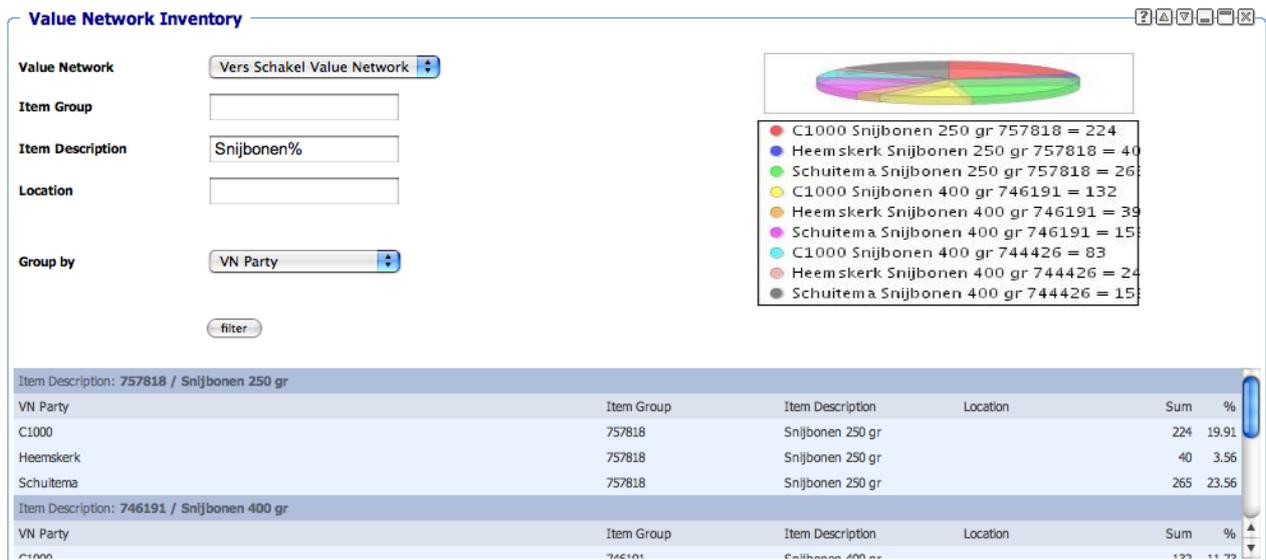

Figure 22: Management Dashboard Supply Chain Wide Inventory

Management of Crates Pool by Stakeholder

The pilot provided Container Centralen, owner of he crates and stakeholder in the supply chain, with an overview on its pool of crates in the supply chain which was lacking. By knowing the whereabouts of the crates Container Centralen can better manage the flow of the crates and improve the billing process. Figure 23 shows the interface with Container Centralen.
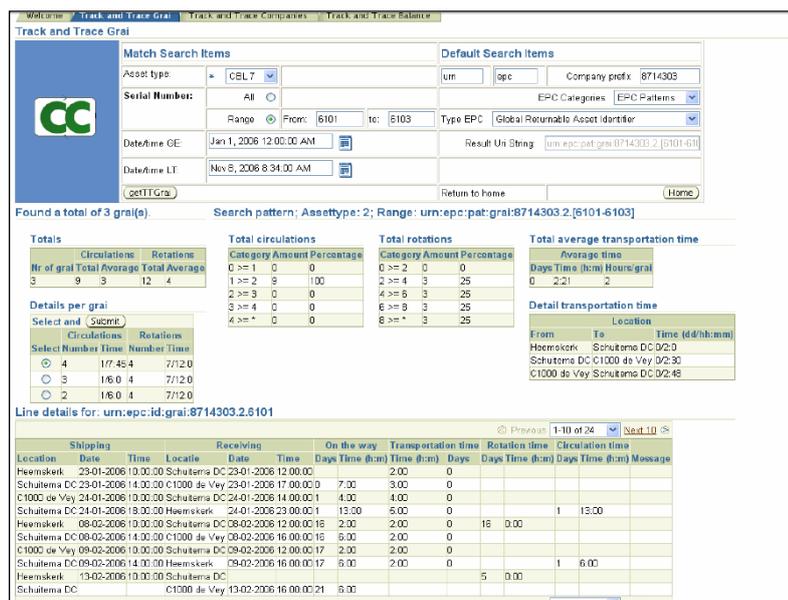

Figure 23: Container Centralen Information System

5.3.5 Conclusions of Vers Schakel Pilot

Several conclusions can be drawn from the Vers Schakel Pilot; these conclusions are discussed along the overall objectives defined in paragraph 5.0

Benefits of a supply chain wide RFID solution

The Vers Schakel pilot showed that with RFID it is possible to increase shelf availability by improving logistical efficiency in the supply plain. The 100% control of every shipment and the direct feedback to the operator enabled to directly correct errors, even before they were made, thus improving logistical efficiency within the Supply Chain.

