RFID-Enabled Cooperation in the Supply Chain

Organizational and Technical Aspects

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Abstract

Radio Frequency Identification (RFID) technology, which allows for the simultaneous identification of several objects without line of sight or human interaction, promises to significantly improve supply chain efficiency. The attention researchers and practitioners are giving it, as well as the spread of RFID technology, has increased substantially in the last few years. Although the highest potential to take advantage of this spread is expected to be realized in cross-company applications, the status quo in the RFID project landscape is dominated by local solutions within companies or pilot projects. The use of RFID in the supply chain is still lagging behind its expectations.

Reasons for this phenomenon include high investment and operational costs, the difficulty of assessing the benefits in advance as well as missing standards. While cross-company applications exacerbate the need for standards (technical), they make it possible to overcome the cost problems (organizational). This thesis will tackle both these technical and organizational factors.

Initially, a conceptual reference framework for structuring cross-company RFID applications is introduced. This classification is followed by presenting the findings of a quantitative cross-sectional study in which a possible imbalance of costs and benefits among the supply chain participants is shown to be a key factor for the perceived likelihood of a successful RFID introduction. In the course of using a collaborative RFID application, it is possible to reduce the costs for the individual player by distributing them between a larger number of participants and repeatedly using the same tag across multiple supply chain steps. Regardless of this, high RFID costs are no longer the crucial factor if the expected benefits exceed them; however, in a multi-echelon supply chain, the players engage in such different functions that the potential benefits will not be distributed equally among all participants. While manufacturers and logistics service providers prefer to track the flow of cases or pallets, retailers typically gain the highest benefit by tracking individual items on the sales floor. In summary, the reasons for these problems are based on the fact that the resulting expenses and benefits realized are by no means distributed equally among the participants. For this reason, a model for cost-benefit sharing – including different categories of compensation as well as temporal dependencies during the life cycle of an application – is developed.

Apart from these organizational dimensions of cross-company RFID applications, the technical dimension has to be investigated because missing technical standards are still an obstacle for the wider adoption of RFID. For the capturing and cross-company exchange of RFID read events, the industry consortium EPCglobal has developed a set of specifications that build the technical basis for the EPCglobal network. Objects that are equipped with an RFID tag that contain an Electronic Product Code (EPC) are identified at several steps in the supply chain and information about the movement of these objects (things) can be accessed via the Internet. Known as the *Internet of Things*, this concept has recently received enormous attention. There are three remaining problems, however, which are identified in this thesis: (1) generating RFID events does not only require the data that is provided by the RFID readers, but also corresponding context data; (2) the EPCglobal network provides the technical basis for the Internet of Things, but not the applications that might profit from using this architecture; and (3) there is no standardized approach for storing user generated content besides the EPC on the RFID tags. Solutions to these problems will be presented here:

1. We propose an architectural component called Event Capturing Application (ECA) for the association of read events and context data and develop a prototype that implements this ECA on the top of noFilis' RFID middleware – CrossTalk. Experimental results indicate adequate performance.

2. Several higher-level business applications that query the EPCIS repository are possible. In this thesis, Supply Chain Event Management (SCEM) systems are analysed. The term SCEM refers to the practice of observing, prioritizing and reacting to events that can occur in the operation of a supply chain. We specify a tentative protocol layer that follows a push architecture approach; it serves to integrate heterogeneous enterprise systems that exchange EPCIS-based events. Secondly, an objective comparison between the centralized EPCIS-based architecture proposed by EPCglobal is performed with the proposed decentralized one. For this purpose, quantitative evaluation criteria are developed and applied to both architectures.

3. EPCglobal has specified a stack of specifications that enable a standardized identifier to be stored on the RFID tag and all object related data to be kept on the network. Such a standardized concept does not yet exist for storing object related user generated data on RFID tags. We recommend applying ISO 13584, which concerns standardized properties. Following through with this recommendation, we conceptualize how to use ISO 13584 to store data on RFID tags.

Finally, case studies on two companies will validate the concepts developed in this thesis. A case study on the use of RFID in the fashion industry will highlight all aspects concerning cost-benefit sharing. The second case describes two scenarios on using RFID at a kitchen furniture manufacturer. A study of tracking white goods will verify the conceptual framework and a study of storing data on RFID tags attached to cupboard fronts will show that our proposed approach for storing data on tags using ISO 13584 is feasible.

Keywords:
RFID, Interorganizational Information Systems, Supply Chain Management, Internet of Things

Zusammenfassung

Radiofrequenz-Identifikation (RFID) ermöglicht eine automatische Erfassung von verschiedenen Objekten gleichzeitig und ohne Sichtkontakt und verspricht durch diese Eigenschaften eine maßgebliche Verbesserung der Effizienz in Wertschöpfungsketten. Sowohl die Aufmerksamkeit von Forschern und Praktikern an diesem Thema als auch die Verbreitung von RFID-Technologie haben in den letzten Jahren verstärkt zugenommen. Doch obwohl das größte Potenzial von RFID in unternehmensübergreifenden Anwendungen gesehen wird, konzentriert sich der heutige Einsatz meist auf innerbetriebliche Anwendungen oder Pilotprojekte. Die Verbreitung von RFID liegt immer noch weit hinter den Erwartungen.

Als Gründe für dieses Phänomen werden hohe Investitions- und Betriebskosten, die Schwierigkeiten Nutzen einer geplanten Anwendung vor der Realisierung zu quantifizieren und eine fehlende Standardisierung angeführt. Während unternehmensübergreifende Anwendungen die Notwendigkeit an Standards noch vergrößern, liegt in ihnen eine Chance zur Überwindung des Kostenproblems. Die vorliegende Arbeit adressiert sowohl diese technischen als auch organisatorischen Aspekte.

Einführend wird ein begrifflicher Bezugsrahmen vorgestellt mit dem Ziel, unternehmensübergreifende RFID-Anwendungen zu strukturieren. Nach dieser Klassifikation werden Ergebnisse einer quantitativen Querschnittsstudie präsentiert, bei der eine mögliche ungleiche Verteilung von Kosten und Nutzen unter den Wertschöpfungskettenteilnehmern als ein Einflussfaktor für die wahrgenommene erfolgreiche Einführung einer unternehmensübergreifenden RFID-Anwendung identifiziert wird. Die Nutzung einer kollaborativen RFID-Anwendung und die Wiederverwendung eines RFID-Transponders auf verschiedenen Stufen der Wertschöpfungskette eröffnet die Möglichkeit, die Kosten für jeden einzelnen Teilnehmer durch eine Kostenaufteilung zwischen allen anderen zu reduzieren. Unabhängig davon spielen die Kosten eine geringere Rolle, wenn die erwarteten Nutzen sie übersteigen. Allerdings führt die Arbeitsteilung in der Wertschöpfungskette dazu, dass diese Nutzen nicht gleichermaßen von allen Teilnehmern realisiert werden können. Während Hersteller und Logistikdienstleister im Vergleich zum Kosteneinsatz am meisten von der automatischen Identifikation auf Ebene von Paletten oder Kartons profitieren, erlangen Händler üblicherweise den größten Nutzen von der Identifikation auf Produktebene. Zusammengefasst lässt sich das Problem darauf zurückführen, dass sich die notwendigen Kosten und Nutzen von unternehmensübergreifenden RFID-Anwendungen nicht gleichmäßig auf die teilnehmenden Partner verteilen. Aus diesem Grund wird ein Modell zur Kosten-Nutzen-Aufteilung entwickelt, welches eine Kategorisierung von Kompensationsformen sowie zeitliche Abhängigkeiten in dem Lebenszyklus der Anwendung umfasst.

Neben diesen organisatorischen Dimensionen unternehmensübergreifender RFID-Anwendungen bilden technische Dimensionen einen weiteren Schwerpunkt der Arbeit, da fehlende Standardisierung nach wie vor als ein Hindernis für eine größere Verbreitung betrachtet wird. Für die Erfassung und den unternehmensübergreifenden Austausch von RFID-Leseereignissen wurde vom Industriekonsortium EPCglobal eine Reihe an Spezifikationen entwickelt, die die technische Basis für das EPCglobal-Netzwerk bilden. Objekte – ausgestattet mit einem RFID-Transponder, der einen elektronischen Produktcode (EPC) speichert – werden auf verschiedenen Stufen in der Wertschöpfungskette identifiziert und auf Informationen über diese Objekte (Dinge) kann über das Internet zugegriffen werden. Diesem Konzept, bekannt als das Internet der Dinge, wurde in letzter Zeit große Beachtung zuteil. Die vorliegende Arbeit widmet sich diesbezüglich drei identifizierten Problemen: (1) Die Generierung von RFID-Ereignissen benötigt nicht nur die Daten von einem RFID-Lesegerät sondern zusätzliche Kontextdaten; (2) das EPCglobal-Netzwerk stellt die technische Grundlage für das Internet der Dinge, aber beschreibt nicht die Anwendungen, die auf dessen Basis realisiert werden können; (3) und es besteht bislang kein standardisierter Ansatz um neben dem EPC weitere Daten auf dem RFID-Transponder zu speichern. Lösungskonzepte für diese Probleme werden in dieser Arbeit vorgeschlagen:

1. Für die Assoziation von gelesenen RFID-Daten und Kontextdaten wird die Architektur einer Event Capturing Application (ECA) vorgeschlagen und auf Basis der RFID-Middleware CrossTalk von noFilis prototypisch implementiert. Die Ergebnisse einer experimentellen Evaluation zeigen eine angemessene Performance.

2. Verschiedene Anwendungssysteme, die auf die Datenbank mit RFID-Leseereignissen (EPCIS) zugreifen, werden derzeit diskutiert und getestet. Diese Arbeit legt den Fokus auf ereignisgesteuertes Wertschöpfungskettenmanagement, unter dem das Kontrollieren, Priorisieren und Reagieren auf Ereignisse verstanden wird, die im operativen Ablauf der Wertschöpfungsprozesse entstehen. In dieser Arbeit wird eine Architektur entwickelt, der ein dezentraler Ansatz und das Paradigma des aktiven Verbreitens von Ereignissen zu Grunde liegen. Anschließend wird

ein Vergleich zwischen einem zentralen Ansatz mit dem Abrufen von relevanten Ereignissen und dem vorgeschlagenen dezentralen Ansatz durchgeführt. Für diesen Zweck werden quantitative Evaluationskriterien definiert und auf beide Architekturansätze angewendet.

3. Die Spezifikationen von EPCglobal basieren auf dem Konzept, ausschließlich eine standardisierte Identifikationsnummer auf dem RFID-Transponder und alle objektbezogenen Daten in Netzwerkdatenbanken zu speichern. Für das standardisierte Speichern von objektbezogenen Daten auf dem RFID-Transponder besteht derzeit noch kein vergleichbares Konzept. In dieser Arbeit wird ISO 13584 für die Speicherung von Daten mittels standardisierter Merkmale vorgeschlagen und für den Einsatz mit RFID-Transpondern konzipiert.

Letztendlich werden die Ergebnisse aus Fallstudien mit zwei Unternehmen herangezogen, um die in dieser Arbeit entworfenen Konzepte zu evaluieren. In der ersten Fallstudie über den Einsatz von RFID-Technologie in der Bekleidungsindustrie wird das entwickelte Modell zur Kosten-Nutzen-Aufteilung angewendet. Die zweite Fallstudie beschreibt zwei Szenarien für den Einsatz von RFID bei einem Küchenmöbelhersteller. Im ersten Szenario wird Weiße Ware mit RFID-Transpondern ausgestattet, um die über- und innerbetriebliche Prozessabwicklung zu optimieren. Das zweite Szenario beschreibt die merkmalsbasierte Speicherung von zusätzlichen Daten auf RFID-Transpondern und dient dem Nachweis der Durchführbarkeit des Speicherkonzepts nach ISO 13584.

Schlagwörter:
RFID, Unternehmensübergreifende Informationssysteme,
Wertschöpfungskettenmanagement, Internet der Dinge

Contents

Chapter 1

Introduction

1.1 Motivation

Radio Frequency Identification (RFID) technology, which allows for the simultaneous identification of several objects without line of sight or human interaction, promises to significantly improve supply chain efficiency [Niederman et al., 2007]. The attention researchers and practitioners are giving it has increased substantially in the last few years. Experts believe that RFID is an innovation that – after the Internet – might revolutionize the ways we conduct businesses [Lee, 2007]. In light of this, current studies show that the adoption of RFID technology is increasing as there is a perceivable shift from RFID pilot projects of the early days towards a broad deployment of RFID [Wolfram et al., 2008]. But although the highest potential to take advantage of this spread is expected to be realized in cross-company applications, the status quo in the RFID project landscape is dominated by local solutions within companies Thole [2008]. This has lead to a situation, where the use of RFID in the supply chain is still lagging behind its expectations [Schmitt and Michahelles, 2008].

Reasons for this phenomenon include high investment and operational costs, the difficulty of assessing the benefits in advance as well as missing standards [Straube et al., 2005]. Especially because of cost-effectiveness, the initial euphoria over RFID's potential has recently made way for a more down-to-earth view of its benefits in the supply chain. Companies who consider using RFID usually conduct a conservative preliminary analysis of the financial impact of such an investment. These analyses typically focus on three types of benefit expected from RFID: the reduction of labour, capital and non-conformity costs such as those caused by incorrect deliveries. Labour and capital costs can be decreased by RFID-enabled process speedups, while non-conformity costs can be reduced by detecting mistakes made during the distribution process and taking appropriate action to prevent them. Given the still relatively high cost of passive RFID transponders (currently about 7 Eurocents), the use of disposable transponders on the item level represents a significant increase of variable costs in the short run. The one time use of RFID transponders on consumer goods to support standard distribution processes (e.g. picking, packing, shipping etc.) is hardly justifiable in financial terms.

There are two interdependent reasons for the sluggish item level introduction of RFID: high transponder prices and low demand. In 2006, the biggest share of RFID transponders produced worldwide (556 million) went to products such as smart cards, keys, passports and tickets [IDTechEx, 2007]. Only 153 million of them were sold for the purpose of identifying goods such as drugs, tools, books, apparel and other consumer products. Roughly 235 million transponders went to the identification of logistical units such as packages, cases and pallets. The market price of RFID transponders is the pivotal parameter of most profitability calculations. The efficiency gains achievable in the logistics operations of organizations such as labour cost savings and prevention of process errors has to outstrip RFID transponder and infrastructure costs; otherwise, the vision of pervasive RFID tagging is unlikely to become a reality. According to industry experts, the RFID market is supposed to take off as soon as item level tagging in logistics applications becomes economically viable. On the other hand, economies of scale in producing RFID transponders cannot be fully realized since no large-scale item level RFID implementations exist so far.

In contrast to RFID applications realized within one company, cross-company applications make it feasible to overcome the cost problems. This is discussed in the first part of this thesis among other organizational aspects. Initially, a conceptual reference framework for structuring cross-company RFID applications is introduced. This classification is followed by presenting the findings of a quantitative cross-sectional study in which a possible imbalance of costs and benefits among the supply chain participants is shown to be a key factor for the perceived likelihood of a successful RFID introduction. In the course of using a collaborative RFID application, it is possible to reduce the costs for the individual player by distributing them between a larger number of participants and repeatedly using the same tag across multiple supply chain steps. Regardless of this, high RFID costs are no longer the crucial factor if the expected benefits exceed them; however, in a multi-echelon supply chain, the players engage in such different functions that the potential benefits will not be distributed equally among all participants. While manufacturers and logistics service providers prefer to track the flow of cases or pallets, retailers typically gain the highest benefit by tracking individual items on the sales floor [Gaukler and Seifert, 2007b, p. 44]. In summary, the reasons for these problems are based on the fact that the resulting expenses and benefits realized are by no means distributed equally among the participants. For this reason, a model for cost-benefit sharing – including different categories of compensation as well as temporal dependencies during the life cycle of an application – is developed.

Apart from these organizational dimensions of cross-company RFID applications, the technical dimension has to be investigated because missing technical standards are still an obstacle for the wider adoption of RFID in a collaborative context. For the capturing and cross-company exchange of RFID read events, the industry consortium EPCglobal has developed a set of specifications that build the technical basis for the EPCglobal network [EPCglobal, 2009]. Objects that are equipped with an RFID tag that contain an Electronic Product Code (EPC) are identified at several steps in the supply chain and information about the movement of these objects (things) can be accessed via the Internet. Known as the *Internet of Things*, this concept has recently received enormous attention. There are three remaining problems, however, which are identified in this thesis: (1) generating RFID events does not only require the data that is provided by the RFID readers, but also corresponding context data; (2) the EPCglobal network provides the technical basis for the Internet of Things, but not the applications that might profit from using this architecture; and (3) there is no standardized approach for storing user generated content besides the EPC on the RFID tags. Solutions to these problems will be presented here:

1. We propose an architectural component called Event Capturing Application (ECA) for the association of read events and context data and develop a prototype that implements this ECA on the top of noFilis' RFID middleware – CrossTalk. Experimental results indicate adequate performance.

2. Several higher-level business applications that query the EPCIS repository are possible. In this thesis, Supply Chain Event Management (SCEM) systems are analysed. The term SCEM refers to the practice of observing, prioritizing and reacting to events that can occur in the operation of a supply chain. A tentative protocol layer that follows a push architecture approach is specified here; it serves to integrate heterogeneous enterprise systems that exchange EPCIS-based events. Secondly, an objective comparison between the centralized EPCIS-based architecture proposed by EPCglobal is performed with the proposed

decentralized one. For this purpose, quantitative evaluation criteria are developed and applied to both architectures.

3. EPCglobal has specified a stack of specifications that enable a standardized identifier to be stored on the RFID tag and all object related data to be kept on the network. Such a standardized concept does not yet exist for storing object related user generated data on RFID tags. We recommend applying ISO 13584, which concerns standardized properties. Following through with this recommendation, we conceptualize how to use ISO 13584 to store data on RFID tags.

Finally, case studies on two companies will validate the concepts developed in this thesis. A case study on the use of RFID in the fashion industry will highlight all aspects concerning cost-benefit sharing. The second case describes two scenarios on using RFID at a kitchen furniture manufacturer. A study of tracking white goods will verify the conceptual framework and a study of storing data on RFID tags attached to cupboard fronts will show that our proposed approach for storing data on tags using ISO 13584 is feasible.

1.2 Contributions

This thesis provides the following contributions:

- A conceptual reference framework for cross-company RFID applications is developed. This framework will contain all factors, extracted in a literature review, that influence cross-company RFID systems. The goal of this framework is to differentiate different types of systems if the technology is mature enough for an immediate introduction or if there is still a need for further research.

  These results have previously been published in Tribowski et al. [2009c].

- Based on a quantitative cross-sectional study, factors affecting the perceived likelihood that cross-company RFID is adopted are identified. Our empirical results indicate that profitability is one key success factor in this context. Related important factors are the uncertainty of costs and returns; and the possible imbalance of costs and returns among the supply chain participants.

  These results have previously been published in Goebel et al. [2009a].

- A high discrepancy between the occurring costs and the resulting benefits for each of the network partners may result in a cross-company

RFID system. This unequal distribution puts the success of the application at risk. A model for cost-benefit sharing – including different categories of compensation as well as temporal dependencies during the life cycle of an application – is developed.

These results have previously been published in Bensel et al. [2008].

- For the cross-company exchange of RFID-related data, the industry consortium EPCglobal has specified the EPC Information Services (EPCIS). According to EPCglobal, all RFID-related data recorded by an organization should be stored as EPCIS events in a dedicated database; however, generating an EPCIS event does not only require the data provided by the RFID readers, but also the corresponding context data (e.g. physical locations, related business process steps and related transactions). We propose an architectural component called Event Capturing Application (ECA) for this association of read events and context data.

  These results have previously been published in Tribowski et al. [2009a].

- Supply Chain Event Management (SCEM) systems are decision support systems that allow for monitoring, prioritizing and reacting to events pertaining to the flow of goods in a supply chain. We propose a system architecture based on RFID and the EPCglobal network in order to provide the informational basis for SCEM. Using analytical methods, we evaluate these architectures with respect to efficiency and reliability.

  These results have previously been published in Goebel and Tribowski [2008] and Tribowski et al. [2009b].

- The cross-company usage of RFID can only work if the collaborating companies agree on the syntax and semantic used. EPCglobal has specified a stack of specifications that enable a standardized identifier to be stored on the RFID tag and all object related data to be kept on the network. Such a standardized concept does not yet exist for storing object related data on RFID tags. We recommend applying ISO 13584, which concerns standardized properties. We conceptualize how to use ISO 13584 to store data on RFID tags.

  These results have previously been published in Leukel et al. [2006a] and Tribowski et al. [2009d].

- To test the feasibility of the developed concepts, two case studies on companies from the apparel and kitchen furniture industries have been conducted. These results have been published in Bensel et al. [2008], Tribowski et al. [2009c], Goebel et al. [2009b] and Tribowski et al. [2009d].

1.3 Methodology

This thesis is positioned in the Information Systems (IS) community. The objects of this scientific discipline are information and communication systems in economy and administration in general [Fachkommission Wirtschaftsinformatik, 2007]. This thesis will especially concentrate on supply chain management as a subtopic of intra and inter-organizational information systems. Supply chain management can be defined as the cross-company coordination and optimization of the flow of material, information and finance and spans the whole value adding process from raw material production, to overall processing steps to the final customer [Arndt, 2005, p. 46]. This thesis focuses on RFID technology as a means of contributing to the goals of supply chain management.

The IS community can be characterized as a methodologically pluralistic discipline, which ranges from behavioural science to design science [Wilde and Hess, 2007]. Except for Section 2.2, where a quantitative cross-sectional study is used to discover the factors that affect the perceived likelihood of cross-company RFID adoption, this thesis follows the latter community's orientation.

Design science can be described as a two-step research process where a conceptual phase is always followed by a phase in which at least one evaluation method is applied [Hevner et al., 2004]. The results of the conceptual phase are an IT artefact. Hevner et al. [2004] define IT artefacts as constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices), and instantiations (implemented and prototype systems), which are concrete prescriptions that enable IT researchers and practitioners to understand and address the problems inherent in developing and successfully implementing information systems within organizations.

The IT artefacts developed in this thesis are: a conceptual reference framework for structuring cross-company RFID applications; a method for cost-benefit sharing; an architecture approach and prototype for context data management; an architecture approach and protocol for SCEM; and, finally, a method on how to use ISO 13584 for storing data on RFID tags.

In design-science research, the utility, quality, and efficacy of the design artefact must be rigorously demonstrated via well-executed evaluation methods. The selection of evaluation methods must be matched appropriately with the designed artefact and the selected evaluation metrics. The applied evaluation methods in this thesis consist of: empirical findings from case studies; theoretical quantitative calculations; practical proof of concepts with prototypes; a performance experiment of a prototype; and a combination of the above-mentioned concepts.

Among these, the case study approach is dominant – for this reason, the empirical data gathered from the case studies are put in a separate chapter. Case studies are popular both in operations management and information systems research [Voss et al., 2002] since they offer insights into the activities and experiences of a particular company. Given today's low RFID adoption rates, empirical investigations of the benefits and challenges involved in the application of RFID in cross-company applications would not be very fruitful at this time, so research on RFID applications in supply chain management have had to focus on the ex-ante estimation of benefits. In contrast to this, the analysis of single RFID adoption cases already makes sense and should be the preferred research method until adoption has spread further.

Case study research can be used for exploratory, descriptive and explanatory purposes [Schmitt and Michahelles, 2008]. In contrast to quantitative research methods, case studies serve to analyse single or multiple cases with respect to several dimensions of relevance. The cases presented in this thesis serve to explore technical and organizational challenges involved in the design, implementation and deployment of item-level RFID in cross-company settings.

Figure 1.1 depicts the classification of the contributions of this thesis against the behavioural vs. design science paradigm and the degree of formulization (qualitative vs. quantitative) [Wilde and Hess, 2007].