The quality of products was also improved through three mechanisms. First, the temperature progress within the "closed cold" supply chain was checked by the combination of temperature loggers and RFID. A temperature progress within the "fresh" temperature range prevents unnecessary decay. The second mechanism warned if a product was too long outside a cooled area preventing unnecessary decay. The third mechanism, the BBD alert in the cooling cell, prevented fresher BBD to be placed on the shelves before older BBD. This also contributed to the reduction of decay.

In the Vers Schakel case, the improvement of transparency and logistical efficiency and the reduction of decay influence one another. If products move faster through supply chain there will be less chance of decay. Vice versa, if there is less decay then the logistical efficiency increases, as there will be no need for reordering of products. Thus, improvements in one field will lead to improvements in the other.

Performance of the proposed RFID IS

In the Vers Schakel project several parts of the RFID IS were successfully used to improve the performance of the Vers Schakel supply chain:

Real time Registration and Processing

After initial problems with the tags, attachment and oxidation, the project was able to follow the crates through the Supply Chain. With read portals at the end and begin of business processes and a read rate of near 100%, transparency of the supply chain was highly improved (see Appendix C)..

The operator console used in the Vers Schakel pilot is another element of *real time registration and processing*. The operator console gave direct feed back of a registration event. If confronted with an error, the operator was enabled to correct this error instantly, preventing logistical inefficiency, or accept the situation by updating the present information, providing real time information. In both situations, eventually supply chain performance will benefit.

Role based management system

As stated earlier, the EPC-IS interface and the EPC-Discovery interface were used for the design of the technical infrastructure in the Vers Schakel pilot. The level of detail of information that could be retrieved was adjustable to each participant. The pilot proofed that the level of detail of information was adjustable to the need of the participant. Information is shared across the supply chain but the level of detail a certain participant can see can be restricted. This feature proved important to convince companies to share information across the supply chain.

Management Dashboard, with value chain/supply chain KPI's

Based on the supply chain wide KPI's provided through the management dashboard, managers were able to measure the performance of the supply chain. Areas of improvement can be identified and aimed acts can be undertaken to improve the logistical efficiency of the supply chain.

Improved Service Level Agreements between Supply Chain Partners (Liability of Decay)

While no changes to existing SLA requirements were made between Supply Chain partners as part of the Vers Schakel pilot, potential for future improvements to Service Level Agreements was uncovered. The temperature progress information provided by the temperature loggers and RFID can be used as decisive information in the possible discussion towards the liability of potential decay, as it can be determined where in the supply chain the temperature exceeded the correct range. This and other criteria can be included in future SLA's.

Refinements to the RFID IS

During the Vers Schakel pilot, some improvements to the RFID IS became apparent.
At some read portals problems occurred with readings of tags that were not supposed to be read. In a scaled up situation this undesirable event is likely to occur more and have a negative impact on product visibility. Further research should be done to prevent this from happening.

The pilot also showed that the RFID system can be used for the return transport of the crates. The returnable crates were registered automatically replacing physical labour and reducing the chance on errors. The settlement of the deposit also could be done automatically.
Implications for the RFID IS are that visibility is not necessarily included to products but can be expanded to include all items moving through the Supply Chain, such as Returnable Transport Items. This information can support processes involved with such items, like administration, financial settlement etc.

Finally, the Vers Schakel pilot proved that not only supply chain participants are benefited by sharing information across the supply chain, also stakeholders can benefit from the supply chain information. In the pilot Container Centralen was provided with an overview of its crates in the supply chain. This enabled Container Centralen to improve the billing process and the management of its own Pool of crates which eventually can result in better availability of crates, better reaction on situation in the market and a better service towards customers, the supply chain. Therefore, the RFID IS should not limit itself to supply chain partners but also

evaluate the inclusion of other stakeholders (with the proper role based rights management) if it benefits the supply chain.

Chapter 6 Conclusions and Future Research

6.1 Conclusions

The objective for this research was to develop a design of an RFID Information system that enables improvements in the performance of supply chains.

To reach that objective, three research questions were defined

> *1. What are the requirements for an RFID Information System to improve Supply Chain Performance?*
>
> *2. What does a design of an RFID Information System across the Supply Chain look like?*
>
> *3. Is the design of an RFID Information System implementable in practice?*

The answers to these questions are presented, in sequence, in the following three conclusions.

A Supply Chain wide RFID IS has four key requirements to improve Supply Chain Performance:
- Improvement of Product visibility
- Creation of a efficient technical interface for sharing information
- Delivery of a trusted platform to share information
- Fostering understanding by Managers for the need for information sharing.

The performance of a supply chain can be improved by ensuring the right information is at the right place at the right time. This enables a company to make a decision that benefits both the company and the supply chain. As such the key requirements for a Supply Chain wide RFID implementation are to promote an effective flow of information across the supply chain by addressing key bottlenecks.

Improvement of Product Visibility. One issue with sharing information in Supply Chains is that the information is not known / not accurate. This can be countered by improving product identification in combination with a more accurate location registration and by keeping this information up to date (Real Time).

Creation of an efficient technical interface for sharing information. Information exchange in supply chains is hampered by both systems incompatibility and different levels of connectivity between SC actors. This can be resolved by providing one efficient technical interface for information sharing

Delivery of a trusted platform to share information. Trust is a prerequisite for information sharing. Supply chain actors will not share information if they are not convinced it is safe. The solution is twofold: provide a "technical" trusted platform, but also facilitate and enhance the perception of trustworthiness

Fostering understanding by Managers for the need for information sharing. Even if there is a trusted platform in place, companies will not start sharing information by itself. For managers to invest in changes of business culture towards information sharing, managers must be convinced that sharing information provides them with overall supply chain benefits.

The RFID IS should harness existing RFID hardware, middleware and standardization and add a trusted information sharing platform, managed by a third party, and a management dashboard

The requirements define what the RFID IS should be capable of to improve supply chain performance. This conclusion presents several functionalities that the RFID IS should have to meet the requirements.

Improve Product Visibility: the RFID IS improves product visibility through *Real time Registration and Processing* of product type, location and time. Registration events are processed through RFID middleware and routed through the appropriate destination

Create efficient technical interfaces for sharing information: the RFID IS creates an efficient interface through a *technical standard for information exchange.* It leverages characteristics of RFID middleware to provide connectivity and EPC IS to insure data compatibility

Deliver a trusted platform for supply chain actors to share their information: the RFID IS delivers a trusted platform through a *sophisticated role based management system* which provides the ability to define who can see which information and by introducing a *Trusted Third Party Trusted to provide a platform for information Sharing.* Trust and willingness to share data is increased while the third party has no concern in the supply chain, additional advantage is the sharing of cost and complexity.

Foster understanding by Managers for the need for information sharing: the RFID IS makes the benefits for sharing information transparent for managers through a *Management Dashboard, with value chain/supply chain KPI's.* By providing information about supply chain wide KPI's managers can make better decisions. Visibility in the benefits of sharing information is further enhanced through *Improved Service Level Agreements between Supply Chain Partners.* Based on the supply chain KPI's, a supply chain wide framework of SLA's can improve supply chain performance.

The design of the refined RFID Information System can be illustrated as follows (Figure 24)
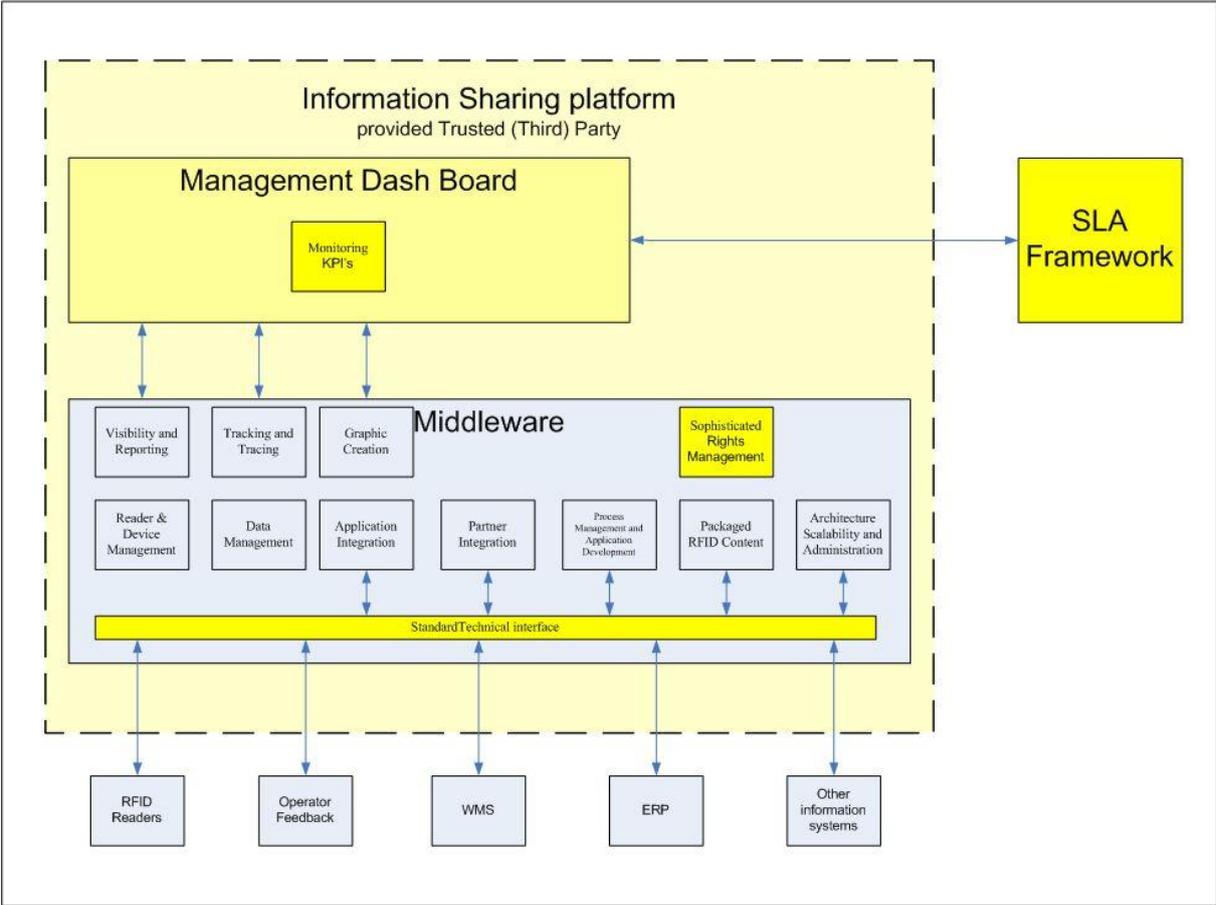