1.4 Structure of the Thesis

This thesis is structured as follows. In the current chapter, the introduction and problem statement, the research method and the main contributions have been presented. This thesis will then tackle organizational as well as technical aspects concerning cross-company RFID applications. The organizational aspects form Chapter 2. Initially, the conceptual reference framework for structuring cross-company RFID applications is introduced. This is followed by the findings of a quantitative cross-sectional study in which a possible imbalance of costs and benefits among the supply chain participants is shown to be a key factor for the perceived likelihood of a successful RFID introduction. This is why a model for cost-benefit sharing – including differ-

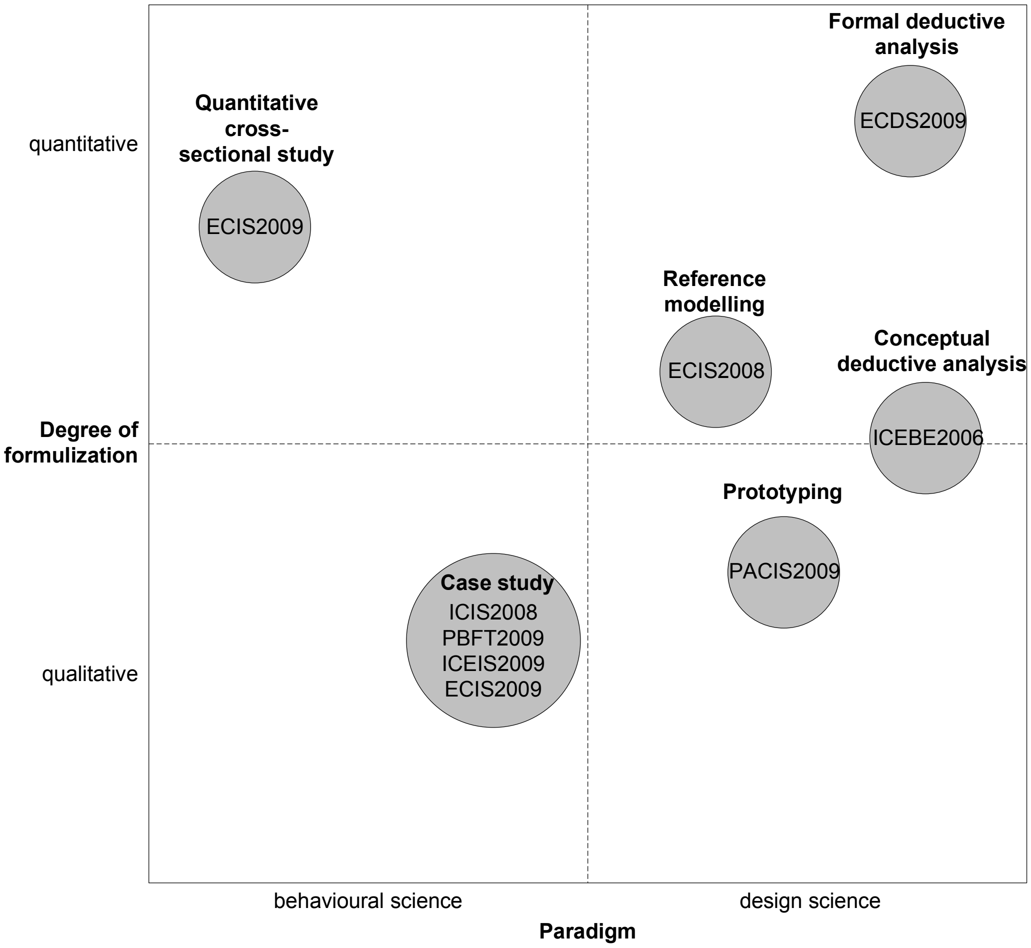


Figure 1.1: Categorization of published papers

ent categories of compensation as well as temporal dependencies during the life cycle of an application – is developed in the third section.

Technical aspects of cross-company RFID applications are the focus of Chapter 3. For the capturing and cross-company exchange of RFID read events, the industry consortium EPCglobal has developed a set of specifications that build the technical basis for the EPCglobal network. After giving an overview of these specifications, three remaining problems are addressed. The first problem is that generating an EPCIS event does not only require the data that is provided by the RFID readers, but also the corresponding context data. We propose an architectural component called Event Capturing Application (ECA) for this association of read events and context data. The second challenge is that although the EPCglobal network provides the technical basis for the Internet of Things, it does not provide the applications that might profit from using this architecture. This is why we develop the architecture for an RFID-based Supply Chain Event Management system that profits from an improved information basis gathered by RFID. The EPCglobal specification regarding tag data contains memory for both the standardized Electronic Product Code and for user generated content. So far, there exists no unified standard for storing user generated content on RFID tags. To solve this, in the last section of the chapter on technical aspects, an approach for using standardized properties will be proposed.

In Chapter 4, case studies on two companies will validate the concepts developed in the previous chapters. The first study on the use of RFID in the fashion industry will highlight all aspects concerning cost-benefit sharing. The second study describes two scenarios on using RFID at a kitchen furniture manufacturer. The scenario of tracking white goods will verify the conceptual framework and the scenario of storing data on RFID tags attached to cupboard fronts will show that our proposed approach is feasible.

Finally, Chapter 5 will summarize the results of this thesis – closing with an overview of open research problems. Figure 1.2 depicts the structure of thesis at a glance.

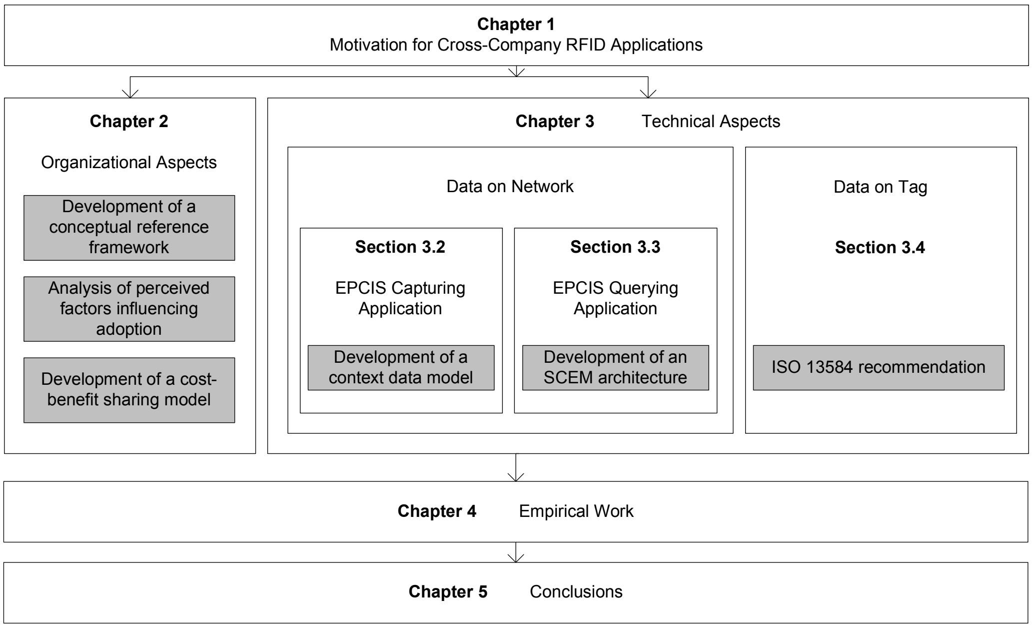


Figure 1.2: Structure of this thesis

Chapter 2

Organizational Aspects

2.1 Conceptual Reference Framework

The goal of this section is to show for which type of RFID applications the requirements for an immediate introduction are fulfilled and for which applications there is still a need for research. To structure the types of RFID applications, in the following sections the influencing factors are captured by applying a morphological method; existing and prospective cross-company RFID applications are sorted into this structure; and finally a classification of application types is deduced.

Following the two-step research approach of design science [Hevner et al., 2004], the developed conceptual reference framework developed in this section will be evaluated with a confirmative case study [Meyer, 2003] in Section 4.2.2. In the field of RFID, numerous case studies on cross-company distribution logistics processes are available [Bendavid et al., 2006], [Loebbecke, 2005], [Loebbecke et al., 2006], [Romanow and Lundstrom, 2003], [Wamba and Boeck, 2008], etc., so in this case study, the focus is on production logistics, which is currently receiving less intensive research. The representativeness of this work will be gained by abstracting from the findings within the furniture industry and focusing on the generally valid order processes.

To develop a conceptual reference framework for cross-company RFID applications by applying a morphological classification method, the relevant parameters and parameter values are first derived from a literature analysis. However, this morphological method is not used as a creative technique to develop a problem for each possible combination of parameter values; rather, existing and future applications are classified. Two types of applications are deduced from the similarities in their parameter values.

2.1.1 Classification Parameters

The application area of RFID projects is an important classification parameter [Frey et al., 2007]. In CE RFID's reference model [CE RFID, 2007] (Coordinating European Efforts for Promoting the European RFID Value Chain), eight different application areas (including sub-categories) are distinguished. The association of tags with humans as well as applications from the fields of leisure, access control and the like are excluded because the focus of this work is on B2B applications. In Asif and Mandviwalla [2005], in addition to the application area of RFID, a classification based on its major purpose (identification, authentication, data acquisition, location) and transponder type (active, passive, etc.) is proposed.

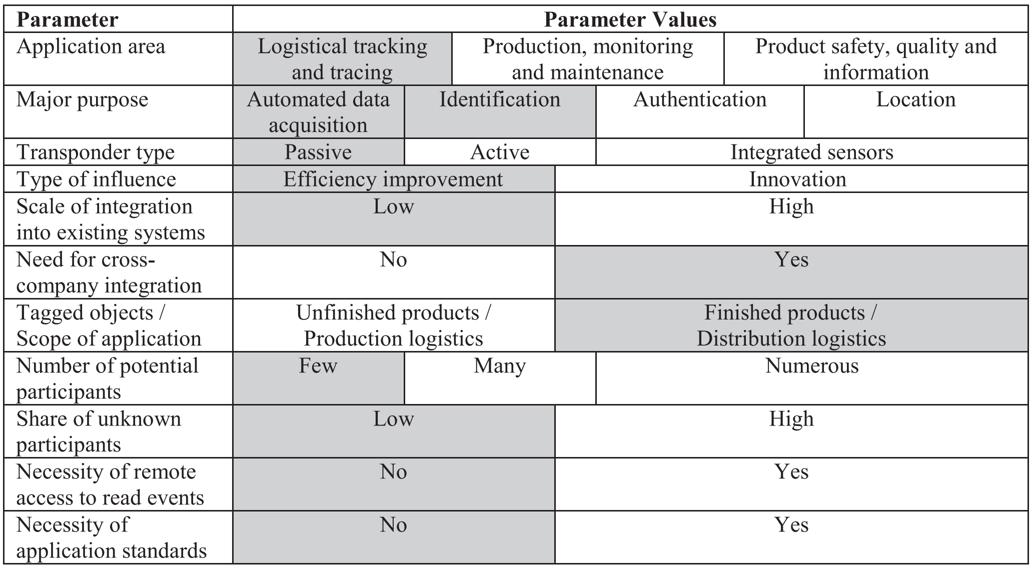
A further parameter, which is used to structure the benefits of RFID, is the type of influence that RFID has on the supply chain. These impacts can be characterized by an improvement of efficiency on existing processes or an enablement of radical new processes and services [Leimeister et al., 2007]. This categorization is used by various authors and is called either the automation vs. information vs. transformation effect [Tellkamp, 2006] or existing games vs. new games [McFarlane and Sheffi, 2003, p. 12 and 20] or substitution vs. scale vs. structural stages [Lee, 2007].

From the point of view of information systems research, the scale of integration of new information and communications systems into the existing IT infrastructure is of great importance. At low scale integration, the new RFID application manages the RFID-based data completely independently from the ERP system. At medium scale integration, the RFID application additionally has access to business data from the ERP system; while at large scale integration, supplementary transactions in the ERP system are initiated [Frey et al., 2007]. Furthermore, especially for applications with the goal of increasing process visibility, an inter-organizational integration of software systems becomes necessary.

A further parameter to distinguish cross-company RFID applications is the tagged object. While in production logistics it is mainly components and unfinished products that are tagged, in distribution logistics products and logistical units are identified. If only a few partners are participating in the application and if all participants are known to each other, the contact person from the other company (e.g. for the configuration of the EDI interface) will always be known. On the other hand, applications exist where one or more participants do not know each other in advance.

Closely related is the number of potential participants in the application. These participants can be: cooperating companies, users within companies or end customers in general. With many participants who are only partially known to each other, the requirements of high degree of standardization and loose coupling become very important.

RFID-based data can either be used directly in the form of raw read events or aggregated first. In a slap-and-ship scenario, no additional interfaces between the business partners to exchange raw read events are necessary because the raw read events are aggregated at the shipping area and the dispatch advice is sent to the business partner. This criterion is called *necessity of remote access to read events.* In every application, standards are used more or less on purpose. This especially concerns the more technical standards with regard to frequencies, transponders, air interfaces, etc. Furthermore, using certain applications, data, process, and application standards become necessary. Figure 2.1 aggregates all parameters with the corresponding parameter values mentioned above.



Parameter	**Parameter Values**			
Application area	Logistical tracking and tracing	Production, monitoring and maintenance	Product safety, quality and information	
Major purpose	Automated data acquisition	Identification	Authentication	Location
Transponder type	Passive	Active	Integrated sensors	
Type of influence	Efficiency improvement	Innovation		
Scale of integration into existing systems	Low	High		
Need for cross-company integration	No	Yes		
Tagged objects / Scope of application	Unfinished products / Production logistics	Finished products / Distribution logistics		
Number of potential participants	Few	Many	Numerous	
Share of unknown participants	Low	High		
Necessity of remote access to read events	No	Yes		
Necessity of application standards	No	Yes		

Figure 2.1: Morphologic classification for cross-company RFID applications

2.1.2 Classifying Existing and Future RFID Applications

Companies from the fast moving consumer goods (FMCG) industry were the pioneers of cross-company RFID applications. As early as 2002, the large German retailer Metro AG started an RFID initiative with selected suppliers [Loebbecke, 2005]. The benefits were gained mainly through increased process efficiency by increasing the use of automation. As of 2009, though, its use is still limited to pallets and cases. Other examples of retailers with similar projects are REWE [GS1 Germany, 2007] and Wal-Mart [Romanow and Lundstrom, 2003].

In the textile supply chain, investigating the potential of RFID applications is fairly advanced. After gaining experience in a pilot project with Kaufhof in 2003 [Loebbecke et al., 2006], Gerry Weber started a project in January 2008 to fully implement RFID on the item-level within the Gerry Weber controlled supply chain. Producers in Turkey and China are involved as well as transport and logistics service providers, which also operate the consolidation and distribution centres; and the Houses of Gerry Weber as retail sales points.

The existing applications can be classified into the developed framework in the following way:

- All applications mentioned above have the application field of logistical tracking and tracing in common.
- Passive RFID tags are used for automatic data acquisition and identification of products (and cases or logistical units respectively), with the goal of efficiency improvements in existing processes.
- The scale of integration into the existing IT infrastructure is low.
- Although the necessity of cross-company integration is required, there is no need for accessing read events in the other companies' information systems.
- The number of participating companies is small and they know each other because of existing business agreements.
- The necessity for yet to be developed RFID specific application standards does not exist.

All these parameter values are highlighted in grey in Figure 2.1.

In applied research, there are several studies on cross-company RFID applications. Two of them are described here to demonstrate the vision of the EPCglobal network [EPCglobal, 2009]. The supply chain event management (SCEM) application provides the ability to proactively translate business events with a target/nominal comparison into alerts and to provide action suggestions based on saved business rules [Bretzke and Klett, 2004]. RFID as an automated data acquisition technology has the ability to improve the data basis for such decisions. In Section 3.3, a protocol is described that facilitates SCEM on the basis of the EPCglobal standard EPCIS.

In a pilot project with the participation of SAP, several supply chain participants cooperated to contain product counterfeiting [Jeschke, 2008]. Not only RFID tags were used in this application, but also hybrid solutions where bar code technology is applied. 2D-bar codes are involved in this application because they can be scanned by end customers without any RFID infrastructure. SAP's object event repository, which is based on EPCglobal's EPCIS, is implemented in this solution. Information about the easy integration of external systems has not been published yet.

2.1.3 Interpretation

Most cross-company RFID applications that have passed the pilot phase and have been implemented into daily processes fall into the class highlighted grey in Figure 2.1. The technological requirements for the implementation have been tested and are well-proven.

If all the parameter values not highlighted in Figure 2.1 are considered, a second class emerges. These parameter values can be explained using the future application examples given in Section 2.1.2. Both in SCEM and anti-counterfeiting systems, the number of participants is very large – especially if the end customer uses the application. In addition, the participants are not known to each other in advance. In both applications, the raw RFID read events, which have to be remotely accesses across company borders, play an important role. On the basis of the new information base created from RFID data, the effects of the application can be described as innovative. For these future application fields, a standardized infrastructure for discovering item-level information is particularly important. The EPCIS Discovery Services for the realization of the EPCglobal network are currently under development. Furthermore, application-specific standards or process standards have to be developed.

Practice shows that the diffusion of RFID is marginal even in the first class of application types. At best, only the initial spread of cross-company applications in the distribution logistics can be observed. In Section 4.2.2, the classification parameters of the conceptual reference framework deduced from the literature review are evaluated using a confirmative case study. Because this case study focuses on production logistics instead of distribution logistics, it fills a gap in current research. Finally, the difference between using data standards in distribution and production logistics are extracted and transformed into conclusions, which are especially useful for practitioners interested in implementing cross-company RFID applications.

2.2 Empirical Analysis of Perceived Success Factors

2.2.1 Introduction

The conclusion of the previous section was that even for those RFID applications where the technology is mature enough for immediate introduction, the diffusion of RFID is still marginal. Unfortunately, the introduction of cross-company IT systems has always been a difficult and time-consuming task. A well-known example of such systems from the supply chain domain is Electronic Data Interchange (EDI), which took decades to be successfully introduced. Among other things, asymmetric costs and benefits, different risk attitudes and capabilities across the supply chain participants can complicate the adoption and efficient usage of inter-organizational information systems [Scala and McGrath Jr., 1993].

In this section, we focus on the factors related to the successful introduction of inter-organizational RFID systems. We identify a number of candidates and empirically test the corresponding hypotheses using data from a recent survey. To the best of our knowledge, this is the first empirical work conducted on non-technical success factors of cross-company RFID systems.

In Section 2.2.2, we provide an overview of related literature. Our hypotheses and a conceptual model are presented in Section 2.2.3. In Section 2.2.4, we describe the employed methodology and the results of an empirical study. Section 2.2.5 discusses managerial implications of our work. Section 2.2.6 contains our conclusions.

2.2.2 Related Work

The academic literature on RFID and its use in supply chain management is already substantial. Recent literature reviews include Ngai et al. [2008]. Most of the publications directly related to our research topic can be allocated to one of two groups: (i) conceptual and empirical research on RFID adoption on the company level, and (ii) analytical research on the distribution of RFID benefits between a hypothetical manufacturer and retailer.

A number of papers belonging to the first group concentrate, with different emphases, on collecting the views of practitioners concerning the benefits of RFID within their organizations. Leimeister et al. [2007] investigated the perceived strategic importance of RFID among IT decision makers. They found that the perceived strategic importance is correlated with industry affiliation and company size. Seymour et al. [2007] developed a framework of possible factors of RFID adoption based on several accepted theories on technology adoption and diffusion, e.g. Bakry [2003]'s e-readiness model and Rogers [2003]' Innovation Diffusion Process. Sharma et al. [2007] proposed a model for RFID adoption on the company level that is, among other things, grounded in the literature on inter-organizational systems; they adopted a number of factors form research on the adoption of Electronic Data Interchange (EDI), in particular Chwelos et al. [2001] and Teo et al. [2003]. Madlberger [2008] investigated the influencing factors on the introduction of RFID in supply chain management applications and found that internal process improvements, inter-organizational benefits, technical advantages and the costs of RFID, but not the company size, have an influence on the introduction of RFID. Using data from a survey among 146 German companies, Gille and Strüker [2008] measured how the type and sophistication of benefit and performance analyses conducted before and after RFID introduction impact the productivity gains achieved by RFID. They found that the frequent use of particular measurement methods is strongly correlated to the improvement of target variables such as lead time and labour costs. In another paper, the same authors addressed specific aspects of small and medium sized companies [Gille and Strüker, 2008]. They found that RFID adoption is easier in smaller enterprises.

Some researchers have begun to investigate the distribution of benefits across prototypical supply chains; this automatically leads to the question of how RFID transponder costs should be shared optimally if benefits are distributed unequally. Gaukler et al. [2007a] investigated this research question using an analytical model. They showed that sharing the tag costs results in overall profit maximisation if the manufacturer is more powerful than the retailer; however, if the retailer is more powerful, there is a need for sharing tag costs in order to realize the most profit. Unfortunately, the analytical model is based on a highly stylized supply chain model and only captures information benefit and tag costs while ignoring the benefits resulting from labour and error cost savings.

In this work, we empirically investigate the factors that determine the adoption of cross-company RFID. The focus on the entire supply chain instead of single companies sets it apart from previous empirical business research on RFID. While using an empirical approach makes it easier to grasp real world conditions, our findings leave more room for interpretation than results obtained from analytical models.

2.2.3 Hypotheses and Conceptual Model

Our conceptual model consists of one major dependent variable, namely the perceived likelihood of cross-company RFID adoption. The model is designed to reveal the influence of several factors on this dependent variable. These independent variables include the expected degree of RFID profitability across the supply chain, the uncertainty of RFID benefits, the uncertainty of RFID costs, the asymmetry of RFID profitability across the participants, the existence of a driving organization that takes the initiative in planning cross-company RFID deployment, the existence of a dominant supply chain participant which can force the introduction of cross-company RFID, and the existing RFID experience in the supply chain. In addition to this greater model, we also investigate how expected degree of RFID profitability is impacted by two more independent variables: the depth and the breadth of the inter-organizational RFID implementation. We propose the following related hypotheses:

H1: *The expected profitability of cross-company RFID positively influences the perceived likelihood of adoption.*

With this hypothesis, we imply that higher stakes provide an incentive for better coordination. In other words, we hypothesize that if the supply chain participants expect a higher profit for the supply chain as a whole, they will be more motivated to collaborate in order to realize (and possibly redistribute) this return. This factor – profitability – appears in many studies on technology adoption; however, it is usually split up into benefits and costs [Sharma et al., 2007]. We focus on profitability since we are interested in the 'size of the pie' to be distributed among all the supply chain participants. The current uncertainty involved in estimating the costs and benefits of RFID may cause risk-averse decision-makers to forgo participation in or bail out of cross-company RFID projects.

Transaction cost theory suggests that in situations where the outcome of a joint investment is highly uncertain and the assets are highly specific, the emerging negotiation, monitoring and legal costs can be significant [Williamson, 1979]. Furthermore, the fear of opportunistic behaviour can result in a complete failure to coordinate on technology adoption. We therefore hypothesize that the uncertainty of RFID benefits as well as the uncertainty of the eventual cost of the RFID implementation have a negative effect on the perceived likelihood of adoption.

H2: *The uncertainty of the benefits provided by cross-company RFID negatively affects the perceived likelihood of adoption.*

H3: *The uncertainty of the costs of cross-company RFID negatively affects the perceived likelihood of adoption.*

With regard to the consumer products industry, it has often been argued that RFID will provide higher benefits for retailers than for manufacturers [Byrnes, 2003]. Whereas the former can use it for various purposes on the shop floor, the latter may not be able to reap substantial benefits [Weber and Jensen, 2007, p. 34]. If we take this to be true, without efficient and incentive-compatible methods to redistribute RFID costs, a concerted deployment of RFID along the supply chain will be hard to achieve. Although its importance has been repeatedly stressed, RFID cost redistribution remains an open issue [Bensel et al., 2008]. The more asymmetrically profitability is distributed among the supply chain participants, the more incentives in different forms have to be provided by those participants who gain more. Due to the company-centred vantage point in the existing literature, this factor has not been considered in previous work. Against this background, we formulate the following hypothesis:

H4: *The asymmetry of RFID profitability in the supply chain has a negative effect on the perceived likelihood of cross-company RFID adoption.*

One or several supply chain participants can play a crucial role in initiating and supporting the RFID introduction process. This concept is known in the IS as well as the general management literature, however, rather on a personal level (the 'champion'). Regarding cross-company RFID, there are two prominent examples for such champions: Wal-Mart and Metro. Although their methods of fostering RFID introduction differ, they both stand out as main supporters of the technology in their respective supply chains. Wal-Mart took unilateral action in planning the deployment of RFID and issued mandates to their suppliers [Romanow and Lundstrom, 2003]. On the other hand, Metro actively involved suppliers and other companies by starting the *future store initiative* [Loebbecke, 2005]. In particular, they offered non-monetary compensation to their suppliers, including the timely communication of relevant sales data. We hypothesize that the existence of an RFID champion has a positive impact on the perceived likelihood of adoption, irrespective of the means that this champion applies to foster the adoption process.

H5: *The existence of a RFID champion in the supply chain has a positive influence on the likelihood of cross-company RFID adoption.*

We would like to stress that an RFID champion does not necessarily have to be powerful in the sense that it can 'mandate' the supply chain wide adoption of RFID; however, the existence of a powerful player in the supply chain can have an influence just as crucial as the existence of a champion [Sharma et al., 2007]. From an economics point of view, power asymmetries can intensify incentive problems regarding the adoption of commonly used information technology. If one supply chain participant (e.g. the supplier) is economically dependent on another one (e.g. the retailer), the supplier will fear that the retailer will impose its will when the parties disagree on some issue during the implementation process. This worry is amplified after significant investments have already been made. In anticipation of such opportunistic behaviour, the weaker party may refuse to cooperate right from the start. In the empirical IS literature, the contrary hypothesis is more common: namely that the (potential) coercive influence of a powerful partner positively affects the intention of the 'weaker' party to adopt inter-organizational information technology [Sharma et al., 2007]; however, we would like to emphasize that at least the empirical results of Chwelos et al. [2001] do not show a significant impact of the degree of dependency in the context of EDI adoption. We hypothesize that the existence of a powerful company in the supply chain (semantically similar to 'dependency' as defined by Chwelos et al. [2001] has a negative effect on the perceived likelihood of adoption.

H6: *The existence of a powerful player among the supply chain participants has a negative impact on the adoption of cross-company RFID.*

If the stakeholders involved in a cross-company RFID project have already gained experience with the technology, they should also have a more realistic view of the cost-benefit trade-offs and technical challenges of its inter-organizational use. This in turn should make them more confident of avoiding pitfalls in the planning and implementation phase. We therefore expect that decision-makers estimate the probability of successful cross-company RFID introduction to be higher if there is more existing knowledge about the technology in the supply chain.

H7: *A higher degree of RFID experience in the supply chain positively affects the perceived likelihood of successful cross-company RFID introduction.*

The more details about the movement of goods through the supply chain can be obtained from RFID-enabled information systems, the higher the potential for supply chain process automation. Experts in the field have long argued that benefits are likely to increase when moving from pallet to case and case to item-level tagging [Michael and McCathie, 2005]. At the same time, the more processes are restructured and adjusted to each other in order to effectively use the additional data capturing capability provided by RFID, the higher the ROI of the transponders becomes. However, increasing the depth of an RFID implementation does not necessarily improve its profitability since it comes with higher implementation and integration costs. Just think of the additional transponders required to tag single products instead of cases or the effort involved in redesigning all supply chain processes instead of just one or two. Although this cost-benefit trade-off is non-trivial, we hypothesize that the depth of the inter-organizational RFID implementation has a positive impact on the expected profitability.

H8: *The depth of the inter-organizational RFID implementation has a positive effect on its expected profitability.*

Similar to the depth of a cross-company RFID implementation, its breadth should have a positive effect on the expected profitability. Breadth denotes the number of different organizations participating in the RFID application. If each additional supply chain organization that participates in the inter-organizational RFID application can benefit from the RFID transponders moving through the supply chain, the overall ROI of the transponders should increase with the number of participants. The following hypothesis reflects this reasoning.

H9: *The breadth of the inter-organizational RFID implementation has a positive effect on its expected profitability.*

Figure 2.2 shows the conceptual model and the corresponding hypotheses graphically.

2.2.4 Empirical Study

Survey Design and Sampling

In order to test the hypotheses outlined in the previous section, we developed scales that measure the different variables. Before conducting the survey, several industry experts and representatives were interviewed in a small workshop. The wording of the questionnaire was discussed in order to make sure that the all terms and formulations were clear and interpreted correctly and equally by the practitioners.

The developed questionnaire was appended to a more general survey on RFID in logistical applications. Its online completion was possible in the German or English language. Sample collection took place from April 1st

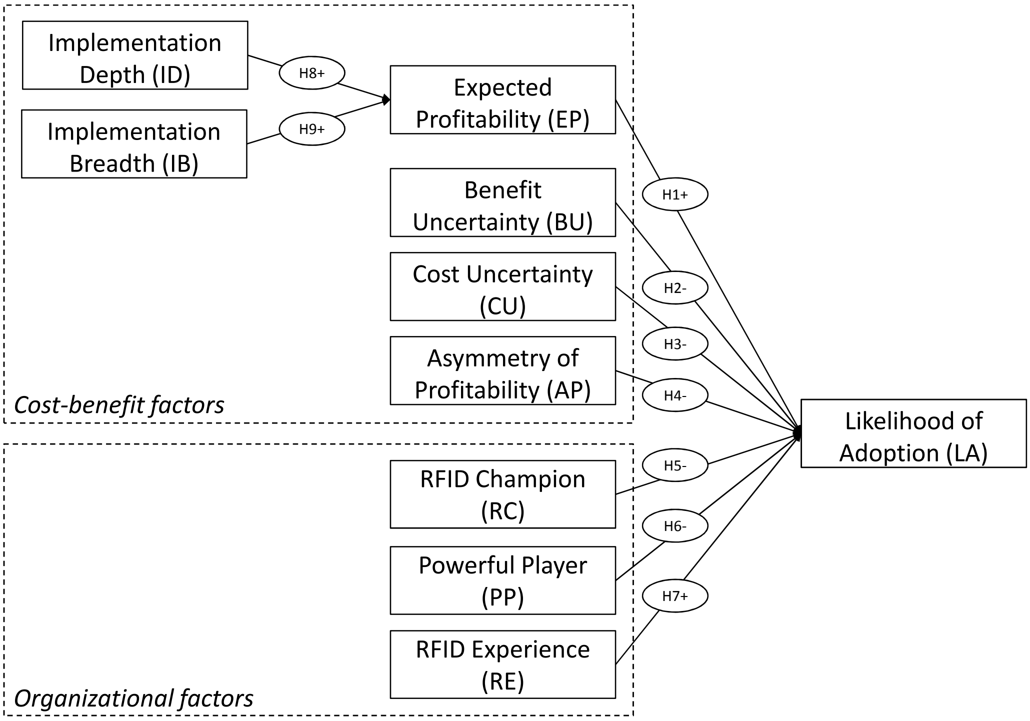


Figure 2.2: Conceptual model

to September 2nd 2008. During this time, 947 personal invitations were emailed. Additionally, the survey was announced in a number of popular logistics and RFID publications and forums. After several weeks, the invited persons were reminded of the survey by phone.

The data collection effort resulted in 153 answered questionnaires. 107 of these were responses to the personal invitations, the rest (46 responses) were filled out anonymously in response to the public announcements. Not considering the anonymous responses, the response rate was 11.3%.

In order to evaluate the representativeness of the sample, we analysed its distribution with respect to four general company profile indicators: size of revenue, number of employees, industry affiliation, and the role that the respondent's company plays in the supply chain. Table 2.1 summarizes the general sample description. None of the indicators exhibits any unexpected concentration. The companies represented in the sample take on different roles in the supply chain: as the corresponding sample description data indicates, our data reflects the opinion of managers who represent suppliers, manufacturers, retailers, logistics service providers and IT service providers. This ensures that questions referring to the supply chain as a whole are answered from different vantage points and therefore increases the validity of

Table 2.1: General sample characteristics

Revenues in mln. Euro	% of companies	Employees	% of companies	Industry	% of companies	Supply chain role	% of companies
< 100	14.7%	< 500	29.4%	Electrical	16.2%	Supplier	10.3%
100-1,000	13.2%	500-5,000	22.1%	IT	14.7%	Manufacturer	41.2%
> 1,000	27.9%	5,000-50,000	27.9%	Retail	11.8%	Retailer	17.6%
n.a.	44.1%	> 50,000	20.6%	Logistics	8.8%	Logistics SP	8.8%
				Automotive	7.4%	IT SP	22.1%
				Consumer goods	5.9%		
				Engineering	5.9%		
				Others	29.4%		

Table 2.2: RFID-related sample characteristics

Type of RFID use	% of companies	Duration of RFID use	% of companies	Typical RFID project budget in Euro	% of companies
None	23.5%	0	23.5%	0	23.5%
Pilot	26.5%	< 1 months	11.8%	< 100,000	25.0%
Running system	50.0%	1 - 6 months	14.7%	100,000 - 500,000	17.6%
		7 - 12 months	22.1%	500,000 - 1 mln.	20.6%
		1 - 2 years	11.8%	> 1 mln.	13.2%
		> 2 years	16.2%		

our results. In addition to the basic company profile, we provide descriptive statistics on RFID implementation progress indicators. These indicators include the number of respondent organizations that have implemented RFID pilots and running applications, the duration of RFID usage and the budget of a typical RFID project within the respective company. Table 2.2 summarizes the RFID-related statistics. They show that the sample is dominated by respondents who have gained substantial experience with the RFID technology.

Descriptive Results

Table 2.3 provides descriptive statistics of the obtained survey data. A darker cell background indicates a higher concentration in the respective answer. As the results show, the majority of survey participants judge the profitability of cross-company RFID (EP) positively. Slightly more participants believe that

Table 2.3: Descriptive statistics (cell shading indicates concentrations)

Measured Variable	5 Point Scale (1 = very low, 5 = very high)					Mean	Std. Error
Implementation Depth (ID)	9%	13%	31%	35%	12%	3.279	0.016
Implementation Breadth (IB)	19%	19%	31%	1%	29%	3.029	0.022
Expected Profitability (EP)	3%	9%	22%	38%	28%	3.794	0.015
Benefit Uncertainty (BU)	6%	34%	35%	19%	6%	2.853	0.015
Cost Uncertainty (CU)	4%	29%	38%	24%	4%	2.941	0.014
Asymmetry of Profitability (AP)	16%	28%	28%	18%	10%	2.779	0.018
RFID Champion (RC)	3%	13%	26%	28%	29%	3.676	0.017
Powerful Player (PP)	9%	16%	22%	25%	28%	3.471	0.019
RFID Experience (RE)	22%	16%	38%	22%	1%	2.647	0.016
Likelihood of Adoption (LA)	4%	13%	46%	29%	7%	3.221	0.014

cross-company RFID will be adopted (LA) in their supply chain; almost half of the respondents are undecided. Surprisingly, more participants indicated that they find it rather easy to estimate costs and benefits of cross-company RFID ex-ante.

Statistical Methodology and Results

The purpose of our statistical analysis is to test the hypotheses presented in Section 2.2.3 using our data sample. In this section, we outline and justify the applied statistical methodology.

The subset of the collected data used to test the hypotheses of our conceptual model consists of 10 items each with 68 values encoded on a range from 1 to 5. These values represent ordinal measurement points of the defined indicators. Our aim is to determine whether the independent variables in the model have a significant effect on the dependent variables and if so, whether the effect is positive or negative. A suitable statistical methodology to estimate these effects is ordinal logistic regression. We apply this method to the general and the subordinate model with the dependent variables LA and EP respectively. In the first step, we conducted regressions of all independent variables onto the corresponding dependent variables. All statistical computations related to this work were done using the Zelig library for the statistical software R [Imai et al., 2008]. Table 2.4 summarizes the results of the monovariate ordinal logistic regressions.

The statistical effect of the IB variable on the EP variable and the effect of both RC and RE on LA turned out to be insignificant at the 90% level.

Table 2.4: Results of monovariate ordinal logistic regressions

Dep. Var.	Indep. Var.	Est. coef.	Std. error	t-value	Sig. level	Residual dev.	AIC
EP	ID	0.982	0.233	4.210	99.9%	166.91	176.91
EP	IB	0.142	0.154	0.923	-	186.17	196.17
LA	EP	0.679	0.247	2.748	99%	171.21	181.21
LA	BU	-0.410	0.241	-1.696	90%	175.98	185.98
LA	CU	-1.125	0.281	-4.008	99.9%	161.12	171.12
LA	RC	-0.090	0.203	-0.442	-	178.69	188.69
LA	AP	-0.670	0.219	-3.979	99.9%	161.24	171.24
LA	PP	-0.332	0.184	-1.809	90%	175.53	185.53
LA	RE	0.201	0.211	0.950	-	177.97	187.97

Further, the results of the monovariate regressions reveal a significant positive effect of the ID on the EP variable. The variables EP, BU, CU, AP and PP all have a statistically significant effect on LA. While the impact of ID and EP is positive, the impact of BU, CU, AP and PP is negative. The effect of the variables BU and PP is only significant at the 90% level; whereas the other variables' significance reaches higher levels.

In order to compare the relative explanatory power of the independent variables, we also employed multiple regression analysis.

When conducting multiple regression analysis, so-called multicollinearity can cause problems [Mason et al., 1975]: a high degree of correlation between the independent variables in a multivariate regression model can cause the regression coefficient estimates to vary erratically in response to small changes in the model or the data. In particular, the regression coefficients of all independent variables may change drastically depending on which variables are included or left out of the model. Thus, using the regression output without controlling for the adverse effects of multicollinearity on model estimation can lead to false interpretations.

In order to identify potential sources of multicollinearity in our data, we calculated the correlation of the independent variables of the two multivariate regression models using Spearman's rank correlation coefficient. Table 2.5 summarizes the results of this analysis.

The correlation coefficients and the significance levels provided in Table 2.5 reveal a number of significant correlations between the independent variables used in the model. In particular, there are strong positive correlations between the variables DI and BI, BU and CU, AP and EP, PP and CA, as well as between PP and AP.

Multicollinearity can be removed in a number of ways. One is to simply remove independent variables one by one until there is no correlated predic-

Table 2.5: Results of correlation analysis (Spearman's rhos and p-values, cell shading indicates strong and significant correlation)

	ID	IB	EP	BU	CU	RC	AP	PP	RE
ID	1 ∞								
IB	0.5029 0.0000	1 ∞							
EP			1 ∞						
BU			-0.0875 0.4781	1 ∞					
CU			0.0590 0.6332	0.3057 0.0112	1 ∞				
RC			-0.1633 0.1833	0.2716 0.0250	0.0218 0.8600	1 ∞			
AP			-0.2839 0.0190	0.0875 0.4781	0.0066 0.9576	0.0344 0.7806	1 ∞		
PP			-0.1504 0.2209	0.1652 0.1781	-0.0248 0.8410	0.3531 0.0031	0.3853 0.0012	1 ∞	
RE			0.2445 0.0445	-0.1101 0.3713	-0.0540 0.6622	-0.1510 0.2191	-0.0650 0.5983	-0.1751 0.1533	1 ∞

tor variables left in the model. This process has to be conducted carefully – variables should only be removed if they cause an intolerable degree of multicollinearity.

In the first step, we removed the highly correlated variables BI, RC and RE. The results of the monovariate regressions indicate that the influence of these variables on their respective dependent variables is insignificant; therefore, they do not represent important predictors anyway.

The remaining correlations between independent variables include those between CU and BU, AP and EP, and between PP and AP. In order to test whether these correlations cause problems with respect to parameter estimation, models without one variable out of each correlated variable pair were estimated and the corresponding regression coefficients were compared with the estimates from the initial model. These computations revealed that whereas the correlation between the CU and BU variable causes problems when estimating their regression coefficients within the same model, the correlation between AP and EP was unproblematic with respect to parameter estimation.

The impact of the PP variable turned out to be insignificant in the multivariate model and did not contribute to the model fit as measured by the Akaike Information Criterion (AIC) – we therefore dropped it from the model which eliminated the correlation between PP and AP.

Table 2.6: Multivariate ordinal logistic regression results after controlling for multicollinearity

Dep. Var.	Indep. Var.	Est. coef.	Std. error	t-value	Sig. level	Residual dev.	AIC
EP	DI	0.982	0.233	4.210	99.9%	166.91	176.91
LA	EP	0.564	0.254	2.222	95%	156.50	170.50
	BU	-0.657	0.258	-2.543	95%		
	AP	-0.723	0.222	-3.259	99%		
LA	EP	0.502	0.251	2.001	95%	143.53	157.53
	CU	-1.196	0.289	-4.137	99.9%		
	AP	-0.697	0.222	-3.145	99%		

In summary, only the correlation between the BU and the CU variable could not be eliminated without significantly decreasing the explanatory power of the model. In order to resolve this problem, we estimated two models with each containing one of the two variables.

The regression results for the final multivariate models after controlling for multicollinearity are provided in Table 2.6.

As stated earlier, the results of the multivariate regressions allow for a comparison of the different independent variables regarding the strength of their impact on the dependent variables. The estimated regression coefficient (abbreviated by Est. coef. in Table 2.6) indicates the direction (positive or negative) and the strength of the impact (absolute value). The significance levels obtained are sufficiently high (95-99.9%) to assume the existence of the postulated relationships with some confidence.

The PP variable becomes insignificant when it is estimated in the multivariate model. This suggests that its explanatory power is dwarfed by the other independent variables contained in the model. The AP variable has a stronger effect on LA than EP if either BU or CU is included in the model. If BU is included in the model, its impact is stronger than EP's but weaker than AP's. If CU is included, its impact is about twice as high as EP's and AP's.

As the results of the regression analysis indicate, hypotheses H1, H2, H3, H4, and H8 are supported by our data. The support for hypotheses H3, H4 and H8 is particularly significant. The statistical support for hypotheses H5, H6, H7, and H9 is not significant. Possible implications of the statistical results are discussed in the following section.

2.2.5 Discussion and Managerial Implications

The support for H1 suggests that the respondents who expect a high financial return on the introduction of cross-company RFID in the supply chain are more confident with respect to its realization. It implies that higher stakes in the form of unrealized profit make coordination on collaborative RFID introduction more likely. This result appears intuitive. More intriguing is the strength of the statistical support for H1 compared to the effect that uncertainty (BU and CU) and asymmetry of profitability (AP) have on the perceived likelihood of adoption. Higher uncertainty of both benefits and costs reduces the likelihood of successful introduction more strongly than the expectation of higher overall profitability. The same applies to the impact of a more unequal distribution of profitability (AP): the negative impact of asymmetric profitability on the perceived likelihood of cross-company RFID introduction is stronger than the positive impact of expected profitability. These results suggest that the adoption of cross-company RFID can be seriously threatened by both the uncertainty of its profitability and the imbalance of the financial returns realized by the different participants – even in situations where the overall profitability of such applications is judged very positively.

Our results indicate that cost uncertainty has a much stronger effect on the likelihood of adoption than benefit uncertainty. In other words, uncertain costs make decision-makers more pessimistic regarding the introduction of cross-company RFID than uncertain benefits. Given the current problems of accurately quantifying RFID benefits, this result comes as a surprise; however, it could be explained by a possible bias towards cost-based assessment of RFID applications in general. An indication supporting this theory is the finding of Gille and Strüker [2008] that the costs of RFID applications are currently quantified more frequently than their benefits because they can be quantified more easily.

The lack of statistical support for hypotheses H5, H6 and H7 indicates that compared to the examined cost-benefit factors, the considered organizational factors have a less crucial influence on the expected success of cross-company RFID. The promotion of RFID by a 'champion' organization does not seem to play a decisive role (H6), nor do our results indicate a substantial influence of dependencies due to the existence of powerful supply chain participants (H7). The degree of existing RFID experience in the supply chain does not seem to be relevant either (H8).

The lack of statistical significance of H7 corresponds with the results of Chwelos et al. [2001], who tested the influence of dependency on intent to adopt EDI. We believe, however, that it is still interesting since it encourages further research on the usefulness of RFID mandates such as the one issued by Wal-Mart.

The strong statistical support for H8 suggests that the benefit gain achieved by increasing the depth of cross-company RFID implementations is steeper than the corresponding cost increase. H9 can neither be supported nor rejected based on our data: the breadth of an inter-organizational RFID application in terms of participating organizations does not seem to affect its expected profitability. The economic network effect implied by this hypothesis would justify more upfront funding of initiatives that develop and standardize scalable system architectures for the Internet of Things: if profitability increased with the number of participants, the emergence of large clusters of companies that are connected by a common RFID back-end infrastructure would become more likely. We believe that more research on possible economic network effects related to the use of RFID is definitely warranted.

Summarizing our interpretations of the statistical results, the main adoption hurdle of cross-company RFID implementation is the unequal distribution of profitability and the difficulties involved in estimating costs and benefits on the supply chain level. The influence of the considered organizational factors was dwarfed by the considered economic factors. In light of high expectations regarding the profitability of cross-company implementation of RFID (see Table 2.3), our results suggest that in order to advance here, managerial efforts should for now concentrate on the development of adequate cost sharing arrangements and tools that support more accurate ex-ante cost and benefit estimation.

2.2.6 Conclusions

Our research has lead to a number of insights regarding the factors that are perceived to influence the success of cross-company RFID. The impact of all considered cost-benefit factors – namely the expected overall profitability of RFID across the supply chain, the uncertainty of costs and benefits, and the asymmetry of profitability – was statistically significant. The influence of the considered organizational factors – in particular the existence of a powerful player, the existence of an RFID 'champion' and the extent of RFID experience in the supply chain – could not be proven. Our results therefore indicate that the role of organizational factors may be overrated in the given context – at least in direct comparison to cost-benefit factors. However, the collection of more empirical data and the application of more sophisticated statistical methods are warranted in order to legitimately draw conclusions along those lines.

Technical challenges related to the use of RFID in supply chain operations, in particular the often criticised lack of technical standards for RFID hardware and software, have not been considered in our model although they could also be an important determinant of the expected success of cross-company RFID applications. Follow-up research should therefore explicitly address technical issues and evaluate their impact on the adoption and success of cross-company RFID.

Based on our results, we recommend that future non-technical RFID research should focus on effective and more reliable ways to estimate and measure RFID costs and benefits across the supply chain and to share RFID technology costs in an incentive-compatible way. The latter aspect is the focus of the next section.

2.3 Cost-Benefit Sharing

2.3.1 Introduction

The spread of Radio Frequency Identification (RFID) technology has increased substantially in the last few years and professionals are even considering the possibility that it will replace bar code technology in the long run. Although the highest possibility of taking advantage of this spread is expected to be realized in cross-company applications, the status quo in the RFID project landscape is dominated by pilot projects and isolated solutions in specific fields. One of the reasons for this phenomenon is the high investment and operational costs [Straube et al., 2005, pp. 54-55]. In the course of using a collaborative RFID application, these costs should be reduced for the individual player by distributing them between a larger number of participants and the repeated use of the same tag across multiple supply chain steps. On the other hand, high RFID costs are no longer the crucial factor if the expected benefits exceed them. In cross-company RFID applications, costs should be reduced for individual companies by distributing them between a larger number of participants and by repeatedly using the same tag across multiple supply chain steps.

However, in a multi-echelon supply chain, the players engage in such different functions that the potential benefits will not be distributed equally among all participants. While manufacturers and logistic service providers prefer to track the flow of cases or pallets, retailers typically gain the highest benefit by tracking individual items on the sales floor [Gaukler and Seifert, 2007b, p. 44]. In summary, the reasons for these problems are based on the fact that the resulting expenses and benefits realized are by no means economically fairly distributed among the participants. The concept of fairness in this context does not assume an equal distribution of costs and benefits, but rather has to be interpreted subjectively: all participants need to feel that they are being treated fairly because the success of a collaborative RFID application depends, to a great extent, on the acceptance of the participants.

To create this acceptance, the balancing of costs and benefits should be considered. The research question of this section is how and, to a lesser degree, which of these costs and benefits should be distributed among which participants in the context of a cross-company RFID application. Giving answers to these questions is the mission of cost-benefit sharing – the focus of this work. To develop a practical, relevant solution, we use an empirical research method based on an exploratory case study. To ensure that the obtained knowledge is generally valid, we complement the identified characteristics in the case study with findings from the literature.

Taken together, the contribution of this section is fourfold:

- With cost-benefit sharing in cross-company RFID applications, we address an innovative topic which is on the current research agenda.
- Applying an empirical research method, our findings are closely related to practical problems and so suggested measures could be easily implemented.
- With the case study about cost-benefit sharing in an item tagging RFID application in the fashion industry in Section 4.1.6, we present a real-world application which can be used as an example later on.
- We deduce strategies for the different phases for an RFID application project life cycle.

This section is structured in the following way: first, we define what we understand as cross-company RFID applications and give an overview about the related costs and benefits in Section 2.3.2. On this basis, the necessity for a redistribution of costs and benefits is explained in Section 2.3.3. Subsequently, the research questions of this chapter are framed based on related research in Section 2.3.4 and a general discussion of the aspects of cost-benefit sharing – including influencing factors and a cost-benefit analysis – is presented in Section 2.3.5. An in-depth presentation of an exploratory case study on cost-benefit sharing in the fashion industry is given in Chapter 4, Section 4.1.6. In the final section, 2.3.6, we answer the research questions by highlighting two different aspects of the design approach for the cost-benefit sharing presented in the case study: categories of compensation as well as temporal dependencies during the life cycle of a cross-company RFID application.

2.3.2 Costs and Benefits

RFID technology is used for object identification and can be applied in numerous scenarios in almost all industries. According to the CE RFID initiative's RFID reference model [CE RFID, 2007], there are eight application fields which can be differentiated: public services; sports, leisure and household; health care; smart cards with customer, membership and payment functionalities; access control and tracking & tracing of people and animals; product safety, quality and information; production, monitoring and maintenance; as well as logistical tracking & tracing.

For the purpose of this work, an important restriction on these RFID applications is that objects tagged with RFID are handled across companies. The resulting application fields for RFID concern supply chain management. It is defined as the cross-company coordination and optimization of product, information and financial flows across the entire process from primary production through all processing steps to the end consumer [Arndt, 2005, p. 46]. This definition explicitly includes local applications at certain processing steps; and we also take them into consideration as long as RFID tagged products, logistical units, carriers, etc. – or through this tagging created data – are exchanged between at least two involved supply chain participants.

In this context, RFID applications are mostly separated into open and closed loop systems. In open loop systems, the transponder remains on the product after it has been sold. In closed loop systems the transponder is either removed at the end of the supply chain, carried back and reused; or together with the tagged object, e.g. a carrier, introduced to the closed loop again. Hence, a cross-company use does not inherently imply an open system. Consequently, locally closed, collaboratively closed and globally open systems can be differentiated from each other in principal [Strassner, 2005b, p. 126]. In the following, the locally closed systems are excluded; this is because in this kind of application a sharing of costs or benefits would not be relevant.

Cost Drivers of RFID Applications

An RFID system basically consists of transponders, readers and data processing information systems. The costs for readers as well as the costs for information system hardware and software are defined as infrastructure costs. The amount of expenses is highly dependent on the complexity of the RFID application. This complexity is driven by the integration of additional rewriteable memory (e.g. for use in production) or of one or more sensors (e.g. for monitoring the cold chain); and different forms of readers (e.g. mobile handhelds, identification gates or integrated into shelving units). Software costs have to be considered as well. With these costs, the initial purchase prices for the software have to be taken into account as well as the costs associated with customizing, designing and implementing the interfaces to the existing information systems, or even modifying these legacy systems. Besides the integration costs for software and hardware (e.g. installation and configuration), it is essential to take training costs and costs for business process changes into consideration, because these costs often dominate the direct costs [Brynjolfsson and Hitt, 1998, p. 55] [Irani, 2002, p. 22].

Only the one-time costs of an RFID application have been discussed so far. Additionally, the recurring operating costs are of great importance. Of these costs, transponders easily have the majority share in open loops. Further costs which fall into this category are costs for control, maintenance, repair and replacement of hardware, as well as yearly dues for unique manufacture IDs or shared services.

To create transparency in the cost structures of an RFID application, the total cost of ownership (TCO) analysis is an appropriate method to follow. The goal of a TCO analysis is to assess the indirect costs of an IT workspace as well as the usual direct costs. An important observation which should be assigned to RFID systems is the fact that costs for installation, integration, education, support, as well as administration and maintenance of the applications are often significantly higher than the direct costs.