Figure 24: Design of RFID Information System (in conclusions)

From practical testing in the two pilot cases, two refinements to the RFID IS are included:

Concerted effort to deliver product visibility during implementation
Both pilots show that 100% readability is still not guaranteed. There must be a concerted effort to achieve 100% readability in early stages of implementation. Unwanted registrations must also be prevented. In some cases, tags were registered by mistake, because they were unintentional in range of readers. This events corrupt information and therefore have negative impact on supply chain performance. Attention should be paid to the design and installation of reader configurations to prevent such unfavourable events.

Expand the information sharing platform to include Stakeholders
Not only supply chain participants are benefited by sharing information across the supply chain, also stakeholders can benefit from the supply chain information. Based on the supply information stakeholders can improve there services, as shown in the Vers Schakel Pilot.

A supply chain wide rollout of RFID is feasible and delivers added value

In both pilots, TelliTrace and Vers Schakel, a roll out of a supply chain wide RFID Information System provided by a trusted third party was realized. TelliTrace satisfied three requirements of the RFID IS -product visibility, technical interface, trusted information sharing platform- successfully. Vers Schakel was able to meet all four requirements. It proved the concept of a sophisticated role based management system, a management dashboard, and the ability to implement Improved Service Level Agreements between Supply Chain Partners. In the case of Vers Schakel direct benefits to the performance of the supply chain, improvement of product quality and logistical efficiency, were realized.

Besides the answers to the research questions, several other interesting conclusions can be drawn from the knowledge gained by performing the pilots.

The theoretical benefits to product visibility of RFID, cannot (as yet) be completely realized in practice

The first aspect of Product Visibility, Product Identification, is not completely realized in practice. In particular the bulk reading of multiple items is not reliable enough. Advances in new generations of tags and readers will improve this situation, but probably not enough to reach 100% reliable bulk reading. Therefore it is often necessary to come up with workarounds to bring Product Visibility to an acceptable level.

The second aspect, Location Registration, is trivial in case of fixed readers at known locations. In that case the exact location of the product is simply the location of the fixed reader that made the observation. If mobile RFID readers are used (which was not the case in the pilots), additional measures will have to be taken to determine the exact location. Practical solutions are for example: in a warehouse to use RFID tags to identify specific locations, or in a truck to use a GPS system to determine the location.

The third aspect, Real Time, was realized satisfactorily because all RFID readers were connected to the information sharing platform, and the clocks of all components of the solution were synchronized. Therefore the information sharing platform had a near-real-time log of registration events, that was the basis of all KPI's and notifications.

Realizing full supply chain benefits requires RFID enhanced supply chain reorganization

Using RFID in TelliTrace had no positive impact on the business processes. The explanation why RIFD brought no improvement is that the supply chain was designed and optimized for barcode. To realize the full potential benefits of RFID in the supply chain, a supply chain

should be redesigned with the features and abilities of RFID in mind. E.g. installing more registration points with RFID is easier than with Barcode.

RFID is a means to provide product visibility; several elements of the RFID IS are not limited to RFID

In essence, RFID is only a means to provide product visibility. Compared to another (commonly used) means of providing visibility, RFID has advantages over barcode but that that does not mean that an implementation of RFID automatically outperforms barcode (TelliTrace). Furthermore, RFID features can work counterproductive as shown by the unwanted read in Vers Schakel.

In short, if an alternative technology can provide the same level of product visibility and the flow of information is guaranteed, it could substitute RFID in the RFID IS. RFID's middleware does provide benefits for overcoming systems incompatibility issues and different levels of connectivity between the multitudes of systems in the Supply Chain, but other technologies may provide a similar interface layer. Basically the other elements of the RFID IS can be added on to other systems that have the objective to improve information sharing between various actors. Having a trusted third party set up a platform for information sharing with sophisticated role-based rights management, will encourage actors to participate. Furthermore, a dashboard that provides them with clear and direct feedback of the benefits of the information sharing will increase participation even further.

Summarizing, we can conclude that the approach taken is very promising but not mature enough to be used in practice. The deficiencies in Product Visibility may be solved by work-arounds, e.g. in the Vers Schakel pilot every crate had two RFID tags to ensure that even with an 80% read rate of RFID tags, in most cases a 100% observation of crates was realized, but that is hardly an ideal situation for mass adoption.

Furthermore, we have only barely scratched the surface of important issues such as key SCM KPI's, and which SCM partner needs to know what to contribute to an optimal supply chain. Also how to deal with sub-optimal situations in the supply chain needs further consideration. It can for example be solved through direct intervention (alarm signal at dock door, to prevent that an incomplete order is shipped) or business process refinement or by creating the right incentives (i.e. adapting Service Level Agreements based on target SCM KPI's).

New technologies such as RFID may lead to completely new forms of collaboration in supply chains, with a bigger role for real-time measurements of quality parameters. This way many new challenges to design SCM theories, tools and best practices exist, which will surely require further research, but the potential for RFID (or other visibility enhancing technologies) in Supply Chain Management is tremendous.

6.2 Future Research

To realize full supply chain benefits, requires RFID enhanced supply chain reorganization. Research can be performed on how the RFID enhanced supply chain should be organized to realize full supply chain benefits. Essential to this research is that it should explore this optimization of the supply chain and in what way RFID can support that optimization, instead of on how the supply chain can be optimized for the use of RFID. I.e. The research main focus should be the optimization of the supply chain and not RFID.

The RFID Information System enables the measurement of KPI's across the supply chain. These supply chain wide KPI's have the potential to provide managers with information on the overall performance of the supply chain and potential improvement areas. Further research is needed to establish which supply chain wide KPI's a manager needs to improve supply chain performance.

Current SLA's are agreements about minimal service levels between two parties, Supplier and Customer. However, the supply chain wide KPI's make it possible to measure the service level of non adjacent supply chain partners, of specific parts of the supply chain and of the overall supply chain. This enables SLA's not only with direct supply chain partners, but also with non adjacent supply chain partners, SLA's for parts of the supply chain, or even for the total supply chain. Research should be performed on how to design an SLA framework covering the complete supply chain, in order to improve overall supply chain performance.

The RFID IS provides managers with supply chain wide information through the management dashboard. Based on this information, managers can make better decisions that benefit both their company and the supply chain. If the manager is convinced of the benefits of information sharing, he will invest in the necessary company-wide change in attitude towards information sharing. Further research needs to be conducted on how an RFID IS can support the manager in this change in attitude. E.g. in what way can an RFID IS support and convince a warehouse employee to share information with e.g. a truck driver of a distributor, with the objective of improving supply chain performance.

To reduce complexity, this thesis restricted itself to linear supply chains. However, most supply chains are far from linear. Most companies have multiple suppliers and customers making the supply chain a network of companies, as shown in Figure 3: Networked Supply Chain, p 11. This networked environment will introduce new challenges to the RFID Information System. Further research is proposed to identify these new challenges and, if necessary, to redesign/adjust the RFID Information System to enable the improvement of Supply Chain Performance in a complex, networked supply chain.

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Appendix A Measurements Lead times TelliTrace Pilot

Table 6: Measurements Lead Times TelliTrace Pilot (KPN; TNT Logistics; Symbol; Zebra; 2006)

	measurements in seconds per shipment	Actual Process	RFID pilot	RFID enhanced alternative Process
Picking (and packing during RFID pilot)	**Login**	26	85	26
	Identify order	0	7	0
	Use empty box	0	13	0
	Replace collo id	0	13	0
	Print RFID tag per box and attach label	0	83	0
	Scan individual items	0	360	0
	Print RFID tag per item and attach label	0	400	0
	Put article in box	0	800	0
	Close box	33	50	33
	Transport to buffer	13	22	13
Packing	**Transport to packing table**	14	14	14
	Identify order, count colli and input WMS	69	69	69
	Print RFID tag per box and attach label	0	0	83
	Print shipment label and documents	24	24	12
	Put on folie top	103	103	103
Seconds per shipment		**282**	**2042**	**352**
Impact of additional item scan (sec. per shipment)		**+600**	**0**	**0**
Minutes per shipment		**5**	**34**	**6**
Number of scans (RFID or barcode)		**1**	**6**	**5**
Based on the experiences in the shops it's estimated that the introduction of the RFID-process in the shops will lower the manual activity with regard to register the received products, with about 30 minutes per delivery. Average a shop receives 2 deliveries a week.				