Besides the distinction based on how costs occur (one-time vs. operating), the distinction based on the activity level (fixed and variable costs) has to be taken in consideration. While infrastructure and integration costs compose the fixed costs of an RFID application, the transponder costs in open systems are variable depending on their relative base: here the tagged objects. Important influence factors for the quantity of transponders are integration depth and scope. The integration depth consists of the level of material flow (tagging of pallets, cases or items) and the objects' quantity on the corresponding level (classified in ABC goods by the following criteria: relevance, replacement effort, current value and shrinkage rate) [Strassner, 2005b, p. 123 et seq.]. The integration scope describes the distinction between open and closed systems and their sub-categories. While the transponders are the cost determining factors in open systems with a large quantity of objects that need to be tagged [Strassner and Fleisch, 2005a, p. 47], the importance of their acquisition costs decline with multiple use. If the transponders are removed from the objects at the end of the chain, the expenses for recirculation and reuse, instead of acquisition costs, become dominant [Tellkamp and Quiede, 2005, p. 156].

Potential Benefits of RFID in the Supply Chain

The impact of RFID implementation into the supply chain can be characterized in two different ways: on the one hand, the efficiency of existing processes can be improved; on the other hand, new processes, products or services are enabled because of the radical reorganisation [Leimeister et al., 2007, p. 48]. This categorisation is used by various authors and is called, for example, process automation vs. process innovation [Melski, 2006, p. 23 et seq.] or existing vs. new games [McFarlane and Sheffi, 2003, p. 12 and 20].

The advantages of RFID over bar code technology include the possibility to simultaneously identify several objects without contact, without line of sight and without human interaction. Furthermore, additional data can be stored on RFID transponders, which can be rewritten many times. Not only different product classes, but also each individual item in a product class can be distinguished. RFID transponders are also better protected than bar codes against environmental influences. Because of this, the benefits of automatic identification can be realized in all processes where manual registration activities take place. Due to the substitution of manual contact, the following two effects are achieved: first, the procedure is accelerated because there is less human interaction; and second, mistakes (e.g. due to faulty inputs) can be avoided. In an automated goods receipt and goods issue, for example, the manual count of items, the check for completeness, the matching with the delivery receipt and the accounting entry into the system can be omitted. In general, in all processes a 100% check instead of a sample check can be done without extra effort. Further processes that need manual registration activities are the placing and releasing from stock, picking and packing, as well as the cycle count.

The possible savings due to these automation effects (substitution of manual work and due to higher data quality less follow-up costs because of mistakes) are to a great extend dependent on the automation level of the considered processes. In a very large distribution centre equipped with modern bar code technology, for example, the automation potential is less than for uncoordinated container management processes [Strassner and Fleisch, 2005a, p. 48]; therefore, the automation level is an influencing factor on the potential benefits for each specific participant. On the other hand, the increased productivity due to higher automation does not have an immediate effect on economic advantages for firms – instead, it has to be translated into cost reductions first. In general, this succeeds either by an organic growth of the firm without hiring new employees or by the reduction of jobs.

The second important point is that the adoption of RFID can lead to a process redesign. The amount of actual product inventory in a supply chain can be determined faster and more accurately. With other technologies, this is only possible with huge cost inputs. On the basis of this higher level of visibility [Dittmann, 2006, p. 160], the adoption of new inventory and order policies becomes feasible. Furthermore, a warehouse could be chaotically structured according to efficiency criteria instead of purposes of clarity if the warehouse workers are supported by a pick by light application [Sheffi, 2004, p. 12]. In addition, by using data storage on objects, new services (e.g. processing of warranty, innovative accounting methods and proof of product authenticity) become possible [Strassner, 2005b, p. 137 et seq.].

The potential benefits realized by the introduction of RFID applications for process automation and innovation mentioned above appear in different ways in each step of the supply chain; therefore, in numerous publications, the investigation of RFID benefits concerns production (see, e.g., [Bapat and Tinnell, 2004]; [Günther et al., 2008]); transportation and warehousing (see, e.g., [Alexander et al., 2002]); the point of sale (see, e.g., [Loebbecke, 2004]; [Thiesse and Fleisch, 2007]) as well as cross-company supply chain processes (see, e.g., [Gaukler and Seifert, 2007b]).

RFID benefits in production can be realized by closed local applications, e.g. RFID in asset management for an improved capacity utilization of machines. This kind of RFID benefit is only relevant insofar that other applications – also at supply chain partners – are provided with more accurate, detailed and timely information. Basically, the tagging of products during production enables the implementation of other applications. RFID technology can be used in production management to monitor the progress of production by reading and writing the transponder data at selected production steps [Melski, 2006, p. 41]. Through RFID-based production monitoring, flexible production concepts can be realized when production steps are controlled, modified, and reconfigured. In the assembling process, RFID can be used to check that the correct components are used, e.g. by tagging raw materials with detailed specifications and automatically triggering alarms at assembling operations if the usage of an incorrect part is imminent [Bapat and Tinnell, 2004, p. 10]. In the case that faulty products have to be recalled, the traceability of production runs or even individual products can be improved by the use of RFID tagging.

In transportation and warehousing, efficiency improvements through less labour, higher accuracy and higher performance are primarily discussed. These can be realised in goods receipt, goods issue as well as picking and packing processes [Alexander et al., 2002, p. 15 et seq.]. Future RFID applications enable the automatic self-control of logistic processes where the monitoring and controlling the destination of goods is done by the goods themselves or by intelligent systems which are connected with these goods.

One of the central problems in retailing which can be addressed by RFID is the on-shelf availability of goods. An automatic logging of the movement of goods in the store offers the possibility of redesigning the shelf replenishment process [Thiesse and Fleisch, 2007, p. 1]. An item-level tagging of products and the equipping of shelves; doors between storage and retail area; and the checkouts with RFID readers create the needed transparency on the actual amount of inventory in the store. If the amount of products on a shelf falls below a critical level and the product is still available in the storeroom, shop clerks can be made aware of the imminent out of stock situation [Gaukler and Seifert, 2007b, p. 32]. Additionally, with these smart shelves, misplaced products can be easily recognized and the number of unsaleable products (e.g. due to expiry date) can be reduced. Further benefits in efficiency include accelerated checkouts and integrated article surveillance. Apart from using RFID applications for inventory control and efficiency improvements, using it in retail can contribute to a better shopping experience for the customer. In the clothing industry, an example of this improved experience is a smart changing room, where suggestions of combining the selected clothing with other articles and availability information of other sizes and colours are displayed. For fast moving consumer goods, the customer could get product specific information on the shop floor (front-end content integration), e.g. about the origin of the products [Loebbecke, 2004].

While the above described benefits can be separately realized at each step of the supply chain, some benefits do not occur until the whole supply chain is considered. By using real-time information about inventory and the demands of each actor in the supply chain, the safety stocks and the bullwhip effect (the built up fluctuation of demand from retailers to suppliers) can be reduced. This assumes the willingness of the participating companies to share the needed information (e.g. about current production utilization, current inventories, and point-of-sale data). Because of more detailed localization information and organizational actions about the property transfer of goods in the supply chain, the loss of products, e.g. due to internal or external theft, could also be reduced. In addition to the direct amount saved because of writing-off these losses, the transparency of current inventories is improved and therefore the safety stock can be reduced further [Alexander et al., 2002, p. 18]. In addition, the tracking and tracing of products in a supply chain can be improved because of more detailed information about location, origin and product history; thus, better protection against counterfeiting and faster warranty services become possible.

2.3.3 Necessity for a Redistribution of Costs and Benefits

In cross-company RFID applications, costs for realization should be reduced for individual companies by distributing them between a larger number of participants and by repeatedly using the same tag across multiple supply chain steps. A closer look at the benefits shows that they have to be differentiated into individual benefits and overall benefits. Individual benefits describe the benefits which each individual company can gain. Usually, more than one participant is involved in the creation of one company's individual benefits. The overall benefits are the cumulative benefits of all participating companies in the system. These benefits can exceed the sum of the individual benefits in a non-cooperative situation, because of the synergetic effects in a collaborative one [Strassner, 2005b, p.122].

Because of this, the participation of each company might significantly affect the overall benefit of the system. Taking the implementation of RFID in the textile supply chain as an example, the greatest benefit will be realized at the retail level because of the early information about product availability at the item-level on the sales floor [Gaukler and Seifert, 2007b, p. 44]. The overall benefit increases with the integration of further supply chain steps, because the flow of materials control becomes more effective with the availability of more accurate and timely information. For this scenario to work, products have to be tagged by the manufacturer, who only marginally benefit from the overall application; therefore, a discrepancy between where the costs incur and where the benefits are realised emerges.

The disadvantaged company lacks the motivation to participate in the cross-company RFID application and, therefore, the overall benefits are at risk [Tellkamp, 2006, p. 143]; hence, a solution has to be found so that the circumstances are reached where the application is economically reasonable for each partner. The goal of cost-benefit sharing is the economically fair distribution of resources between the supply chain participants. Although the term fairness is part of habitual language use, it is difficult to derive a concrete definition, so fairness always has to be understood subjectively. It has to be applied to the others involved and they have to decide if the situation is just and appropriate in the circumstances. It does not require an equal distribution, though; i.e., a situation in which costs and benefits are distributed unequally can be perceived as fair as well. To extend the definition of the goal of cost-benefit sharing: it is the creation of a situation in which all participants perceive being treated economically fair enough to actively take part in the network activities in the long-run.

The highest incentive to create this situation is up to the stakeholder with the greatest share of the overall benefit. This participant will be willing to carry the costs of others or share the benefits with others until his share of the overall benefits is equal to his individual benefits. Special attention has to be put on the power structures in the supply chain [Fisher et al., 2004], which have a great influence on the individual subjective perceptions.

2.3.4 Related Research on Cost-Benefit Sharing

Research in the area of collaborative investments into network technologies in general and especially RFID is quite low, although evidence in case studies show that a successful RFID introduction will imply some cost-sharing [Günther et al., 2008, p. 155]; [Tedjasaputra, 2007]. Even the public sector is calling for closer cooperation between participants along supply chains which will generate true win-win situations and generate economic effects through cost-sharing models [Bovenschulte et al., 2007, p. 41]. They state that these cost-sharing models should be derived from pilot projects. Other studies show that alternative cost-sharing models (in contrast to the scenario where the suppliers pay the majority of the costs) could solve the issue of collaborative investments, but are currently not being used [Weber and Jensen, 2007, p. 34].

Regardless of this lack of research, there are a few cost-benefit sharing concepts in the context of supply chain management; but they are either too focused for the purposes of cross-company RFID applications or very broad. Jain et al. [2006] developed an economic order quantity based model to quantify the benefit accrued due to supply chain coordination and described a benefit sharing mechanism, which is based on the optimal order quantity of the supply chain system. One of their assumptions is that the supplier is not only willing to compensate for their loss, but to share its benefits with the retailers including sharing the profit accrued due to coordination. In the other focused research paper, Chalasani and Sounderpandian [2004] developed a model for sharing the costs of a virtual private network among the partners of a B2B supply chain information system. Both fixed and variable costs were taken into consideration. In this technical-related calculation, variable costs were charged for the number of bytes transmitted through the network over an accounting period.

On the other side of the spectrum, general approaches for cost and/or benefit sharing in supply chain management have been developed. Cachon [2003] reviewed and extended the supply chain literature on the management of incentive conflicts with contracts. The coordination of companies becomes necessary if the supply chain participants are primarily concerned with optimizing their own goals, which are often not aligned with those of the whole supply chain. A number of different contract types, which all establish a transfer payment scheme, were identified. While Cachon [2003] used quantitative models to calculate the needed optimal parameters, Riha and Weidt [2004] stated that such models are practically irrelevant. The main reason is that the model assumptions are too restrictive and, thus, the practical application of the results of this research is limited. For this reason, they developed a framework for rules of cooperation in networks and proposed a measurement of supply management key figures, using a Balanced Scorecard [Kaplan and Norton, 1992]. Because only their initial research was presented, Riha and Weidt [2004] did not explain how a model for cost-benefit sharing should look like. Along the same lines, [Wildemann and Schorr, 2007] stated that the benefits of supply chain improvements have to be identified and quantified first; therefore, they suggested a concept to measure tangible as well as intangible benefits in the form of key performance indicators. In the end, the allocation of costs between the supply chain participants should be based on this quantified value of supply chain benefit. As in Riha and Weidt [2004]'s work, the substance in the model for cost-benefit sharing was missing. Subsequently, Hirthammer and Riha [2005] presented a comprehensive approach for a cost-benefit sharing framework which consisted of two layers. The structural layer provided an institutional frame for the network, consisting of a board, information broker, controller, mediator and the companies themselves. The cost-benefit sharing process is described on the operational layer and contains: analyses of the network; the cost-benefit sharing itself; an implementation phase; and a controlling process. Although a very detailed cost-benefit sharing framework is presented in Hirthammer and Riha [2005], two disadvantages make it unusable for our purpose. First, in the most important cost-benefit sharing process, the components are only named and not explained further. Second, in our opinion the overhead produced by the different institutions and support processes are an obstacle for practical applicability.

Finally, there exists one piece of research which has applied a cost-benefit sharing model to the introduction of cross-company RFID applications. Gaukler et al. [2007a] addressed the question of how the RFID tag costs should be shared among the supply chain partners if the costs and benefits of a collaborative technology are distributed in an asymmetric fashion. To answer this question, an analytical model of item-level RFID in the retail supply chain was developed. It was shown that sharing the tag costs is not an issue when the manufacturer is the more powerful partner; however, when the retailer is more powerful, there is a need for sharing tag costs. The optimal tag cost allocation was calculated depending on a manufacturer's participation constraint. Although the paper addresses a similar research question in relation to this work, its approach is completely different. To apply quantitative modelling as a research method, restrictive assumptions have to be made to simplify real-world complexity. The effect of this is its non-applicability in practice. However, to our knowledge, no empirical research exists that puts a cost-benefit sharing into the context of cross-company RFID applications. Thus, this section contributes to the field by developing a practical, relevant model for cost-benefit sharing in cross-company RFID applications.

2.3.5 Cost-Benefit Sharing Model

Supply chain networks are, as mentioned above, highly complex systems with a number of different interacting participants; hence, the configuration of an RFID application which is embedded in such a system and, therefore, the possible distribution of costs and benefits are influenced by a variety of factors. Sample questions for both external influencing factors from the enterprise environment and intra-enterprise characteristics are depicted in Figure 2.3.

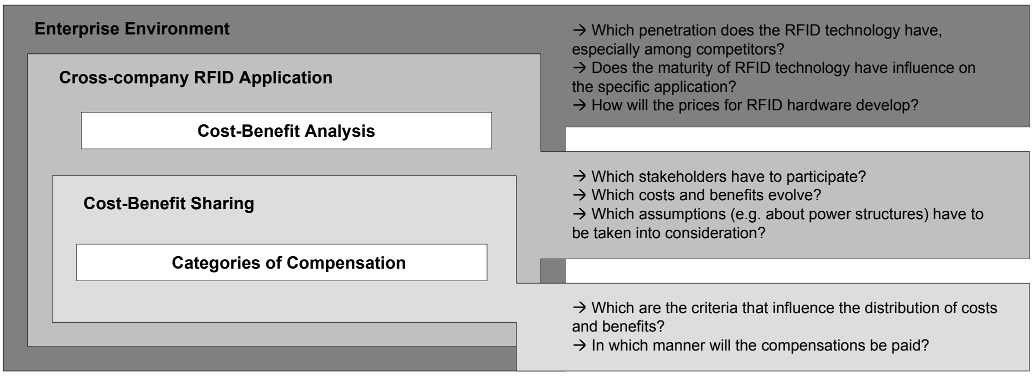


Figure 2.3: Context dependent design of a cost-benefit sharing model

At the end of the model, to allocate costs and benefits of a cross-company RFID application to the participants, it is important to collect the needed information to describe the configuration of the application as well as to understand the company-specific and cross-company influencing factors. For this reason, the influencing factors of cross-company RFID applications are first described and subsequently a cost-benefit analysis is specified. If the cost-benefit analysis has been applied in practice to the different individual situations and its results show that RFID technology is beneficial for the supply chain, then a fair cost-benefit sharing strategy should be applied with the final goal of increasing the chances of a successful introduction of a cross-company RFID application.

Influencing Factors on Cross-Company RFID Applications

The configuration of the supply chain being considered and the position of the participating companies in it are one of the most important factors which influence the realization of a cross-company RFID application. The reason for this lies in the fact that the distribution of costs and benefits is highly dependent on the tasks of each company. While the costs for RFID infrastructure and system integration accrue at every step in the supply chain, the participants have to invest in the RFID tags only once. The heterogeneity of potential benefits has an influence on the distribution of the benefits themselves, and can also lead to different expectations for the technology. While manufacturers and logistics service providers prefer to tag pallets or cases as a rule, retailers typically gain the greatest benefit from product tracking at the item-level on the sales floor [Gaukler and Seifert, 2007b, p. 44]. The tagging level is, therefore, one of the significant influences, and it also depends on the product type. For pharmaceutical products or fashion goods, item-level tagging will be more likely to be implemented in the next few years than for fast moving consumer goods. Subsequently, in some industries – in particular logistics, pharmaceutical and information technology – RFID is rated as more relevant [Knebel et al., 2007, p. 99].

Apart from these criteria, certain network characteristics have an influence on the introduction of RFID. Power relationships between the companies in the fast moving consumer goods supply chain, for example, are affected by brand effects on the part of manufacturers and the high market share of a few big retailers who could threaten to remove certain products from their inventory. If the power structures are highly asymmetric, requirements can be placed and enforced without considering business partners [Gaukler and Seifert, 2007b, pp. 43-44]. Furthermore, the length of the partnership will influence the introduction of a cross-company RFID application. The tendency is that long-term relationships which are contractually fixed result in a higher security of investments and facilitate the participation in collaborative RFID projects.

The boundary between supply chain specific factors and company characteristics is not always clear-cut. According to an up-to-date study [Knebel et al., 2007], representatives of larger companies attach a higher importance to the topic of RFID. Closely related to this is that the current technological resources of a company [Gross and Thiesse, 2005] (e.g. application systems and identification technologies) either support the immediate introduction of RFID or cause additional costs and time for its implementation; as well, the internal availability of technical know-how in terms of operational experiences for the introduction of a new technology has to be considered. This expertise in investing in and implementing new information technologies forms a self-amplified effect; this is because investments in IT are closely related to the developments of the organizations structure, employee competences and processes and, therefore, the expertise can be seen as a business value which pays off in the long run itself [Brynjolfsson and Hitt, 1998, p. 54 et seq.]. Compared with this, a high level of automation of technical processes can negatively influence the value of possible benefits.

Apart from the internal factors described above, the decision to introduce RFID also depends on external ones [Strassner, 2005b, p. 127 et seq.]. In recent years, the costs for RFID have dropped significantly; nonetheless, compared to bar code technology, for instance, the costs for RFID are still

Table 2.7: Overview of influencing factors on cross-company RFID applications

External Factors	Supply Chain Specific Factors	Company Specific Factors
Price trend of RFID hardware	Potential costs and benefits	Potential costs and benefits
Technological maturity of RFID	Structure of the supply chain	Position in the supply chain
Standards in the sphere of RFID	Goals of the supply chain	Size of the company
Spread of RFID technology	Product type	Technical know-how
Measurement of benefits	Industry	Resources and organization
	Resources and organization	Level of process automation
	Closed vs. open systems	
	Power structures	
	Length of relationships	

so high that the price trend can be seen as an essential element. At present, RFID technology is experiencing fast technological progress, so that performance characteristics are increasing and existing physical limitations are being overcome. Ongoing product innovations might complicate the decision for a specific solution.

Closely related is the continuous standardization in the sphere of RFID, which in turn facilitates the integration of cross-company processes and application systems. From a strategic point of view, with very little spread of RFID technology, companies currently have a chance to position themselves as early adopters in the marketplace.

The last external factor identified in this work is the difficulty of measuring the benefits. While efficiency benefits through automation can be quantified quite precisely, the effects of improved data quality and transparency or the strategic benefits just mentioned can not be measured easily.

Cost-Benefit Analysis

The basic requirement for sharing costs and benefits is their assessment. Before the introduction of the application, the costs and benefits can be estimated based on previous experiences or calculated under uncertainty. Calculation methods offer support for this task; however, a current study [Gille and Strüker, 2008] shows that only fifty percent of the companies surveyed that plan to implement or currently use an RFID application have applied at least one calculation method:

- Process key figures and scoring mechanism are used the most, but both methods are not suitable for making financial decisions.

- The total cost of ownership (TCO) analysis at least encompasses the investments in RFID technology.

- Additionally, activity based costing includes benefits through process automation.
- The net present value method offers a comprehensive financial evaluation of costs and benefits if the payments within an investment period can be accurately predicted.

Calculation methods are partly provided within tools created by people with expert knowledge. One example is the MS-EXCEL®-based RFID calculator from GS1 Germany and IBM [GS1 Germany, 2005], which allows for the mapping of whole supply chains and offers a cost-benefit calculation for each individual company. For the measurement of benefits, the RFID calculator concentrates on efficiency improvements that can be gained through RFID. A second example is the Auto-ID calculator [Tellkamp, 2003] developed by the Auto-ID Centre. This web-based tool, which stresses logistics applications, offers the possibility to get a rough financial overview from using RFID. A more detailed alternative for calculation is offered by another MS-EXCEL®-based RFID/EPC Benefits Calculator, which was jointly developed by Stanford Global Supply Chain Management Forum and the Massachusetts Institute of Technology with financial support from EPCglobal [Lee et al., 2005]. This tool especially addresses retailers and quantifies diverse kinds of benefits and costs.

Although the assessment of costs and benefits is of great importance for the overall topic, we will not focus on the different methods, which have to be individually applied in each situation.

Cost-Benefit Sharing: Research Questions

The past sections have given answers to the questions: who is involved in an RFID application; which costs and benefits could be generated; and what influences the amount paid for compensation. The fourth aspect of the cost-benefit sharing which is the focus of this chapter describes how compensation can be realized. Since the literature review has shown there is a lack of research on this topic, the following research questions have been framed:

- How should the costs and benefits of a cross-company RFID application be distributed among which participants?
- Which compensation measures are possible and how can these measures be structured?

- Which compensation measures are suitable for the different stages of the RFID implementation?

2.3.6 Findings from the Case Study

In the following sections, we answer the research questions by highlighting different aspects of the design approach for a cost-benefit sharing presented in the case of Gerry Weber in Section 4.1.6.

Categories of Compensation

In the case study, several compensation measures will be mentioned – including financial compensation for related costs; cooperative usage of hardware and software; provisions for training courses; as well as intangible values, such as the status as a preferred partner. To structure these compensations, a classification of economic goods will be used. According to this classification, economic goods can be divided into nominal – or monetary – goods and real assets, which can be tangible or intangible. According to this classification, compensations in the field of RFID fall into five categories: monetary, tangible and intangible compensations as well as combinations of these and no compensation at all.

Financial payments fall into the category of monetary compensation. On the one hand, these are financial compensations for expenses related to the RFID implementation – including the financing of RFID modules and IT systems; partial payments for operational expenses; and the payment of a financial premium for additional services. On the other hand, revenues generated can be shared among the partners in the form of a single or continuous payment(s).

Besides being provided with hardware, the collective or exclusive use of software by the partners is counted in the tangible compensation category. Both software and hardware can be made available for permanent or temporary use. In the case of temporary use, the assets can be claimed back or sold to the partner after the utilization period expires, e.g. after the technology tests. In general, all components of an RFID system – transponder, reading devices, middleware and application software – can be considered as assets and hence be part of a tangible compensation. Since the provision of assets requires a certain degree of stability in the buyer-supplier-relationship, this measure is not suitable for volatile procurement markets.

The third category, intangible compensation, subsumes all the measures that include neither a financial payment nor a provision of assets. According to the classification of economic goods, intangibles can be distinguished into

Table 2.8: Categories of compensation measures

Category	Subcategory
1. Monetary compensation	Cost sharing: subsidy, full compensation Benefit sharing: payment
2. Tangible compensation	Provision of hardware (tags, readers, infrastructure) Provision of software etc.
3. Intangible compensation	Information sharing Work force Training courses Prestige Knowledge transfer Better contract terms etc.
4. Combination of the measures	combination of categories 1-3
5. No compensation	No interest Power constellation Difficulties in measuring and allocation etc.

four subcategories: services, work force, information and rights [Meffert and Bruhn, 2000, p. 32].

The fourth category contains possible combinations of the measures mentioned above. An example for a reasonable combination is the provision of RFID hardware combined with related training or assistance during run-up. For the sake of completeness, a fifth category – the exclusion of any compensation – is introduced. In case of asymmetric power structures and redundant partners, there might be a decision not to share costs and benefits. Examples for this option are so called RFID mandates that force suppliers to adopt the technology.

Table 2.8 summarizes the findings of this section by showing the structured categories and the RFID-related examples.

Temporal Dependencies

The RFID rollout described in the case study follows a realization plan that has multiple stages. The aim of this kind of multi-stage plan is to reduce the substantial risks associated with the implementation of any innovative technology [Kopalchick and Monk, 2005]. The implementation of RFID is a complex process that depends on several parameters such as the number of participants involved, the type of application planned and the organizational and technological readiness of the supply chain under consideration.

It is thus impossible to suggest a universally valid number of stages for the implementation of RFID; but it can be observed that the configuration of cost-benefit sharing is a function of the degree of implementation a supply chain has reached. This is especially true for the allocation of costs and benefits as the knowledge and ability to asses both evolves while implementation is proceeding. In order to avoid over-complication, we decided to analyse the impact of the degree of implementation on cost-benefit sharing based on Gerry Weber's three stage implementation scheme described in Section 4.1.5.

The first phase is the pilot when the possibilities and boundaries of the technology are tested within the operating process. Moreover, the technical feasibility and the expected economic benefits of the planned use cases are verified. At the beginning of the run-up, the technology is implemented in selected sites and tested with a limited number of tagged items in order to check if the single components of the technology work well together and the expected benefits can be realized. The scope of the last and final stage of the implementation plan is to lead the system into a stable, productive operation. Because of the difficulties in estimating the potential benefits, a combination of tangible and intangible compensation measures is likely to be preferred to a financial payment.

After the realization of a pilot project, a decision has to be made whether the RFID project should be taken to the next stage or terminated. The decision is based on an ex-post assessment of the costs and benefits of the pilot and an updated cost-benefit forecast for the rollout. Due to the higher information value of this analysis, uncertainty can be reduced; moreover, essential investments in hardware and software had already beed made during the pilot phase. The second benefit resulting from the pilot phase is the experience gained, which can be used to identify additional fields of application and potential problems associated with a full rollout. In the case of the service providers, the activities can be used to identify potential uses in their own operations and as references to acquire new customers.

While pilot and run-up stages normally only last from between a few weeks up to a few months, the RFID system in productive operation will usually be used for several years. There is a high probability that contracts with suppliers and logistics service providers will to be renewed at some point after the system has gone operational; at that point, compensations will also have to be renegotiated. By then, all partners have gained a sufficient level of understanding of the costs and benefits associated with the use of the technology so that compensation measures can be agreed upon based on the actual costs and benefits identified for each supply chain partner individually.

Theoretically, all types of compensation measures are applicable during the lifespan of an RFID application. Monetary compensation for additional efforts related to RFID is no longer paid as a supplement, but is an inherent part of the renewed supply or service agreement. As with any other contract renewal, suppliers might be faced with demands for cost reduction by their customers. Suppliers should thus be able to derive maximum benefit from the technology for their own operations to reduce dependency on compensation payments. Experience from the presented and other cases suggests that initiators of the RFID application will reduce tangible compensation measures once the system is operational. That is to say, extensions and maintenance of the RFID infrastructure have to be covered by each supply chain partner.

2.3.7 Conclusions

The benefit generated by a network technology such as RFID is related to the diffusion of the technology among the participating partners. Often, the overall success of applications depends on the participation of a single player – e.g. the supplier in the textile supply chain. For an economically reasonable decision, the benefits of each player have to be higher than the costs of the technology deployment. Since the distribution of costs and benefits usually is not economically equal, the necessity of redistribution arises.

Within this chapter, the costs and benefits of an RFID deployment were discussed; moreover, the elements of a cost-benefit sharing were presented. For the design of a cost-benefit sharing model influencing factors, such as the power structure or the progress of the technology, have to be kept in mind. To assess costs and benefits, different analysis tools can be used. Since the benefits of an RFID deployment are difficult to forecast, the reliability of ex-ante calculation is low; hence, a cost-benefit analysis has to be conducted several times during the rollout. The rollout should be structured into several phases: the pilot, the run-up and transition to productive operation. The design of the cost-benefit sharing changes from phase to phase.

For compensation, different measures can be applied: financial payments, tangible and intangible measures. The tangible measures include the provision of hardware and software. Potential intangible measures are, for example, the assistance in site assessment and technology selection or the sharing of information. The analysis of the case study has shown that in the pilot phase a combination of tangible and intangible measures are preferred. In the run-up phase each partner has to contribute financially. In the productive operation, partners get paid for RFID-related services and profit from intangible compensation measures.

Chapter 3

Technical Aspects

3.1 EPCglobal Network

The accuracy and detail of RFID data are expected to open up new and more efficient ways to manage the supply chain and reduce many of the inefficiencies plaguing today's businesses such as incorrect deliveries, shrinkage and counterfeiting. Since production and distribution of physical goods are seldom in the hands of one organization and efficiency gains in supply chains often emanate from centralized supply chain control, it makes sense in most cases to share selected RFID data among supply chain participants.

For the cross-company exchange of RFID reader events, the Auto-ID Center and the industry consortium EPCglobal have specified a stack of specifications – which is currently one of the predominant standardization efforts of the RFID community [Floerkemeier et al., 2007b]. In the next sections, we will sketch the specifications of the EPCglobal network that are most relevant for this work. Section 3.1.1 gives an overview of the architecture of the EPCglobal network [EPCglobal, 2009]. The Electronic Product Code [EPCglobal, 2008b] is introduced in Section 3.1.2. In Section 3.1.3, the EPC Information Services [EPCglobal, 2007] and in Section 3.1.4, selected Core Services [EPCglobal, 2008c] are presented.

3.1.1 EPCglobal Architecture Framework

The EPCglobal architecture framework describes a number of components required to realize a platform-independent system architecture for collecting, filtering, storing and retrieving EPC-related data. EPCglobal does not define *the* system architecture that end users have to implement, but defines interfaces that the components of end users' systems (hardware and software) may implement. These interfaces as well as these hardware and software roles are separated in Figure 3.1.

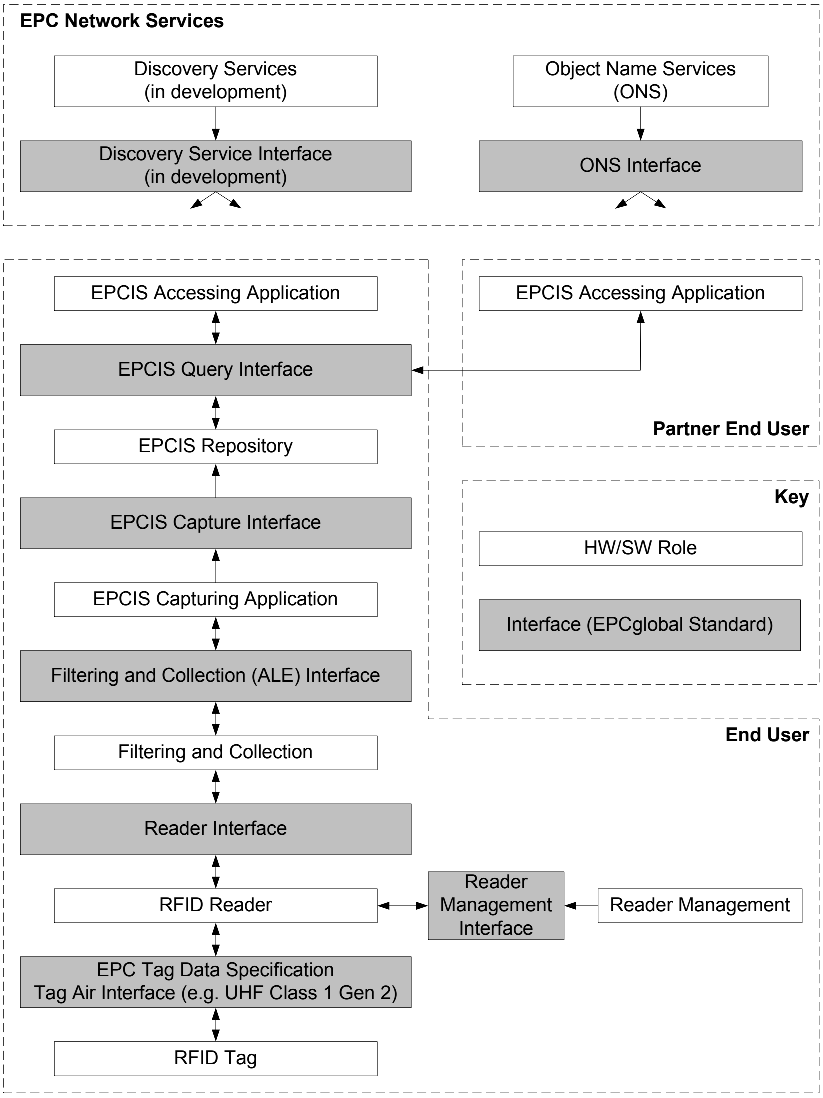


Figure 3.1: EPCglobal architecture framework (based on [EPCglobal, 2009])

EPCglobal has specified air interfaces for several tag types and reader protocols that serve to effectively read out EPC data in multi-tag, multi-reader environments.

The Application Level Events (ALE) specification defines how to request EPC data from readers so that it can be used as input for higher level applications [EPCglobal, 2008a]. This involves accumulating data over intervals of time; filtering to eliminate duplicate and unneeded data; counting and grouping data to reduce its volume; reporting in various forms; and support for writing activities. In simple terms, ALE defines two message types that are exchanged between the Filtering and Collection component and the Event Capturing Application:

- The `ECSpec` is sent from the Event Capturing Application to the Filtering and Collection component and defines the tasks that have to be performed in an event cycle (Event Cycle Specification). An `ECSpec` contains (1) an unordered list of one or more RFID readers used to acquire the tags that should be included in an event cycle; (2) a specification of how the boundaries of event cycles are to be determined, e.g. a start trigger and a duration relative to the start of the event cycle; and (3) a list of specifications each of which describes a report to be generated from this event cycle. This specification includes the option to include all tags in the reporting or only the additional tags to the prior event cycle; the option to generate the report if it does not contain any tags; patterns for EPCs that should be included or excluded; and a pattern for grouping the filtered EPCs.
- The `ECReports`, which are sent from the Filtering and Collection component to the Event Capturing Application, contain one or more reports generated from one activation of an `ECSpec`.

The EPCIS Capturing Application has the context information about the data capturing process and supervises the lower elements in the EPCglobal architecture as described above. The role of the EPCIS Capturing Application may be complex (e.g. loading of a shipment with multiple Filtering and Collection events, a completeness check and human interaction) or straightforward (e.g. generating periodic observations about objects that enter or leave a shelf). Section 3.2 is dedicated to elaborating on context data management in general and particularly the tasks of the EPCIS Capturing Application. Its main task is to create an EPCIS event and store it in the EPCIS repository using the EPCIS Capture Interface. The EPCIS is described in more detail in Section 3.1.3 as well as the Core Services in Section 3.1.4.

3.1.2 Electronic Product Code

The Electronic Product Code (EPC) is a universal identifier that provides a unique identity for any physical object in the world, for all time, and across all categories of physical objects [EPCglobal, 2009]. This means that not only trade items (products), but also logistical units, fixed assets, physical locations and other objects that are encompassed in the EPC Tag Data Standard can be used for the EPC (see Figure 3.2).

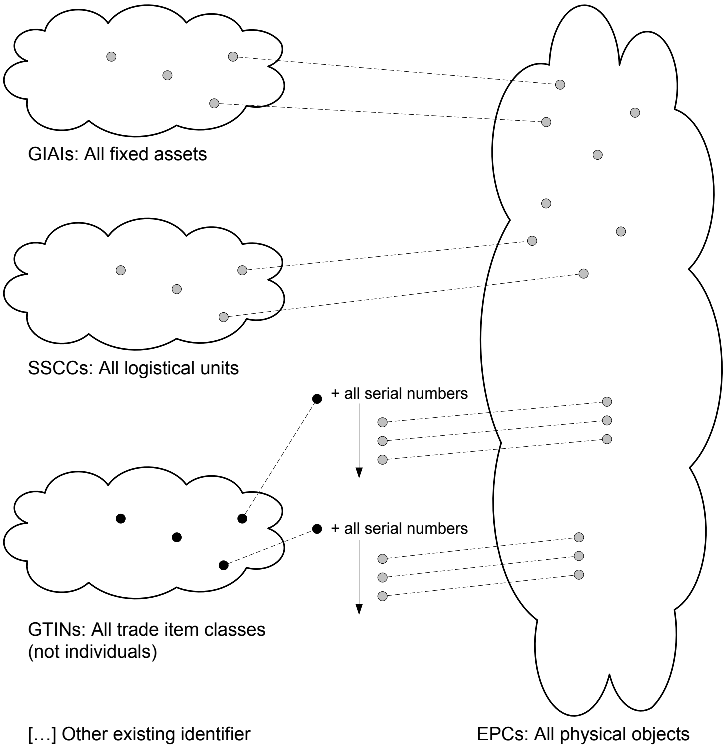


Figure 3.2: Mapping of existing identifiers to the EPC (based on [EPCglobal, 2009])

Figure 3.2 shows that it depends on the identifier whether or not every GS1 key corresponds to exactly one EPC. For example, the GS1 identifiers Global Individual Asset Identifier (GIAI) for fixed assets and Serial Shipping Container Code (SSCC) for logistical units identify unique objects and, therefore, correspond to exactly one EPC. Whereas the Global Trade Item Number (GTIN) – the successor of the European Article Number (EAN) – identifies a category of objects, e.g. the product class, so that the individual items need a separate serial number to be mapped to an EPC.

3.1.3 EPC Information Services

The EPCIS, as conceived by EPCglobal, consists of three components: a repository for event data and two interfaces that serve to capture and query event data stored in this repository. Although EPCglobal does not provide an implementation of any of these components, they have developed the specification for an extendible data model for supply chain events as depicted in Figure 3.3.

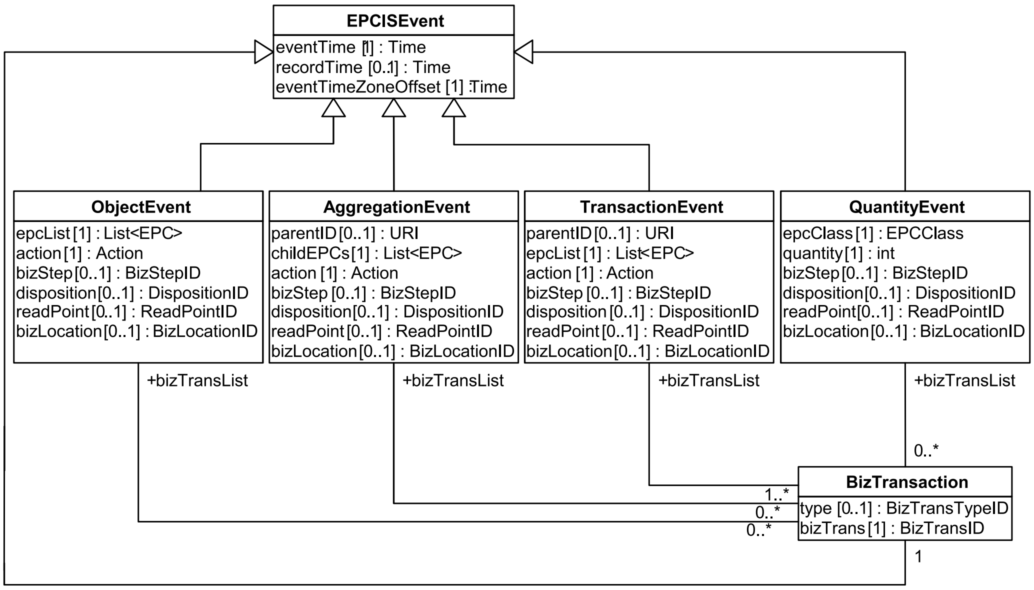


Figure 3.3: EPCglobal's EPCIS data model

The capture interface receives formatted event data from the ALE and adds the required context data – resulting in one of the event types shown in Figure 3.3. The query interface allows applications to specify and manage queries for event data using a query control interface. Querying can be done on-demand ('pull' approach) or by using the control interface to define and register standing queries that are executed periodically ('push' approach).

An EPCIS event can refer to anything happening in a supply chain that can be linked to a physical item and a discrete date. The different event types specified in the EPCglobal data model constitute the basic information handled by the EPCIS. Each event makes a statement about the what, where, when, and why of a supply chain event.

- The *what* dimension is specified by a list of EPCs that identify one or several physical objects and a list of so-called business transactions that these items are involved in. A business transaction can, for instance, be a production order. While the EPCs can be read from the transponder itself, the information of the corresponding business transaction needs to be retrieved from some information system.

- The *when* of an event is established by two time stamps that specify the time the event happened and when it was captured.

- The *where* dimension is specified by the two variables – readPoint and bizLocation – that represent the place where the event was recorded and the place where the item is expected to be located after the occurrence of the event. The readPoint value is expected to be a technical ID (for instance derived from the reader infrastructure), whereas the business location provides the corresponding context information.
- The *why* refers to a business step (bizStep) and disposition ID (disposition) that denote the state of the physical item by the time its EPC is read and its disposition after that moment.

The EPCIS data model defines four event types. An `ObjectEvent` captures information about an event that pertains to one or several physical objects identified by EPCs. Its mandatory attributes are the event and record times inherited from `EPCISEvent`; a list of EPCs; and an action attribute that can have three values: `ADD`, `OBSERVE`, and `DELETE`. If the value of the action attribute is set to `ADD`, it means that the EPCs were associated with the physical object for the first time. `OBSERVE` means that the object has been observed, whereas `DELETE` signifies that the EPCs listed in this event were decommissioned as part of the event. All other attributes of the object represent optional context information and have to be provided by other enterprise applications before the event gets stored in the database.

An `AggregationEvent` describes events that pertain to objects that have been physically aggregated (e.g. products in a box and boxes on a pallet). The action attribute uses the same semantics: `ADD` signifies that the aggregation has been observed for the first time in this event, whereas `DELETE` means that it has been decommissioned – i.e., child tags are no longer associated to a parent tag but are still in existence.

The class `QuantityEvent` represents events that take place with respect to a specified quantity of some type of objects. This event could be captured, for instance, when the inventory level needs to be reported.

Depending on the value of its action attribute, a `TransactionEvent` describes the association or disassociation of physical objects to one or more business transactions. Its structure is similar to the `ObjectEvent` class except that it has to be associated with at least one business transaction.

For more detailed information on the different types of events presented in Figure 3.3, please see Hribernik et al. [2007].

3.1.4 EPC Core Services

To enable easy access to worldwide EPC-related data, EPCglobal has provided the specification for a hierarchical EPCIS lookup service. It is based on similar principles as the well-known Domain Name Service (DNS) used for the resolution of Internet host addresses. The lookup service used to access the EPCIS of the company that commissioned the EPC is specified in the Object Name Service (ONS) standard, whereas the EPCIS Discovery Services standard – used to access the EPCIS of all companies that have information about the object – is still under development.

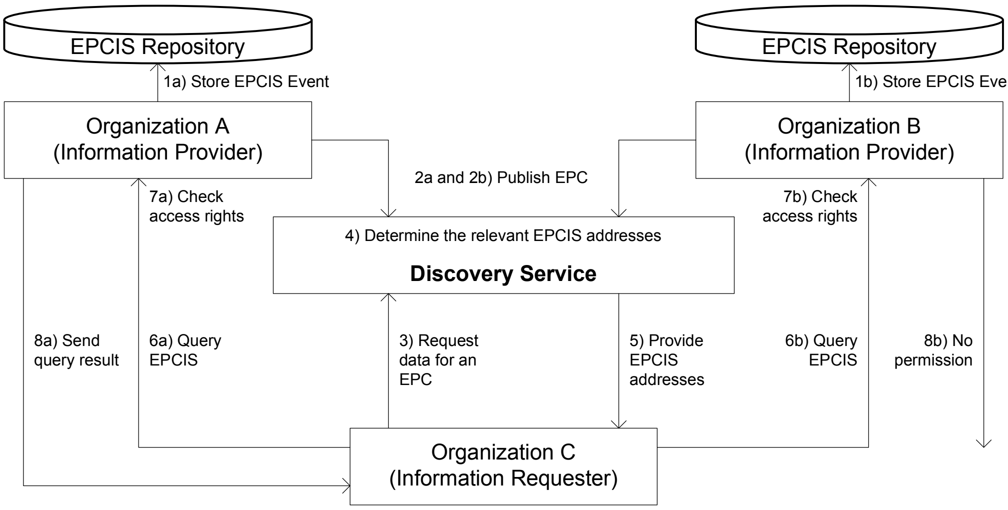


Figure 3.4: Process model of the EPCIS Discovery Service

Figure 3.4 illustrates the process of storing and retrieving information related to a specific EPC ([Kürschner et al., 2008]).

1a and b.) The process begins with two organizations (A and B) that capture RFID events and store the corresponding EPCIS events in their local EPCIS repositories.

2a and b.) Each time this happens, the organizations publish the EPC at the discovery service.

3.) A third organization (C) – the information requester – needs information about a specific EPC-equipped product. It sends its query request to the discovery service.

4.) The discovery service looks up all EPCIS addresses that hold data about the provided EPC number.

5.) The discovery service sends the related addresses back to Organization C.

6a and b.) Then Organization C queries the given EPCISs directly.

7a and b.) The queried information providers, A and B, check C's access rights.

8a and b.) If Organization C is authorized to get information, the query result is sent by the information providers. In this example, only Organization A replies.

For further developments of the ONS, please see Evdokimov et al. [2008] regarding multipolarity and Fabian [2009] regarding Peer-to-peer (P2P).

3.2 RFID Context Data Management

3.2.1 Introduction

As introduced in the previous section, according to EPCglobal all RFID-related data recorded by an organization should be stored in an EPCIS repository in the form of EPCIS events. EPCIS events are contextually enriched RFID reader events; they consist of reader and context data. The information that can be inferred from the EPCIS events stored in the EPCIS repositories along the supply chain enables item level visibility of the flow of goods.

Realizing the vision of EPCIS-based supply chain monitoring implies the existence of software components that connect the RFID reader infrastructure to the ERP systems of organizations in order to do two things: (1) make EPCIS events usable for higher level applications; and (2) generate EPCIS events from read events and the required context data in the first place. In our opinion, efficient ways to perform both of these tasks are critical for the success of the EPCIS; moreover, they are similar in most companies and therefore standardization is possible. Only with a standardization of context enrichment is it possible to decouple the RFID reader infrastructure and middleware from the ERP layer. A clear separation of ERP systems and RFID-related systems including the standardization of the corresponding interfaces is a precondition for efficient competition on the emergent RFID market – it provides opportunities for smaller vendors who do not offer RFID middleware alongside ERP systems.

Numerous technical articles have been published on RFID and the Internet of Things in recent years. Most of these publications either focus on the working of RFID reader protocols, i.e. the architectural layer below the EPCIS, or they investigate applications that access EPCIS data, i.e. the architectural layer on top ([Beier et al., 2006]; [Dada and Magerkurth, 2008]; [Goebel and Tribowski, 2008]; [Kim and Kim, 2007]).

Although the type of context data that should be associated with RFID reader events is well known since EPCglobal's definition of the EPCIS, there are only a few publications that address the management of context data. Nguyen et al. [2007] developed an extended Entity Relationship (ER) diagram for EPCIS data and described the characteristics of event and master data in detail. They reviewed other EPCIS data models, especially the ones used in industry solutions such as the Siemens and Sun RFID middlewares. Although this work provides an in-depth insight into EPCIS event and master data, it implements the EPCIS specification without any contribution to EPCIS context data management. Kim et al. [2006] present a contextual event framework for RFID systems. Their goal is the transformation of RFID reader events into so-called contextual events. Indeed, their Contextual Event Assistant (CEA) is able to receive read events and also provides an API for high-level RFID applications that may query for the contextual events generated by the application; however, their application is supposed to retrieve reference data from the EPCIS, ONS and other pre-existent data sources in order to enrich read events with the necessary context data. This view contradicts the idea of EPCglobal to create one common format and access structure for contextualized events that can be used by higher level applications. For this reason, Kim et al.'s CEA does not comply with the proposed architecture of the EPCglobal network. A real-world application of the whole EPCglobal network is described by No [2008]. For the architectural layer below the EPCIS, a middleware has been developed that associates the observations with other information such as packaging containment and manufacturing meta-data; however, as the functional and technical description on how this is done is not the focus of the paper, it is only stated that the association was done prior to the recording.

The companies and research institutions that are involved in the definition of standards for the Internet of Things have done an excellent job in defining which context should be associated with RFID data and which format for the interchange of RFID data is most appropriate; however, to date they have not extensively addressed the issue of context data management including the retrieval and storage of all necessary context data outside EPCIS repositories. If EPCglobal's EPCIS specification is to be implemented, context data from sources such as ERP systems will have to be added at two architectural levels: the level above and below the EPCIS (see Figure 3.5).

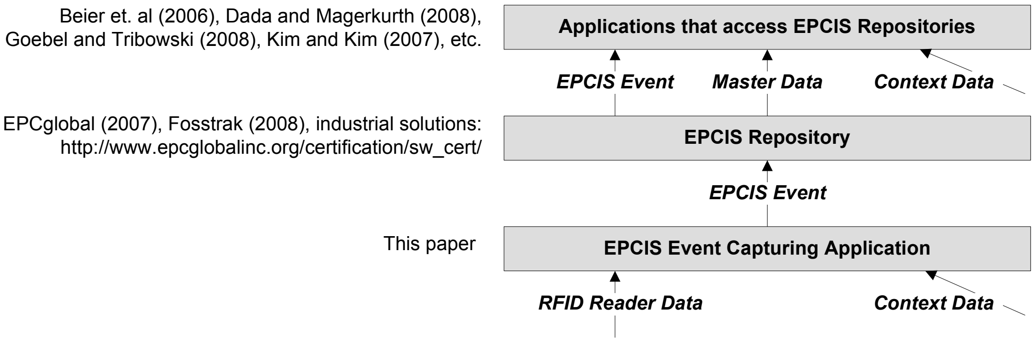


Figure 3.5: Scope of our contribution

Above the EPCIS, higher level applications such as Supply Chain Event Management (SCEM) tools or cross-company pedigree applications have to be able to interpret EPCIS events based on pre-existent background knowledge about the supply chain. This context data may include information on admissible process step sequences, durations, and shipping quantities. EPCglobal has defined an additional query interface for retrieving the context data stored in an EPCIS separately using so-called master data queries [EPCglobal, 2007, pp. 89-92 and 106-110]. Although this can be seen as a first step towards realizing standardized access to context data, the data referred to as 'master data' in the EPCIS specification stems from the EPCIS and its scope therefore does not exceed the information inferable from the sum of EPCIS events and will not be sufficient to realize applications like SCEM.