Appendix B: Management Dashboard

In this appendix the supply chain wide KPI's that were presented in the management dashboard, developed for the Vers Schakel Pilot, are shown and elaborated. The KPI's presented by the Management Dashboard are Tracking and Trace (of an individual item), Lead Times, Inventory Cold Store C1000, Inventory Supply Chain Wide, Reader Sanity and Overview of Exceptions

Tracking and Tracing

The track and trace feature made it possible to gather information of individual tags or product groups, Figure 25. This could be across the entire supply chain or a specific business process or location. The time interval also could be set.

Figure 25: Management Dashboard Track & Trace

Lead Times

With Lead Times, the period between two process steps could be determined. Published were the shortest time, the longest time and the average time.
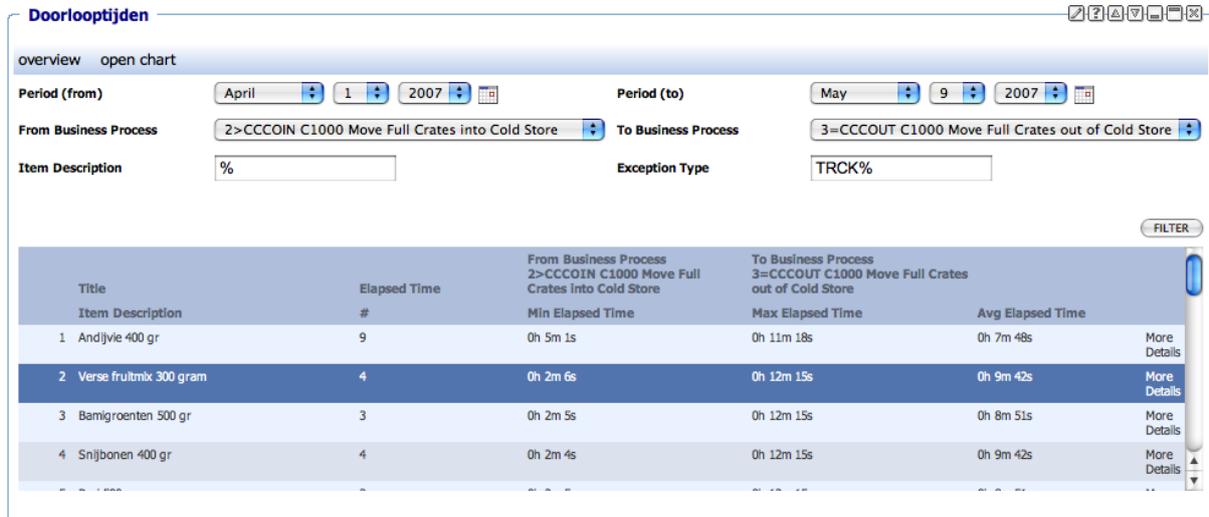
Figure 26: Management Dashboard Lead Times

Inventory Cold Store C1000

The inventory cold store showed an overview of the inventory of the cold store. This could be sorted to Product Group, Best Before Date, and Crate Type. Figure 27 shows the cold store inventory sorted to product group, by clicking on more details, more details were showed of that specific product group on crate level such as BBD.
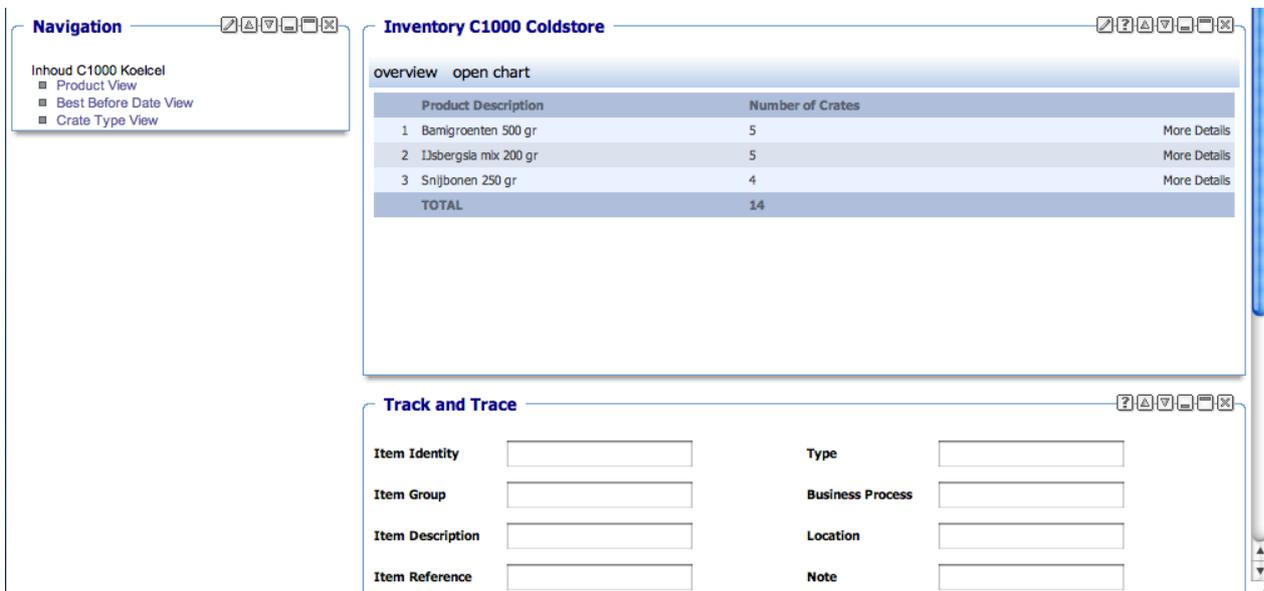
Figure 27: Management Dashboard Inventory Cold Store C1000