Below the EPCIS, all the data received from the RFID readers has to be associated with the context data required for generating EPCIS events. In this section, we will address possible ways to standardize context data management below the EPCIS level or before EPCIS events are interpreted by higher level applications. The rest of this section is organized as follows: in Section 3.2.2, we analyse the typical functionality and requirements of an EPCIS event capturing application; propose a corresponding system architecture including an in-depth explanation of all components and interfaces; and finally provide a comprehensive use case. In Section 3.2.3 we outline the experiences gained from a prototypical implementation. A performance experiment of the proposed architecture is presented in Section 3.2.4, before we conclude in Section 3.2.5.

3.2.2 EPCIS Event Capturing Architecture

Realizing the vision of EPCIS-based supply chain monitoring implies the existence of a number of architectural components. These components should work together in order to guarantee a fast flow of the data stored on RFID transponders all the way to the decision maker who is steering the supply chain.

In the following sections, we concentrate on the technical aspects of EPCIS event capturing. In particular we focus on the definition of interfaces as well as efficient data storage and interchange schemes. The first step from raw RFID data to usable decision making information is the transformation of transponder signals to RFID reader events. Among other things, multiple reads, i.e. signals from the same transponder that are received repeatedly, are removed in this step. The outcomes of this process according to the EPCglobal architectural specification are the Application Layer Events (ALEs). An Application Layer Event contains a list of EPCs transmitted by RFID transponders, the IDs of the readers that have received the transponder signals, and the time when the signals have been recorded. ALEs are usually generated by a read process that is started by an external trigger (e.g. a forklift passing a light barrier) and listens for incoming transponder signals until the reader is switched off by another trigger (e.g. a timer).

The generation of ALEs is contained in the typical functionality of RFID middleware. The solutions of a number of vendors include interfaces for the drivers of RFID hardware, facilities for steering and synchronizing large numbers of readers, and data tools to aggregate and export large volumes of data in different formats.

The process that takes ALEs as input and provides EPCIS events as output has so far neither been described in the literature nor standardized. Clearly, all vendors of RFID middleware who claim to offer EPCIS compatibility must have implemented this process in one way or another. We refer to the application in charge of this transformation as the EPCIS Event Capturing Application (ECA). As we mentioned in the introduction, the standardization of the ECA represents an important task left to be tackled since it allows for a transparent decoupling of the reader infrastructure management and the EPCIS.

Requirements

The implementation of the ECA has to fulfil three requirements: (1) it has to be fully compatible with EPCglobal's specification; (2) context data storage and exchange has to be done in an efficient and standardized way; and (3) the assembly of EPCIS events from the time of observation by RFID readers to the storage of EPCIS events in the corresponding repository has to be fast.

(1) Compatibility with the EPCIS specification implies in particular that the ECPIS ECA is able to handle all core event types. Four EPCIS event types have been defined by EPCglobal: the most general event is the object event, which simply contains context information pertaining to one EPC. An aggregation event serves to describe the physical aggregation of several child EPCs to one parent EPC, e.g. the association of products packed in a box. A quantity event counts the number of objects that belong to a certain class of EPCs without saving their individual EPCs. Finally, the transaction event describes the association of one or more EPCs to a business transaction (e.g. purchase orders and invoices). In Section 3.2.2, we evaluate the compatibility requirement by presenting an example on the basis of the EPC Showcase [GS1 Germany, 2008]. It was jointly developed by GS1 Germany

and Oracle and gives insights into the EPCIS concept by illustrating both the internal and the cross-company flow of data in a use case with a producer and distributor.

(2) The context data processed by the Event Capturing Application should be stored in an efficient manner and be accessible via standardized interfaces. In Section 3.2.2, a corresponding database schema and data exchange formats are described in full detail.

(3) The timely access to EPCIS events is of essence for EPCIS-based supply chain control applications since the corresponding decisions may have to be made in real time. For this reason, the matching of reader and context data has to be carried out very quickly, so in view of the high data volumes that will be served by the RFID middleware, the access to all data items required for the assembly of EPCIS events has to be highly efficient.

Proposed System Architecture

Figure 3.6 provides an overview of the envisioned system infrastructure. The focus of the following details of our proposed ECA is on the specification of its major components including the Context Data Repository, the Rule Engine, and the required interfaces.

In order to introduce the proposed system components in a structured manner, we will sketch the prototypical process of EPCIS event generation in the following. For the sake of clarity, the ECPIS event generation process can be separated into four separate sub-processes. In reality, these sub-processes usually execute in parallel.

The outcome of sub-process one is a cohesive model of the reader context. A straightforward way to generate the reader context is using a dedicated Graphical User Interface (GUI) that allows the supply chain manager to model a supply chain using predefined elements such as facility layouts and RFID readers and to interactively define the required context parameter values (bizStep, bizLocation, etc.). Initial work on such a GUI can be found in Cambridge University et al. [2007]. For small, well arranged RFID infrastructures, adding this data manually using a text editor is also possible. The generated data is relatively stable; it only changes when new physical infrastructure is added or removed and the virtual representation needs to be updated consequently. We refer to the data generated in this phase as Reader Context Data. This data is sent to the Reader Context Interface in the XML format defined by the XML schema provided in Figure 3.7.

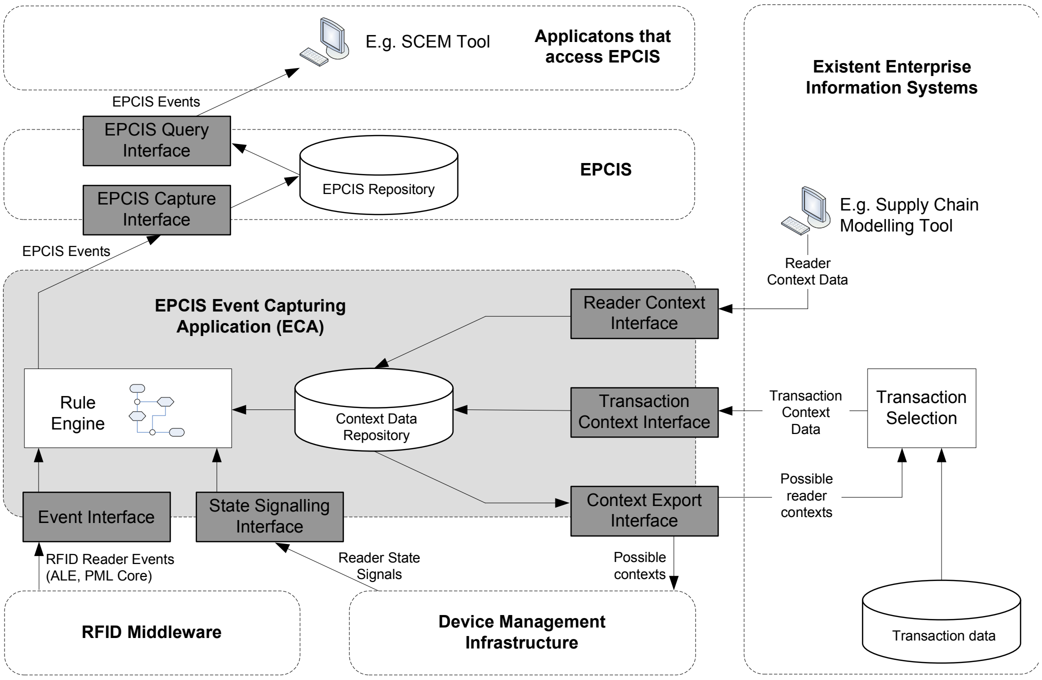
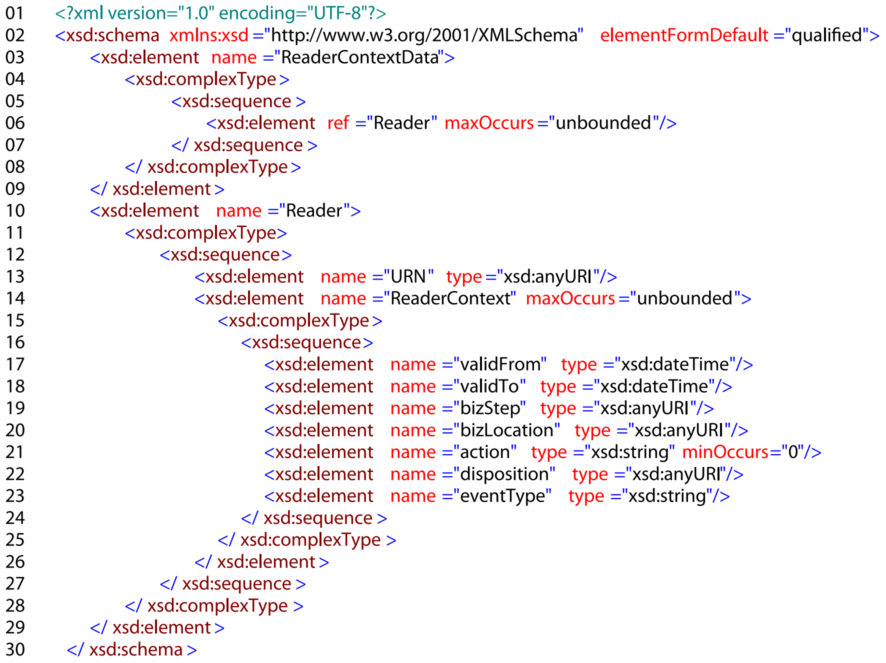


Figure 3.6: Proposed ECA embedment in system architecture

While the Reader Context Interface stores Reader Context Data in the Context Data Repository, a unique identifier for the context of a reader is assigned. For each RFID reader, which is identified with a URN, more than one valid context can be given at a time. This is reflected by the possible repetition of the Reader element (Figure 3.7, row 6). The data elements describing the Reader Context (Figure 3.7, rows 19-23) are derived from the Core Event Types of the EPCIS specification and from the requirement to accurately preserve historical data. The latter is made possible by the elements validFrom and validTo (Figure 3.7, rows 17-18). Contexts that are no longer valid do not have to be overwritten this way, but can be kept in the database.

The second sub-process starts with the export of the possible reader contexts stored in the Context Data Repository to the existent ERP system of the company, which is done via the Context Export Interface. The corresponding XML schema is provided in Figure 3.8.

The ERP system is now responsible for matching the transaction data with the context data received from the Context Data Export Interface of the ECA. For instance, a rule could be applied that associates all customer orders with all reader contexts that contain ’shipping’ as the value of the



```
<?xml version="1.0" encoding="UTF-8"?>
<xsd:schema xmlns:xsd ="http://www.w3.org/2001/XMLSchema"  elementFormDefault ="qualified">
    <xsd:element  name ="ReaderContextData">
        <xsd:complexType >
             <xsd:sequence >
                  <xsd:element  ref ="Reader" maxOccurs ="unbounded"/>
             </ xsd:sequence >
        </ xsd:complexType >
    </ xsd:element >
    <xsd:element   name ="Reader">
        <xsd:complexType>
            <xsd:sequence>
                <xsd:element   name ="URN"  type ="xsd:anyURI"/>
                <xsd:element   name ="ReaderContext"  maxOccurs ="unbounded">
                   <xsd:complexType >
                      <xsd:sequence>
                         <xsd:element   name ="validFrom"   type ="xsd:dateTime"/>
                         <xsd:element   name ="validTo"   type ="xsd:dateTime"/>
                         <xsd:element   name ="bizStep"   type ="xsd:anyURI"/>
                         <xsd:element   name ="bizLocation"   type ="xsd:anyURI"/>
                         <xsd:element   name ="action"   type ="xsd:string" minOccurs="0"/>
                         <xsd:element   name ="disposition"   type ="xsd:anyURI"/>
                         <xsd:element   name ="eventType"   type ="xsd:string"/>
                      </ xsd:sequence >
                   </ xsd:complexType >
                </ xsd:element >
            </ xsd:sequence >
        </ xsd:complexType >
    </ xsd:element >
 </ xsd:schema >
```

Figure 3.7: XML Schema for Reader Context Interface

bizStep variable and 'distribution center: goods issue' as the value of the bizLocation variable. The generated Transaction Context Data is sent to the Transaction Context Data Interface of the ECA in XML format defined by the XML schema provided in Figure 3.9. The ReaderContext element (Figure 3.9, row 19-26) describes a business process in the supply chain by associating a number of Reader Contexts with one or several transactions each; this information only changes when business processes or RFID hardware allocations change. The element TransactionEPCList allows for associating arbitrary physical objects to individual executions of a process (e.g. associating several physical products with a particular customer order).

Upon the receipt of XML data, the Transaction Context Interface stores the corresponding contexts in the Context Data Repository. The selection of the appropriate transactions is not included in the proposed ECA specification because it heavily depends on company particularities and thus cannot be standardized. The third sub-process of the EPCIS event generation process first exports the available context data to the Device Management Infrastructure via the Context Export Interface. The corresponding XML schema has already been provided in Figure 3.8. This data can be processed further and provided as input for the devices that interact with workers or other computerized systems. Based on the context data received via the

```
<?xml version="1.0" encoding="UTF-8"?>
<xsd:schema  xmlns:xsd ="http://www.w3.org/2001/XMLSchema"  elementFormDefault ="qualified">
    <xsd:element  name ="PossibleReaderContexts">
        <xsd:complexType>
            <xsd:sequence>
                <xsd:element  ref ="Reader"  maxOccurs ="unbounded"/>
            </ xsd:sequence>
        </ xsd:complexType>
    </ xsd:element>
    <xsd:element  name ="Reader">
        <xsd:complexType>
            <xsd:sequence>
                <xsd:element  name ="URN"  type ="xsd:anyURI"/>
                <xsd:element  name ="ReaderContext"  maxOccurs ="unbounded">
                    <xsd:complexType>
                        <xsd:sequence>
                            <xsd:element  name ="contextID"   type ="xsd:string"/>
                            <xsd:element  name ="validFrom"   type ="xsd:dateTime"/>
                            <xsd:element  name ="validTo"   type ="xsd:dateTime"/>
                            <xsd:element  name ="bizStep"   type ="xsd:anyURI"/>
                            <xsd:element  name ="bizLocation" type ="xsd:anyURI"/>
                            <xsd:element  name ="action"  type ="xsd:string"  minOccurs ="0"/>
                            <xsd:element  name ="disposition"  type ="xsd:anyURI"/>
                            <xsd:element  name ="eventType" type ="xsd:string"/>
                        </ xsd:sequence >
                    </ xsd:complexType>
                </ xsd:element>
            </ xsd:sequence>
        </ xsd:complexType>
    </ xsd:element>
</ xsd:schema>
```

Figure 3.8: XML Schema for Context Export Interface

Context Export Interface of the ECA, the Device Management Infrastructure is responsible for continuously reporting the current contextual state of the RFID readers via the State Signalling Interface. The corresponding XML schema is provided in Figure 3.10.

The selection of the appropriate reader context by the Device Management Infrastructure is not included in the proposed ECA specification. Similar to the selection of applicable transactions by the ERP system (see above) it heavily depends on company specialities and thus cannot be standardized.

The fourth sub-process of the EPCIS event generation process is responsible for the import of reader data from the RFID middleware via the Event Interface. Because we are implementing the EPCglobal network with all of its specifications, at a minimum we require the ALE format to be supported. Additionally, the event data interface should accept events delivered in the widespread Physical Markup Language (PML Core) format created by the Auto-ID Center. The corresponding XML schemas are provided in EPCglobal [2008a] and Auto-ID Center [2003].

The data model of the Context Data Repository is provided in Figure 3.11 using the UML notation. We recommend the usage of a relational database to store this data. The data model reflects the scope and amount of context data stored in the Context Data Repository. For each reader, more than one context is allowed. There are two reasons for this: firstly, because one reader can be associated with several types of events, i.e. for one read event several EPCIS events (e.g. object and transaction) can be saved in the repository; secondly, because the outdated contexts have to be kept in the database as well. Each transaction can include a list of EPCs. One EPC in turn can be referred to by several transactions.

The component responsible for the assembly of read events and context data to EPCIS events and exporting them to the EPCIS repository is referred to as Rule Engine. The best manner to describe the working of the Rule Engine once a read event was imported by the ECA is to present the detailed algorithm. Because of programming-language independence, we use pseudo-code (see Figure 3.12).

As the pseudo-code of the EPCIS event assembly algorithm indicates, most of its complexity is introduced by the association of the transactions. There are several reasons for this: an EPCIS event can contain more than one transaction; an EPC can be referred to by more than one transaction; and one RFID reader can capture more than one EPC at a certain time that are not necessarily referred to by the same transaction. Therefore, the algorithm adds all transactions to an event as long as all EPCs in the current list of EPCs also belong to the first transaction; otherwise a new event is created and the remaining transactions are attached to the newly created event.

An important requirement stated in Section 3.2.2 was that the matching of reader and context data has to be carried out very quickly and that the assembly of EPCIS events has to be highly efficient. Our algorithm requires the execution of two simple SQL queries in a relational database containing a limited amount of datasets. In comparison to the event data, the reader context data and the transaction context data is quite stable. In the best case, there is only one matching reader context to the read event and no transactions so that the EPCIS event can be assembled with a few instructions. In the average case, there is more than one matching reader context but still no transaction so that for each context one EPCIS event can be assembled with a few instructions. In the worst case, transactions have to be additionally added to the EPCIS event: if EPCs are read that belong to different transactions, the read event has to be split up into several EPCIS events. This procedure needs a few more instructions, but is still straightforward since the number of different transactions is naturally limited.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<xsd:schema  xmlns:xsd ="http://www.w3.org/2001/XMLSchema" elementFormDefault ="qualified">
    <xsd:element  name ="TransactionContextData">
        <xsd:complexType >
            <xsd:choice >
                <xsd:sequence >
                    <xsd:element ref ="Reader"  maxOccurs ="unbounded"/>
                </ xsd:sequence >
                <xsd:sequence >
                    <xsd:element  ref ="TransactionEPCList" maxOccurs  ="unbounded"/>
                </ xsd:sequence >
            </ xsd:choice >
        </ xsd:complexType >
    </ xsd:element >
    <xsd:element  name ="Reader">
        <xsd:complexType >
            <xsd:sequence>
                <xsd:element  name ="URN"  type ="xsd:anyURI"/>
                <xsd:element  name ="ReaderContext"  maxOccurs ="unbounded">
                    <xsd:complexType >
                        <xsd:sequence >
                            <xsd:element  name ="contextID"  type="xsd:string"/>
                            <xsd:element  ref  ="bizTransaction"  minOccurs ="0" maxOccurs ="unbounded"/>
                        </ xsd:sequence >
                    </ xsd:complexType >
                </ xsd:element >
            </ xsd:sequence >
        </ xsd:complexType >
    </ xsd:element >
    <xsd:element  name ="bizTransaction">
        <xsd:complexType >
            <xsd:simpleContent >
                <xsd:extension  base ="xsd:anyURI">
                    <xsd:attribute  name  ="type"  type ="xsd:string"  use ="required"/>
                </ xsd:extension >
            </ xsd:simpleContent >
        </ xsd:complexType >
    </ xsd:element >
    <xsd:element name ="TransactionEPCList">
        <xsd:complexType >
            <xsd:sequence>
                <xsd:element  name ="value"  type ="xsd:anyURI"/>
                <xsd:element  name ="EPCList">
                    <xsd:complexType >
                        <xsd:sequence>
                            <xsd:element  name =" URN"  type ="xsd:anyURI"  maxOccurs ="unbounded"/>
                        </ xsd:sequence>
                    </ xsd:complexType >
                </ xsd:element>
            </ xsd:sequence>
            <xsd:attribute  name ="type"  type ="xsd:string"  use ="required"/>
        </ xsd:complexType >
    </ xsd:element >
</ xsd:schema>
```

Figure 3.9: XML Schema for Transaction Context Interface