Supply chain wide Inventory

With the supply chain wide inventory it was possible to provide an overview of where in the supply chain are how many products. Figure 28 shows an overview for only one product group to keep the figure clear.
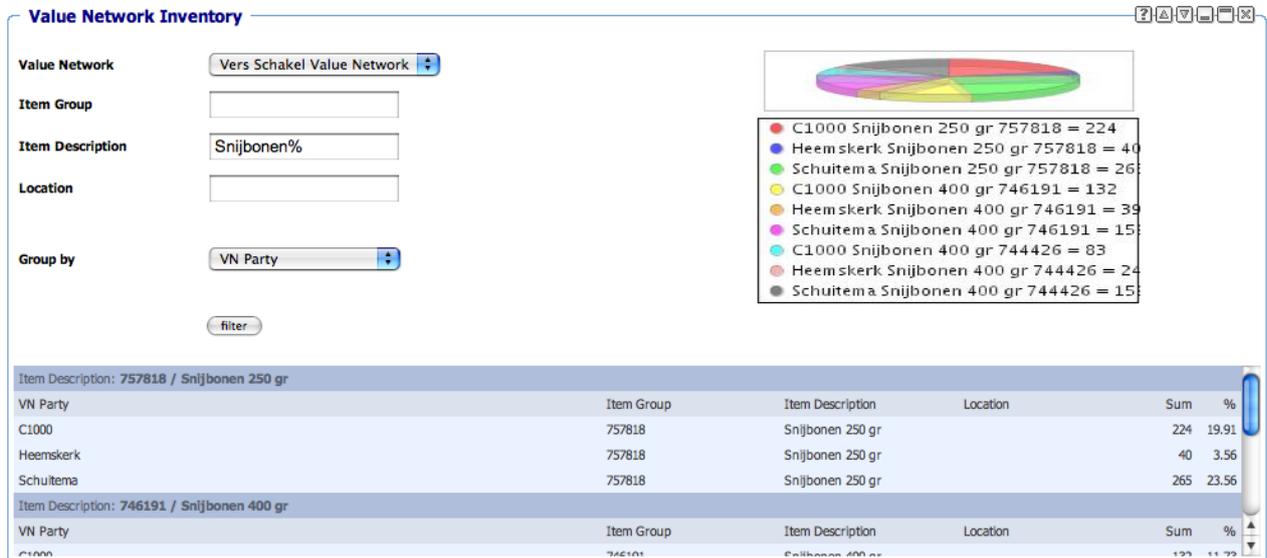

Figure 28: Management Dashboard Supply Chain Wide Inventory

Reader Sanity

With reader sanity the status of readers is checked, Figure 29 . It showed if readers were active or not.
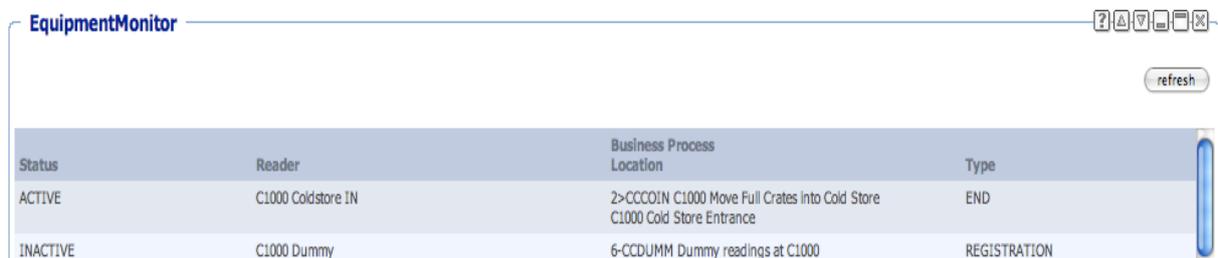

Figure 29: Management Dashboard Reader Sanity

Overview of Exceptions

The overview of exceptions showed the exceptions dividend in three exceptions during a chosen time interval. The different exceptions were BBD exceeding (THT_overscheden), crates too long outside a cooling area (Kratten_te_lang_buiten_koeling), and Missing (manco). *Missing* were occasions where crates were missing from an order.
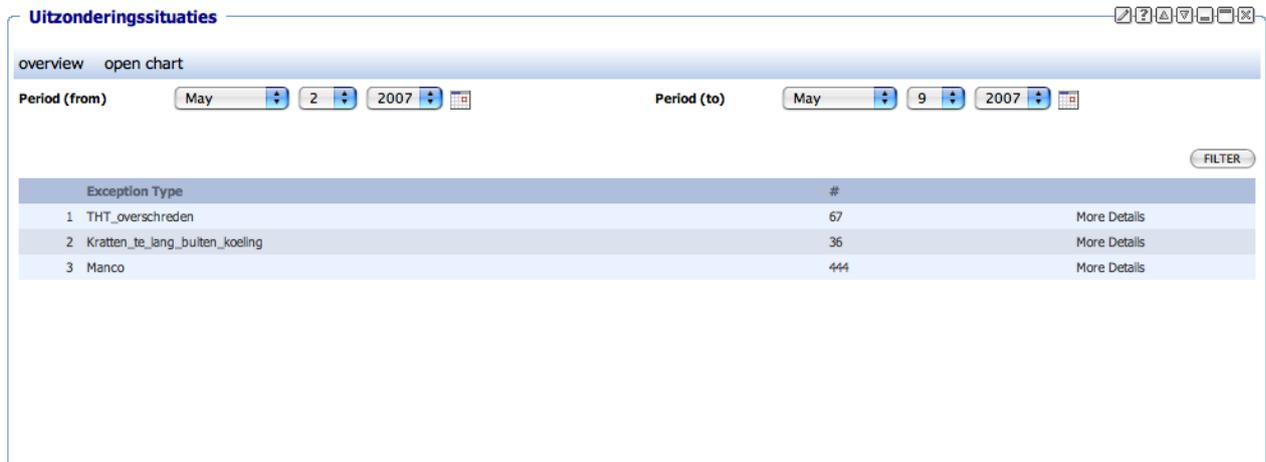
Figure 30: Management Dashboard Overview of Exceptions

Appendix C: Vers Schakel Read Rate Results

In the beginning of the pilot there were problems with the readability and the attachment of the RFID tags. Problems with the readability were caused by oxidation of the not-laminated tags because of the cold and moist environment. Eventually NXP semiconductors provided the pilot with new laminated GEN2 UHF RFID-tags with no decreasing read rates. The attachment problems arouse because of temperature fluctuations. Temperature fluctuated between 2 degrees during normal operations and 50 degrees during the cleaning of the crates. Eventually the right glue was found that kept the tags attached and didn't damage the tag in the process. The read rates measured were all 100% except one measurement at Heemskerk providing a read rate of 97%, Figure 31.

Another problem that occurred with the readability, not shown in the figure, was that the readers picked up nearby tags that were not supposed to be read. This caused read rates of more than 100%. Reading tags that are not supposed to be read may be even worse than missing a tag that is supposed to be read, because it corrupts the information. Attention should be paid to this phenomenon, certainly when the implementations are scaled up.
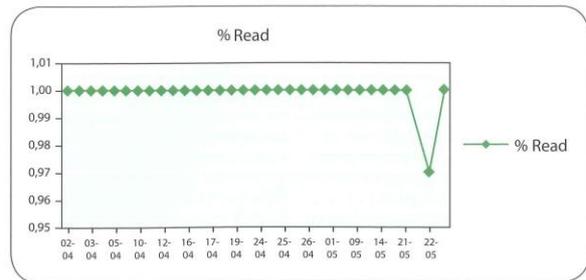
Readrates at Heemskerk at point of departure of products to Schuitema Distribution Centre, April-May 2007
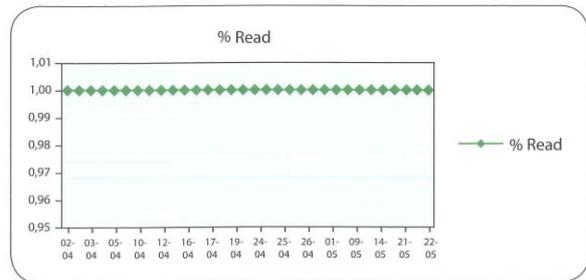
Readrates at Schuitema Distribution Centre at products gathering point Aril-May 2007
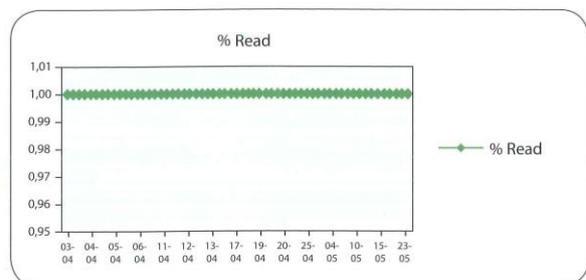
Readrates at receival of products at C1000, April-May 2007

Figure 31: Read Rates Vers Schakel Pilot (KPN; Capgemini; Schuitema 2007)