```xml
<?xml version="1.0" encoding="UTF-8"?>
<xsd:schema  xmlns:xsd ="http://www.w3.org/2001/XMLSchema"  elementFormDefault="qualified">
    <xsd:element  name ="ReaderStateSignals">
        <xsd:complexType >
            <xsd:sequence>
                <xsd:element  name  ="contextID"  type ="xsd:string"  maxOccurs  ="unbounded"/>
            </ xsd:sequence >
        </ xsd:complexType >
    </ xsd:element >
</ xsd:schema>
```

Figure 3.10: XML Schema for State Signalling Interface

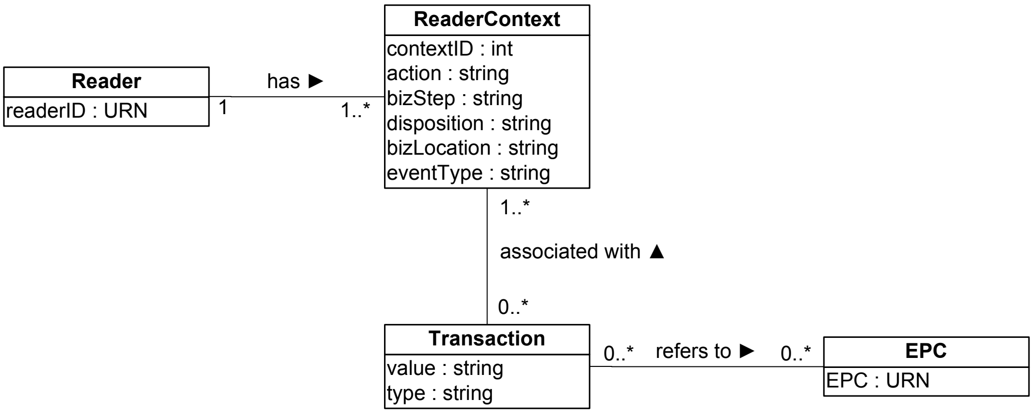


Figure 3.11: Data model for the Context Data Repository

Upon reception of new Reader State Signal:

- Mark the corresponding Reader Context in the repository as active

Upon reception of new RFID Reader Event:

- For all active Reader Contexts that are related to the reader ID of the RFID Reader Event
  - o Retrieve all context data from the context data repository
  - o For all transaction IDs that are associated with the reader ID from the RFID Reader Event and refer to the EPCs from the RFID Reader Event
    - Prepare an EPCIS event of the type defined in the context data
    - Add all EPCs referred to by the current transaction in the EPCs from the RFID Reader Event
  - o If the EPC lists from several EPCIS events are equal
    - Merge those transactions and delete all but one EPCIS event
  - o If EPCs from the RFID Reader Event remain that have not been added to an EPCIS Event
    - Prepare an EPCIS event of the type defined in the context data
    - Add all EPCs from the RFID Reader Event that have not been added to an EPCIS Event
  - o If type of EPCIS Event is Aggregation Event:
    - Identify the parent EPC and add all other EPCs from the RFID Reader Event to the list of child EPCs
    - Add all remaining data from the RFID Reader Event and the context data from the context data repository
  - o Else if type of EPCIS Event is Quantity Event:
    - Identify the EPC class and add the number of all EPCs to it
    - Add all remaining data from the RFID Reader Event and the context data from the context data repository
  - o Add all remaining data from the RFID Reader Event and the context data from the context data repository
  - o Save the EPCIS events in the EPCIS repository using the EPCIS Capture Interface

Figure 3.12: EPCIS event assembly algorithm of the Rule Engine

Table 3.1: Event and context data for Example A

Context Data	
ID of the RFID reader	urn:epcglobal:fmcg:loc:4023339.00006.0
Event Type	object event
Business Steps	urn:epcglobal:epcis:bizstep:picking urn:epcglobal:epcis:bizstep:stocking
Event Data	
Read EPCs	urn:epc:id:sgtin:4000001.099999.1 urn:epc:id:sgtin:4000001.099999.2 urn:epc:id:sgtin:4000001.099999.3
Time of RFID Reader Event	2006-10-20T15:14:58+0200
ID of the RFID reader	urn:epcglobal:fmcg:loc:4023339.00006.0

Exemplary Scenarios

In this section, we provide two comprehensive exemplary scenarios (A and B) to clarify the working of the ECA. The examples are based on the EPC Showcase [GS1 Germany, 2008].

Scenario A refers to the order picking business step in a distribution centre. A mobile RFID reader is used by a human operator to check the completeness of picked product batches. The read EPCs are compared to the picking list to avoid picking mistakes. In addition to this picking business step, the same mobile RFID readers can be used to check the completeness of stocked product batches. In order to use the RFID reader, the operator has to select the task it is used for on a dedicated display. The event and context data for this scenario is depicted in Table 3.1.

Scenario B refers to the receiving and shipping business step at a distribution centre. There is one RFID gate installed at the entrance of the distribution centre, so products that are received by or shipped from the distribution centre have to pass through this gate. Two light barriers installed at each side of the gate indicate the direction in which the gate is crossed. When a shipment arrives, its completeness is checked against the corresponding delivery note; when a shipment leaves the distribution centre, the ERP system automatically creates a delivery note. The tagged products being shipped are associated with the transaction ’purchase order’ at both business steps.

Before the ECA can process incoming event data in these scenarios, the given contexts have to be imported via the Reader Context Interface. The Reader Context Data in particular contains the association of the business steps to the reader IDs, i.e. the association of the two business steps ’picking’ and ’stocking’ to the reader ID of the RFID handheld for Scenario A as well as the business steps ’received’ and ’shipped’ to the reader ID of the entrance

Table 3.2: Event and context data for Example B

Context Data	
ID of the RFID reader	urn:epcglobal:fmcg:loc:4023339.00005.0
Event Type	object event
Business Steps	urn:epcglobal:epcis:bizstep:received urn:epcglobal:epcis:bizstep:shipped
Transaction type (purchase order)	urn:epcglobal:fmcg:btt:po
Transaction value	http://gs1-germany.distribution/po/222222
EPCs referred to by transaction 222222	urn:epc:id:sgtin:4000001.099999.1 urn:epc:id:sgtin:4000001.099999.2
Event Data	
Read EPCs	urn:epc:id:sgtin:4000001.099999.1 urn:epc:id:sgtin:4000001.099999.2 urn:epc:id:sgtin:4000001.099999.3
Time of RFID Reader Event	2006-10-20T15:14:58+0200
ID of the RFID reader	urn:epcglobal:fmcg:loc:4023339.00005.0

gate of the distribution centre for Scenario B respectively.

After these initial steps, the preparation for capturing RFID events is finished. Before the human operator uses the mobile handheld, either the picking or the packing business step has to be chosen on the handheld's display. The associated context ID is sent to the state signalling interface; this triggers the Rule Engine, which marks the chosen business step as active. Shortly afterwards, the event of the three EPCs are captured by the reader at the given time. This ALE event is pushed to the event interface, which triggers the Rule Engine. Following the algorithm in Section 3.2.2, the context data relating to the active context for the reader ID is fetched from the context data repository. The context requires the creation of an object event, which is created and filled with the event data and business step. Because no transaction is associated with the context, the Rule Engine saves the event in the EPCIS repository using the EPCIS capture interface.

The second example is processed in a similar way, with the difference being that a transaction is associated with the contexts: In Scenario B, a transaction 'purchase order' has to be included into the EPCIS Events to be generated. The corresponding Transaction Context Data, therefore, has to be imported via the Transaction Context Interface. The selection of relevant Transaction Context Data can be performed based on the Reader Context Data that has previously been exported from the Context Data Repository via the Context Export Interface. Based on this information, the ERP system can infer which business steps have been defined and which RFID readers are currently used to monitor these steps. As the data in Table 3.2 shows, the context selection can be done based on the business steps 'received' and 'shipped' and their association with the given reader ID. There exist two applicable Reader Contexts for the gate reader, one context for the 'receipt' and the 'shipped' business step respectively. The decision which context to associate with which RFID Reader Event is done based on the current Reader State updated by the Reader State Signals received via the State Signalling Interface. In Scenario B, the state signals determining the applicable business step are sent to the ECA by the light barriers installed on both sides of the distribution centre's entrance. If the light barrier at the inside of the distribution centre is crossed, the Rule Engine marks the 'shipping' context; otherwise the 'receiving' context gets activated.

When the RFID reader at the gate captures the tagged objects, the RFID middleware generates an RFID Reader Event containing the three EPCs listed in Table 3.2. The RFID Reader Event is pushed to the Event Interface of the ECA, which triggers the corresponding process of the Rule Engine. Following the algorithm provided in Section 3.2.2, the active context stored for the reader ID of the mobile RFID reader is fetched from the Context Data Repository. The context data listed in Table 3.2 requires the creation of an Object Event, which is created and filled with the data from the RFID Reader Event and the active context data, in particular the applicable business steps. The Rule Engine also checks all transactions that refer to the EPCs contained in the RFID Reader Event received from the RFID middleware. In Example B, only two of the three EPCs contained in the RFID Reader Event are referred to by the purchase order; therefore, one EPCIS event is created with the two EPCs associated to the transaction and a second one containing the remaining EPC without any associated transactions. After assembling the two EPCIS events, the Rule Engine saves them in the EPCIS repository using the EPCIS capture interface.

3.2.3 Prototypical Implementation

To test the general functionality of the developed concept, we implemented the proposed ECA as an extension of the commercial RFID middleware CrossTalk (developed by noFilis) and tested it in our laboratory. CrossTalk is a device management software for the integration of smart devices into a distributed data network [noFilis, 2007]. According to our framework, CrossTalk is considered as RFID middleware. It supports the integration of RFID hardware from major vendors and decouples the physical layer from the business layer; furthermore, it allows for monitoring the state of all connected devices even in a physically distributed RFID infrastructure. CrossTalk can be used in very heterogeneous environments, spanning from an industry PC installation in a production environment to multiple locations in the supply chain. It has also been reported to be implemented in connection with SAP's Auto ID infrastructure [Bornhövd et al., 2004].

We deployed CrossTalk in a JBoss application server with a MySQL database and tested it first in our laboratory with two RFID readers: Feig LRU 2000 and Sirit Infinity 510. We created a CrossTalk service which performs the web service call to the Event Interface of the prototypical ECA. The EPCIS implementation we used was Fosstrak [Fosstrak, 2009]. Fosstrak is a complete implementation of the EPCIS standard specification, certified by EPCglobal. We deployed both the ECA and Fosstrak in an Apache application server using the same MySQL database as CrossTalk.

A series of tests demonstrated the general working of the developed concept and prototype. Context data similar to the EPC Showcase was imported via the Reader and Transaction Context Interfaces of our ECA implementation. RFID tags conforming to ISO/IEC 18000-6 were read by the RFID readers, transformed to the ALE format by the created CrossTalk service and imported to the ECA via the Event Interface. Manual queries from the EPCIS repository showed that the ECA created all EPCIS events correctly. To date we have not conducted any real performance tests, which measure the feasible data throughput that can be handled by our prototype for more than two RFID readers that capture events simultaneously. A performance test of the EPCIS event generation process on the basis of a simulative approach is described in following section.

3.2.4 Performance Experiment

The real world test of the prototypical realization of the ECA verified the correctness of the tested RFID read events. The goal of the simulative experiment is to show that the computational efforts for the tasks and our implementation are feasible in the given architecture. Three architectural components are part of this evaluation:

- The RFID middleware CrossTalk creates the RFID read events and acts as the trigger of the event capturing process. So, the performance of CrossTalk is out of consideration.

- The self implemented ECA is the focus of the performance evaluation.

- The EPCIS repository FossTrak was used to store the context-enriched RFID read events. The ECA waits for a reply by calling the EPCIS capture interface. Thus, the performance of FossTrak to store EPCIS events in the repository is part of this evaluation. Originally FossTrak was developed as a fast prototyping platform that realizes the EPCIS specification. Subsequently, it has become the most widely used EPCIS implementation and is certified by EPCglobal. Because of the original objectives of providing an RFID prototyping platform that provides the research community with a testbed for RFID experiments [Floerkemeier et al., 2007a, p. 496] and not of developing a solution for the industrial use, the performance expectations are not strong.

The general experimental setup was organized according to Figure 3.6. The RFID middleware captures read events from an RFID reader and forwards these events to the ECA. The ECA enriches the raw data with context data and creates EPCIS events. These events are stored in the EPCIS repository. For the experiment, we replaced the real RFID infrastructure by a dummy reader that can be created and configured in the CrossTalk RFID middleware.

The performance experiment was conducted on two computers in a LAN. CrossTalk was installed on a dual core Pentium IV 2.0 GHz with Windows XP and 2 GB RAM. CrossTalk was installed in version 2.0.0 deployed on a jBoss application server in version 4.0.5. and used version 5.0.22 of MySQL. FossTrak was version 0.4.1. and our developed ECA were installed on a dual core Pentium IV 2.8 GHz with the Linux 2.6 kernel and 1 GB RAM. It was deployed on version 5.5.16 of an Apache Tomcat application server. A version 5.0.22 in its standard configuration MySQL database was used for both FossTrak and the ECA.

To measure the processing time and delays, the Java method `System.currentTimeMillis()` was used. In doing so, we got timestamps just before and after the section we wanted to measure and calculated the duration by logging the difference of the time stamps. After ten measured durations, the results were written to a log file. We measured four different durations in three scenarios. Before each scenario, we cleared the databases to create comparable conditions and set up the necessary infrastructure data and context data.

The four measured durations were:

- The *total time* measured the duration between the generation of an RFID read event and the completed storage of the corresponding ECPIS events in the repository. All other durations were measuring parts of this time.

- The *ECA processing time* measured the length of time for the original tasks of the ECA. These include the algorithm presented in Figure 3.12; the enrichment of RFID reader data with context data and the creation of the EPCIS events. The processing time for data queries in the context data repository and the time for storing the EPCIS events in the EPCIS repository are excluded.

- The *SQL processing time* measured the duration between the query and response of the context data repository. This is composed of a minimal communication latency and the execution of the query on the database server. Several SQL queries have to be made for each RFID read event. First, context data has to be retrieved for the incoming Reader ID. For each context, a query for possible related transactions has to be executed. Aggregation Events would require an additional query but this type of event was excluded from the evaluation. The timestamps are calculated before and after the call of method `executeQuery(query)` and the durations of all queries are summed up.

- The forth measured duration is the *FossTrak processing time*. After processing the incoming RFID read event, the ECA has to store the EPCIS event in the repository using the standardized EPCIS capture interface that is implemented by FossTrak as a Web Service. The timestamps are calculated before and after the call of method `sendEPCISEventToRepository(epcisdoc)`.

We evaluated three scenarios. The goal of the first scenario is to measure the performance where a simple object event has to be created for each read event. Thus, the context data repository contains only one context and no transactions. The only variable in this experiment is the number of RFID tags per read event. Figure 3.13 depicts the processing times depending on the number of tags. At first glance, the bar diagram indicates that the FossTrak processing time has the greatest share of the overall duration. To get a more precise overview of the processing times of our application, the ECA and SQL processing times are depicted separately in Figure 3.14.

According to the EPCIS specification, to be precise the data model depicted in Figure 3.3, not only Transaction Events but all four event classes may contain a number of transactions. Besides the enrichment of RFID reader data with reader context data, the enrichment with transaction context data is the second important task of the ECA. That is why we tested a second scenario in which a variable number of transactions is associated to a fixed set of ten RFID tags. For each RFID read event, 50 RFID tags are captured. Before the experiment, the databases were re-initialized and the transaction context data was inserted. Despite the higher computational effort, the share of the total processing time did not change substantially (see Figure 3.15). The comparison of Figure 3.14 and Figure 3.16 shows that

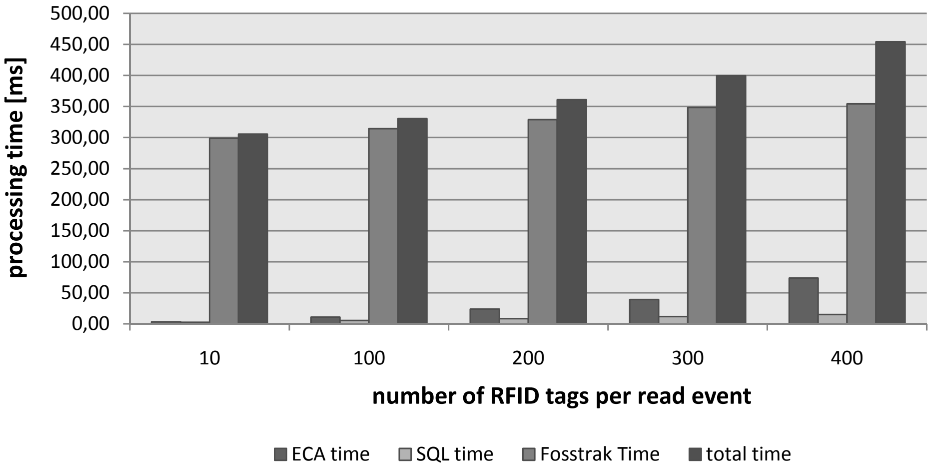


Figure 3.13: Performance evaluation depending on the number of tags per read event

the influence of the number of tags on the performance of the ECA can be regarded as higher.

In the second scenario, the transaction context data matched exactly with the read events. This means that all EPCs associated to a transaction were read within a read event. In a real world scenario, this can be compared with a box of tagged products that all belong to the same transport order and the RFID read event captures only the RFID tags from this box during a read cycle. This condition does not necessarily reflect reality: if the boxes are not read separately but on a pallet, this clear distinction has to be removed. So, we tested a third scenario in which the corresponding transactions matched randomly to the read RFID tags. Figure 3.17 reveals similar results. The direct comparison of the exact and random match of transactions and read EPCs is depicted in Figure 3.18 and confirms the assumptions.

The conclusions from this simulative performance experiment have to be interpreted with caution; nevertheless, the results indicate a sufficient performance of the ECA – especially in comparison to the EPCIS repository. In the worst case scenario of randomly distributed transactions, the ECA was able to process an incoming read event within 20 milliseconds. From the viewpoint of a continuously capturing RFID reader, this means that 50 read events can be processed in one second without delay. In contrast, the processing time of the FossTrak in Scenario 2 was 500 milliseconds for an incoming read event. Only two events can be processed in one second without delay. This proportion even becomes worse if several Event Capturing Applications (e.g. for inventory counting and goods receiving) are connected

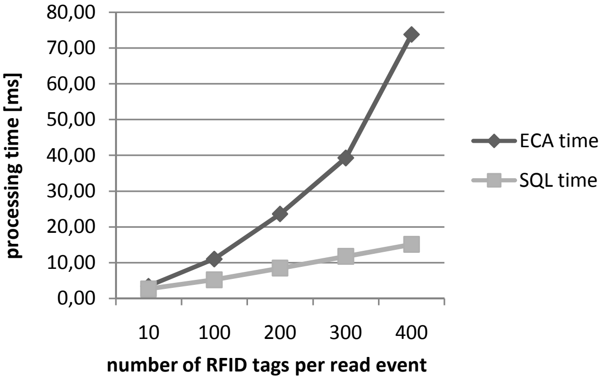


Figure 3.14: ECA and SQL processing time depending on the number of tags per read event

to one company's EPCIS repository.

Different consequences can be drawn from these results. First, the performance requirements of automatic real-time data capturing applications have to be considered carefully. Second, although FossTrak is the most widely used EPCIS repository [Fosstrak, 2009] and certified by EPCglobal, this performance test indicate an inadequate performance for major applications. Besides using another software solution, the performance of the FossTrak repository might be improved or the tasks of the Event Capturing Application can be modified. One option is to buffer incoming read events and combine them into one EPICS event before calling the EPCIS capture interface. However, these tasks are highly application dependent and were excluded from our implementation as we concentrated on the basic tasks of the ECA.

3.2.5 Conclusions

The industry consortium EPCglobal and associated research institutions have developed a stack of standards for the Internet of Things. Besides the hardware related specifications, which have already been adopted by the ISO, there exist three architectural layers designed to enable the EPCIS-based cross-company usage of RFID-related data: the EPCIS itself as well as the event capturing and querying applications. While the applications that access the EPCIS repositories are the focus of numerous research projects, the event capturing applications required to generate EPCIS events in the first place have so far not been in the focus of attention although their development and standardization is both challenging and important.

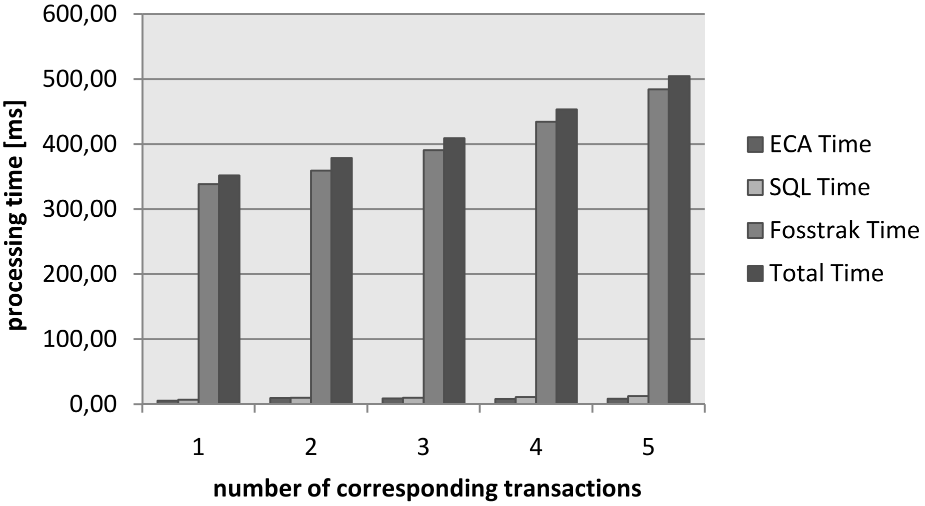


Figure 3.15: Performance evaluation depending on the number of corresponding transactions

This section fills this gap by presenting an in-depth analysis of the requirements for event capturing applications. Our results show that the connection between the different data sources required to generate EPCIS events is very demanding. The required data ranges from rather static process descriptions to highly dynamic state signals from the physical infrastructure.

We have proposed the specification of an ECA that can be standardised and includes the required interfaces, database and event assembly algorithm. To demonstrate the correctness of our specifications, we have developed a prototype that implements them and tested it in our RFID laboratory. The architectural layers interacting with our ECA prototype were represented by solutions accepted in the market (CrossTalk and Fosstrak) in order to assure its usability.

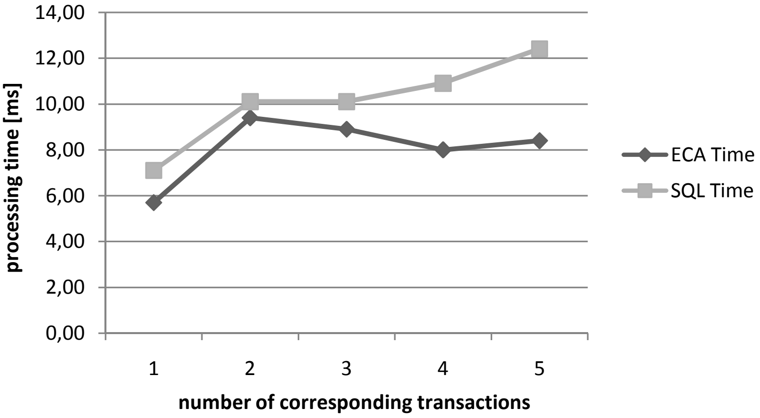


Figure 3.16: ECA and SQL processing time depending on the number corresponding transactions

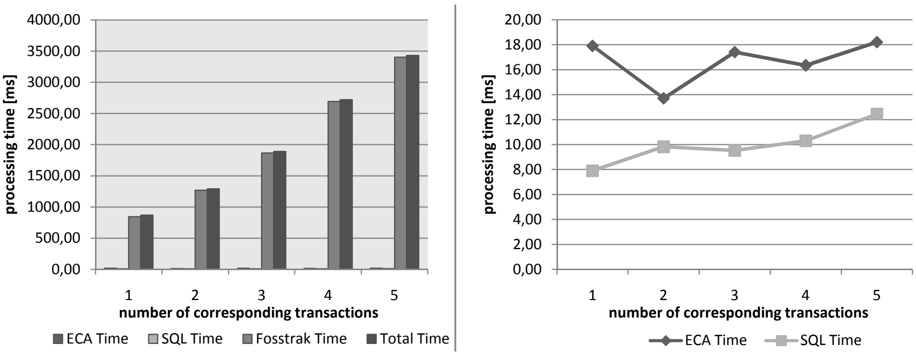


Figure 3.17: Performance evaluation depending on the number of randomly associated corresponding transactions

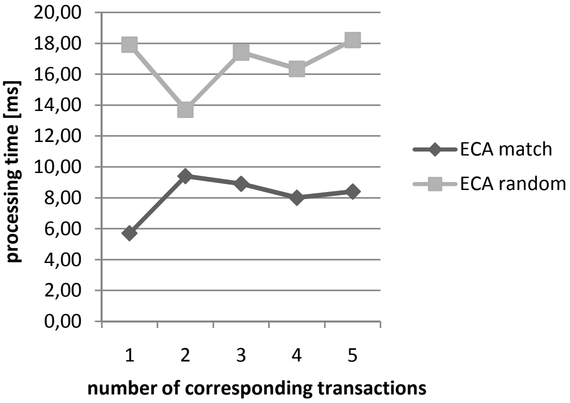


Figure 3.18: Comparison of ECA processing times for matching and randomly associated corresponding transactions

3.3 EPCIS-based Supply Chain Event Management

Supply Chain Event Management (SCEM) systems are decision support systems that allow for monitoring, prioritizing and reacting to events pertaining to the flow of goods in a supply chain [Otto, 2003]. A supply chain event can be any change of state with respect to the flow of goods, currency, or information. SCEM applications allow for the specification of rules, which can be applied to streams of events in order to identify those which are critical, i.e. events which call for immediate action in order to prevent financial loss. The business value of an SCEM application depends on the degree of supply chain visibility and the degree of freedom regarding possible ways to react to critical events; however, since the available options for all actions are as dynamic as the various states of supply chain operations, the logical design of SCEM systems can be very demanding.

Supply chain visibility refers to the amount of information available to the supply chain manager and can be characterized according to the following dimensions: detail, timeliness and accuracy. RFID technology can be used for efficient tracking of materials as they move though the supply chain [Niederman et al., 2007]. In contrast to the bar code, it allows for concurrent reading of item identification data without direct line of sight up to a certain read range [Michael and McCathie, 2005]. RFID is expected to increase supply chain visibility along all three dimensions mentioned. Since SCEM requires a high degree of supply chain visibility, the introduction of RFID into a supply chain could increase the business value of SCEM applications.

3.3.1 Introduction

Information in supply chains flows both upstream and downstream. Orders based on actual or forecasted demand are forwarded upstream, while order status and progress information is forwarded downstream. Supply chain collaboration aims at realizing increased business value by improving supply chain coordination. Research in supply chain collaboration has so far been focused on effectively using demand information with information sharing and coordination mechanisms [Holmström et al., 2002] [Waller et al., 1999]. This has lead to positive results, for instance the reasons for the bullwhip effect and possible countermeasures were identified [Lee et al., 1997]. Some of the concepts developed to tackle typical supply chain problems related to demand uncertainty, such as Vendor Managed Inventory (VMI) and Collaborative Planning, Forecasting, and Replenishment (CPFR), have been implemented in many of today's supply chains; however, the cross-company optimization of scheduling and the execution of schedules are still in an early stage of examination. Its potential advantage is straight-forward: by moving the trade-off between benefits and costs from each stage of the supply chain to activities along the supply chain, the total production and distribution costs of a product can be minimized. Furthermore, the possibility of optimizing production and distribution schedules across organizational boundaries has the potential to improve both the reliability and the responsiveness of supply chains. More specifically to SCEM, it has the potential to improve the supply chains' ability to cope with delays or other problems in an efficient manner, as well as to react efficiently to unexpected demand fluctuations [Otto, 2003].

Automatic identification and tracking of material movement by advanced data collection devices such as Radio Frequency Identification (RFID) is expected to enable more efficient supply chain management [Gaukler and Seifert, 2007b]. Standardization of a number of components, which make up the architecture of event management solutions is on the way. Apart from protocols and data schemas designed to serve the purpose of receiving, accumulating, filtering, and reporting events pertaining to particular electronic product codes (EPCs), EPCglobal has specified EPCIS for storing and exchanging these events across the supply chain [EPCglobal, 2007]. While EPC formats and RFID reader protocols have come a long way, EPCIS is still in an early stage of development. EPCglobal offers the possibility to certify EPCIS implementations. Such certificates serve to guarantee that software applications being offered on the market adhere to the standard. Within industry, IBM has offered an EPCIS-compliant software component since December 2006 [Bacheldor, 2007] and an open source solution that implements the EPCIS specification has been used in Section 3.2.

Although the software industry is quick to offer products able to process EPC data, the development of value-generating business applications still lags behind. As long as real-world applications are rare, it is hard to justify the definition of a comprehensive standard. Little academic research on supply chain wide decision support systems based on auto ID technologies has been published so far. Chow et al. [2007] provided a schematic description of an inter-organizational information system based on RFID that provides visibility of the processes taking place at a third party logistics provider via a web front-end. Trappey et al. [2009] described an intelligent agent system that, among other things, supports real-time surveillance of production progress. Although these authors have provided interesting starting points for the realization of inter-organizational event-based applications, they do not go into technical details concerning the data formats and protocols required to realize these applications. Further research on inter-organizational decision support systems based on auto ID technology is thus needed. In particular, it has to be determined which architectures suit which business applications. Since standardization plays a significant role in the design of inter-organizational information systems, research on the appropriateness of the current standards proposed by EPCglobal is warranted.

Motivated by the knowledge gap identified above, we focus on three promising areas for further research:

- The specification of concrete business applications of event-based inter-organizational supply chain management systems
- The interoperability of the different components that need to be integrated in order to realize such systems
- The intra as well as inter-organizational management of the EPC context data provided by different enterprise applications
- The requirements analysis of EPCglobal's architecture for the supply chain-wide exchange of EPC-related data for SCEM applications

We believe that without a specific requirements analysis, the degree of system interoperability cannot be assessed. The type of context data that needs to be managed and exchanged naturally depends on the application. Our approach thus consists of first putting the discussion about EPC-based material tracking into a concrete business context. To this end, we describe the challenges involved in coordinating decentralized make-to-order assembly networks. Our choice of the business context and application example tries to be as simple and general as possible. Thereafter, we derive technical requirements that need to be addressed by the architectural design, in particular with respect to inter-organizational system interoperability. We present an approach to realize a two-layered inter-organizational event-based architecture. In contrast to the components proposed by EPCglobal, our architecture follows a push approach for the dissemination of event data. In Section 3.3.3, we describe a protocol layer providing all necessary communication primitives to interconnect the enterprise systems of several organizations.

Our main contributions are the following:

- We describe a relevant business application of event-based systems in a multi-organisational context.
- Business requirements are mapped to technical system features while consistently referring to current EPCglobal specifications.

- We specify a tentative protocol layer that serves to integrate heterogeneous enterprise systems that exchange EPC context data.
- We identify strengths and weaknesses as well as guidance for the further development of the current EPCIS standard.
- We develop quantitative evaluation criteria and compare the centralized EPCIS-based architecture proposed by EPCglobal with the decentralized EPCIS-based architecture proposed in the next section.

This work is structured in the following way. Section 3.3.2 outlines the business application we focus on. In Section 3.3.3, the main ideas behind and some details of our proposed architecture are presented. The developed architecture and the centralized architecture are compared in Section 3.3.4. The quantitative evaluation setup is described in Section 3.3.5 and the results are presented in Section 3.3.6. Section 3.3.7 concludes this chapter and outlines further research opportunities.

3.3.2 Business Application

Fierce competition and the resulting pressure to reduce costs while maintaining high customer satisfaction has drawn attention to possible ways to improve supply chain wide coordination. Collaboration in this context means that several independent organizations work together to achieve the common goal of supply chain wide cost reduction [Chopra and Meindl, 2004]; [Simatupang and Sridharan, 2005]. Supply chain collaboration is a growing field of research; however, most collaborative efforts have so far been focussing on the demand side [Waller et al., 1999]; [VICS, 1998]: Sharing information on historical or expected demand and planning production jointly can greatly reduce common supply chain inefficiencies caused by phenomena such as the bullwhip effect [Lee et al., 1997]. Although more advanced identification technology can help to increase downstream inventory accuracy [Atali et al., 2006], it has often been argued that the many benefits of standardized auto ID technologies can be obtained from the ability to track items as they are moving through the supply chain [Gaukler, 2005]. Interestingly, short-term coordination of supply processes using upstream information sources has received little attention in the operations community to date [Chen, 2003].

Event-Based Supply Chain Management

The business application described in this chapter aims at realizing the benefits of short-term supply coordination by sharing real-time order progress information among the participants of a supply chain. Auto ID technologies such as RFID are expected to provide more real time visibility of upstream supply chain stages and, therefore, play a pivotal role in building systems to support operational supply chain management. A recent concept in logistics management termed *Supply Chain Event Management* (SCEM) conceives upstream information as a stream of discrete events that can be used to identify exceptions and trigger alarms [Otto, 2003]; however, little has been published to date about the system architecture required to meet the requirements of SCEM and how they can be integrated into current enterprise system infrastructures. Günther et al. [2006] provide useful starting points for research in this area.

In order to optimize short-term operations, decision-makers along the supply chain need to be informed about problems at upstream stages as well as their options for dealing with a particular problem. The short-term actions available to steer supply vary according to individual supply chain characteristics: in long- and medium-haul transportation there often exists the possibility to choose among different transportation modes, e.g. sea, sea/air, and air; the picking process taking place in warehouses can be accelerated if needed, for instance by skipping certain quality assurance processes; or capacity can be added to production processes, e.g. by increasing machine throughput or by extending shifts. Information on the available short-term control options is usually only valid for a very short period of time; thus, any event management system designed to support operational supply chain management has to include a component capable of transmitting and offering up-to-date control options.

In supply chains providing highly complex products such as cars, the end product usually consists of thousands of parts being delivered to the Original Equipment Manufacturer (OEM) by different suppliers. Those in turn have their own suppliers who are not visible to the OEM because it maintains no direct business relationship with them. As cost pressure further increases, complex assembly networks will become even more dispersed due to specialization, short-term supply contracting and outsourcing of production and transportation functions. Furthermore, many manufacturing companies have introduced just-in-time production to minimize undedicated inventory along the supply chain. The only way to cope with the resulting increase of supply uncertainty is to acquire effective means to coordinate the flow of material on a real-time basis. The information systems used to provide the required visibility and decision support need to be highly flexible and easily deployable.

Formalization of Assembly Networks

To be able to analyse the problem of short-time management of assembly networks in a structured manner, we introduce the semantics of a simple formalization of such networks in the following. According to Chopra and Meindl [2004], the four drivers of supply chain management are facilities, inventories, transportation and information. The way that these drivers are applied determines the performance and operational cost of a supply chain. Each of the four drivers will be reflected in our formalization. According to our model, an assembly network consists of one or more supply chain organizations. A supply chain organization in turn consists of an arbitrary number of internal nodes which can either be an assembly process node, an inventory node or a transportation node. Internal nodes are connected by edges indicating the flow of material. Assembly and transportation processes always need to be decoupled by an inventory node. Furthermore, one inventory node always refers to one particular item type. The upstream end of the formal assembly network is marked by order book nodes. Each order book holds the production orders for a subsequent assembly node.

Figure 3.19 shows an example assembly network consisting of four supply chain organizations forming a three-tiered assembly network. The network conforms to the rules stated above. We will use this example throughout the section to illustrate the working of our event-based architecture.

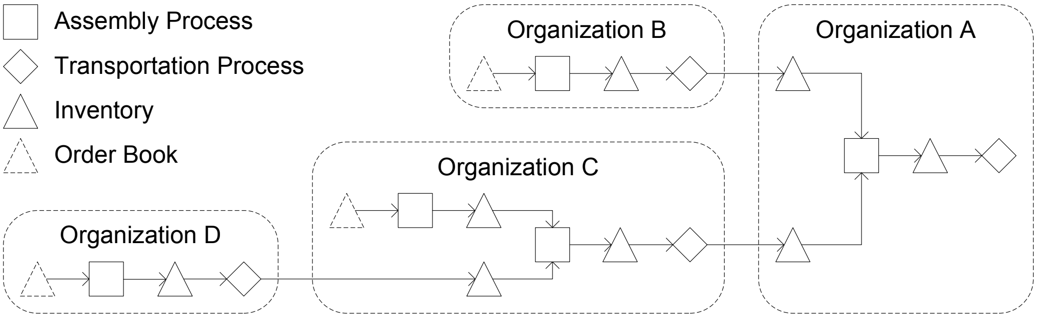


Figure 3.19: Example of formalized assembly network

The information required to optimize the coordination of an assembly network basically consists of schedules, i.e. events that are expected to take place at certain dates, the events actually taking place as material moves downstream, and the relevant control options. The purpose of the system architecture proposed in Section 3.3.3 is to provide all nodes in the network with the technical means to share the required information in a decentralized way.

3.3.3 Decentralized EPCIS-Based SCEM

Data Layer

Using a common data format like the one specified by EPCglobal to store EPC-related data is definitely valuable in providing interoperability between applications used in one organization as well as for the interchange of event data between organizations. However, the business application described in Section 3.3.2 requires context data in the shape of expected events; therefore, we extended the EPCIS event data framework by the class ExpectedEvent (see Figure 3.20).

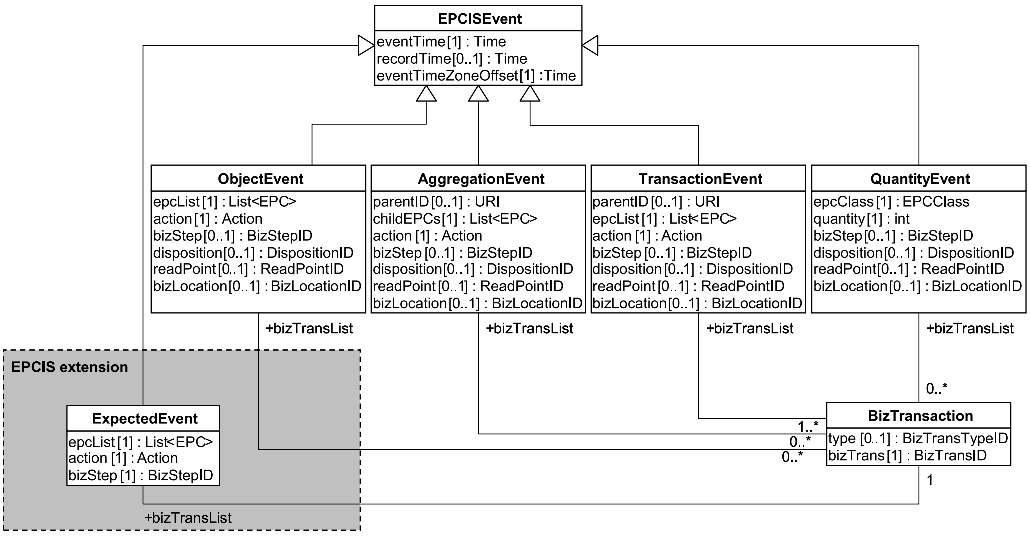


Figure 3.20: Extended EPCIS data model

According to EPCglobal, inter-organizational sharing of event data should be done using the EPCglobal core services, in particular the Object Name Service (ONS) and the EPCIS Discovery Service; however, this results in a centralized query infrastructure in the hands of EPCglobal with the two mentioned services representing single points of failure. Furthermore, the context data required to make sense of the event data would have to be shared via an additional, unstandardized communication channel. We strive to specify an architecture that works in a decentralized manner and takes advantage of existing bilateral business relationships in the supply chain. We believe that the alternative system architecture proposed in the following suits the requirements of our business application better than the one envisioned by EPCglobal.

Protocol Layer

The entities communicating on the protocol layer are the nodes of the assembly network. Within our architecture, these nodes represent communication hubs and controllers at the same time. Each node in the assembly network maintains a list of predecessors and a successor node for each type of product. Upstream messages are sent to some subset of predecessor nodes while downstream messages are sent to the successor node. Different product types have different bills of material, i.e. nodes would maintain at most one predecessor and successor list for each product type.

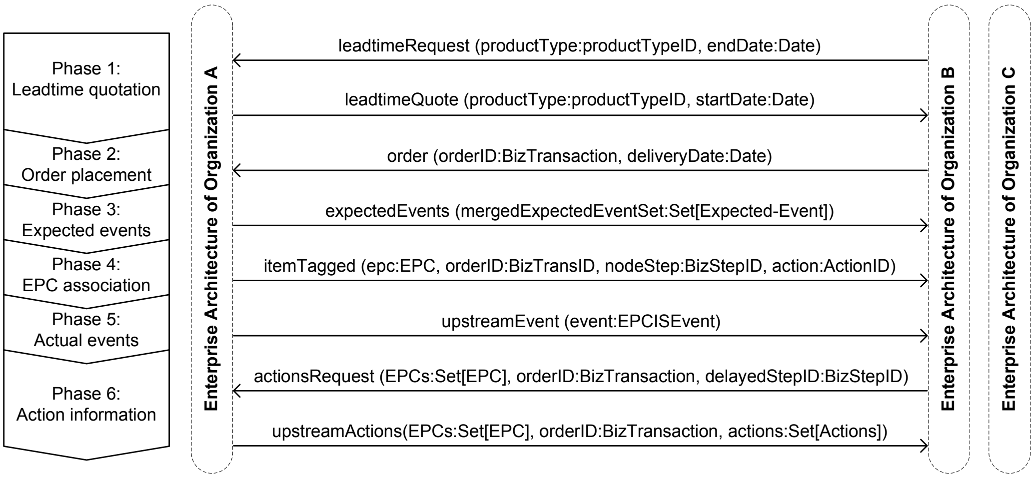


Figure 3.21: Protocol layer for EPCIS-based SCEM

The communication taking place to coordinate the assembly of products is separated into six phases. Figure 3.21 presents an overview of the entire protocol. During phase one, lead times are quoted recursively. Each node implementing the protocol's communication primitives can query its upstream assembly network in order to find out if a certain delivery date can be met. Answering the query implies searching the assembly tree of a particular product type for the maximum lead time path. The answer consists of the date by which the order has to be issued at the root node in order to meet the requested delivery date. There are two message formats defined for this communication phase: an upstream message called leadtimeRequest containing the attributes productType and endDate, and a downstream message called leadtimeQuote containing the attribute startDate. Phase 1 is given as pseudo code below:

- Upon reception of leadtimeRequest(productType:productTypeID, endDate:Date) by node i:

  - If node i is of type orderbook:
    - Set startDate to the earliest startDate incremented by node i's expected duration
    - Send leadtimeQuote(productType:productTypeID, startDate:Date) to involved successor node
  - Otherwise:
    - Send leadtimeRequest(productType, endDate) to all corresponding predecessor nodes

- Upon reception of leadtimeQuote(productType:productTypeID, startDate:Date) by node i from all involved predecessor nodes:
  - Set startDate to the maximum startDate quoted by the predecessors incremented by i's expected duration
  - Send leadtimeQuote(productType:productTypeID, startDate:Date) to the involved successor node

In our example, if the root node of organization A initiates the request, it will eventually end up with the expected lead time of the entire assembly process. From the value of startDate it can infer whether the order can be filled before the requested delivery date or not. If the quoted startDate has already passed, another query using a later delivery date can be initiated.

Order propagation constitutes the second communication phase. In our example, upon reception of a customer order, organization A initializes an upward information diffusion process of order data: A's root node sends an order message to its predecessors indicating that an order has been issued. The message contains a unique order ID as well as the scheduled date of delivery. Each order ID is represented by a BizTransaction object. The predecessor nodes propagate the order ID and the scheduled delivery date decremented by their respective expected process durations. The propagation process terminates when an order book node is reached; thereafter, the order is stored in the order book until the transmitted date coincides with the actual time. If this happens, the assembly process represented by the successor node is triggered. Phase 2 is given as pseudo code below:

- Upon reception of order(orderID:BizTransaction, deliveryDate:Date) by node i from successor:
  - Set deliveryDate to the deliveryDate sent by the successor decremented by i's duration

  - Send order(orderID, deliveryDate) to all involved predecessor nodes

The third communication phase consists of messages containing ExpectedEvent objects which are sent downstream. The expectedEvents messages used in this phase serve to let downstream nodes know when certain items are scheduled to enter and leave each node. The ExpectedEvent class which is used to store expected events represents an extension of the EPCglobal EPCIS standard. We embedded the event type ExpectedEvent as child of EPCISEvent (see Figure 3.20). According to EPCglobal, adding a new event type implies updating the standard specification [EPCglobal, 2007]. In our case the semantics of the EPCISEvent class would have to be adapted to include the possibility of events that have not yet taken place. Upon reception of an expectedEvents message concerning a particular order from all involved predecessors, a node remembers which events are scheduled to take place in the future by storing them in its local event repository or in the volatile storage of an SCEM application. It then creates the events it expects to happen at its own entry and exit points. As indicated by Figure 3.20, an expected event requires the attributes epcList, action and BizStep. By the time an ExpectedEvent object is created, there are no EPCs stored as values of its epcList attribute. If the object is created in response to an order, the action attribute is set to ADD. In case expected events need to be withdrawn, for instance because the corresponding order was cancelled, the action attribute is set to DELETE. The BizStep attribute is needed as a key to later match the expected with the actual events and is either set to the BizStepID of the entry or the exit point of the node. Newly created ExpectedEvent objects are combined with the received objects into a new set and sent downstream. Phase 3 is given as pseudo code below:

- Upon reception of expectedEvents(expectedEventSet:Set[Expected-Event]) pertaining to a particular BizTransaction by node i from all involved predecessors:
  - Capture all ExpectedEvent objects contained in all expectedEventSets
  - Merge all expectedEventSets to obtain mergedExpectedEventSet
  - Create own ExpectedEvent objects and add them to mergedExpectedEventSet
  - Send expectedEvents(mergedExpectedEventSet:Set[Expected-Event]) to the involved successor node

Phase 4 serves to complete the expected events created in phase 3 by the EPCs. This information is needed to identify pairs of expected and actual events which have to be compared in order to detect delays. We assume that EPCs are allocated at about the same time that physical objects are associated with an EPC. We believe that this is a reasonable assumption considering practical constraints such as RFID printers which store fixed EPCs on passive tags. When a physical object gets associated with an EPC at some node, this node sends an itemTagged message to its successor. Each message of this type contains an EPC as well as the keys required to map the allocated or removed EPC to event entries at downstream nodes. Furthermore, it contains the type of action to be triggered by the message, i.e. either association or disassociation of EPC and expected event. When all stored ExpectedEvent objects have been enabled by adding one or several EPCs, each node possesses the information it needs to identify delays as upstream events of any type. Phase 4 is given as pseudo code below:

```
• Upon reception of itemTagged(epc:EPC, orderID:BizTransID, nodeStep:BizStepID, action:ActionID) by node i from a predecessor:
    – If action is ADD:
        ∗ Add EPC to all previously captured ExpectedEvents with the corresponding BizTransID and BizStepID
    – If action is DELETE:
        ∗ Remove EPC from all previously captured ExpectedEvents with the corresponding BizTransID and BizStepID
    – Send itemTagged(epc:EPC, orderID:BizTransID, nodeStep:BizStepID, action:ActionID) to involved successor node
```

In phase 5, messages of type upstreamEvent are being sent downstream to spread the news on actual events taking place upstream. Each of them carries an EPCISEvent object including the attached BizTransaction object which refers to the order. It would be straightforward to only use the generated ObjectEvent objects in the protocol since they are created at all process steps. Phase 5 is given in pseudo code below:

```
• Upon capturing of event:EPCISEvent at node i:
    – Send upstreamEvent(event:EPCISEvent) to the involved successor node
```

- Upon reception of upstreamEvent(event:EPCISEvent) by node i from a predecessor:
    - Capture event
    - Send upstreamEvent(event:EPCISEvent) to the involved successor node

The final phase of the communication protocol allows each node to collect up-to-date action alternatives to make up for a particular delay. By comparing the dates of expected and actual events that have been captured during the previous communication phases, a node can identify upstream delays; however, in order to exert control, the node requires information about which actions can currently be taken to influence the processing of a particular order. The path of nodes between the node that caused the delay and the node that identified the delay, we refer to as the action path of a delay. Our protocol provides the opportunity to query the upstream network for these action paths. Any node can initiate such a query by sending a message of type actionsRequest to all its predecessors. This message contains three attributes: the EPCs that the delayed event refers to, the orderID of the delayed order and the BizStepID of the processing step where the delay occurred. When an upstream node receives a message of type actionsRequest, it first checks whether it has stored an ExpectedEvent containing the EPCs in the message. If this is the case, it compares the BizStepID with the one of its exit points. If the two BizStepIDs are not equal, it forwards the message to all of its predecessors that are involved in the assembly process; otherwise, the node which has caused the delay has been reached. This node then creates a message of the type upstreamActions containing information on all possible actions that can be taken to speed up order processing at its site and forwards the message to its successor. If the successor is not the original requester, it adds its own ways to deal with delays concerning this order and sends the message to its own successor. This way the original requester ends up with a list of all up-to-date opportunities along the action path to speed up a particular order. Phase 6 is given in pseudo code below:

- Upon reception of actionsRequest(EPCs:Set[EPC], orderID:BizTransaction, delayedStepID:BizStepID) by node i from successor:
    - If an ExpectedEvent containing EPCs exists:
        - If delayedStepID equals exitStepID:
            - Retrieve available speedup actions for EPCs and orderID

            - Send message upstreamActions(actions) to involved successor
        - Otherwise:
            - Send message actionsRequest(EPCs:Set[EPC], orderID:BizTransaction, delayedStepID:BizStepID) to all involved predecessors

- Upon reception of upstreamActions(EPCs:Set[EPC], orderID:BizTransaction, actions:Set[Action]) by node i from a predecessor:
    - If node i is the original requester:
        - Evaluate and trigger actions
    - Otherwise:
        - Retrieve available speedup actions corresponding with EPCs and orderID
        - Append these speedup actions to actions
        - Send message upstreamActions(EPCs:Set[EPC], orderID:BizTransaction, actions:Set[Actions]) to the involved successor

Application Layer

Having presented the protocol layer of our architecture in the previous section, we now turn to its application layer. The application layer consists of all enterprise systems that use the primitives of the protocol described in Section 3.3.3.

Capacity in the shape of production slots, warehouse space or transportation capacity is usually managed by a corresponding information system which forms part of an Enterprise Resource Planning (ERP) solution. The quotation of process durations in phases 1 and 2 of the communication protocol described in Section 3.3.3 thus depends on the input from those systems. The data that has to be provisioned to the protocol includes the quotable process start dates, the identifiers of entry and exit points of nodes in the assembly network, and the available speedup actions. Customer facing systems such as order management provide other inputs required for the working of the protocol. These inputs include the requested delivery date for an order, the type of product to be assembled and the allocated order IDs. Order management forms part of most standard ERP solutions.

EPCs are allocated by the EPC management of an organization. Each EPCglobal subscriber manages its own set of EPCs which contain the organization's unique General Manager Number. The subscriber organization is responsible for maintaining the numbers of Object Classes and Serial Numbers which, together with the organization's General Manager Number, form the EPC [EPCglobal, 2008b]. When a new EPC is created and attached to a physical object, this information needs to be published on the protocol layer.

The application layer component of the EPCIS-based decision support architecture required at each node consists of two components: A local EPCIS implementation and a SCEM application interfacing with users. Expected and actual events are stored in local EPC repositories which need to be accessed by the SCEM application to identify delays. Alternatively, SCEM applications can maintain their own event storage which eliminates the need for stand-alone EPC repositories as envisioned by EPCglobal; furthermore, the SCEM application also needs to have direct access to the protocol layer in order to retrieve action paths.

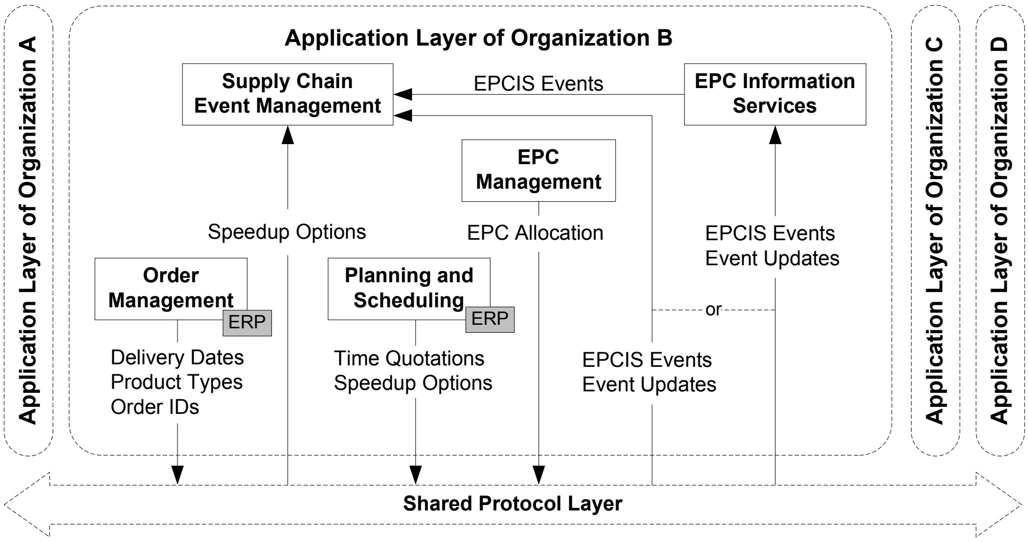


Figure 3.22: Two-layered EPCIS-based architecture for SCEM

The purpose of the SCEM application is to provide the human decision maker responsible for the coordination of the decentralized assembly network with the means to monitor and control activities. The SCEM application could, for instance, allow for the individual specification of service levels that need to be met. These service levels would then be translated into tolerable delays so that action paths are only retrieved if delays reach a certain threshold. Furthermore, the functionality of the SCEM application could include optimization routines that support the decision maker in picking an optimal action plan in each situation. Since there exists a potentially large number of possible actions that can be taken to speed up order processing on the action path and little time to decide which combination results in the least implementation cost, further IT support is definitely warranted.

Figure 3.22 depicts the general layout of the proposed architecture. The three components Supply Chain Event Management, EPC Management and EPC Information Services have to be added to the existing ERP solution in order to let an organization take advantage of the data being transmitted in the protocol layer.

3.3.4 Quantitative Comparison of two Architecture Approaches

Our motivation for conducting the research presented in this section emanates from the importance of providing objective assessments of different architecture choices regarding the distributed system design of the Internet of Things. We focus on the requirements imposed on distributed RFID-related data management by SCEM applications. Our contribution is an objective comparison of the centralized EPCIS-based architecture proposed by EPCglobal with a decentralized EPCIS-based architecture proposed in Section 3.3.3. For this purpose, we develop quantitative evaluation criteria and apply them to both architectures.

EPCglobal's EPCIS specification defines several event types. EPCIS events can be conceived as a compact format for recording the traces of items that have been associated with an RFID transponder containing a unique EPC. If the organizations taking part in the supply chain grant each other access to their EPCISs, the downstream organizations can gain very detailed visibility of upstream processes; however, in order to realize a supply-chain wide SCEM, the supply chain manager also has to know the upstream schedules and options for action in order to optimize operations. A straightforward way to enable downstream parties to detect delays in the flow of goods is to translate schedules to the EPCIS event format and share these 'expected events' before the actual events occur (see Section 3.3.3). Based on the supply-chain wide schedules and the real-time information on the flow of goods, the criticality of events can be evaluated.

In the following two sections, we describe the centralized event sharing architecture proposed by EPCglobal (henceforth referred to as Event Pull), and a competing approach referred to as Event Push. Only the essential characteristics in the form of concrete process steps will be outlined in order to enable an objective evaluation.

EPCIS-based Event Sharing using Event Pull (EPCglobal)

EPCglobal recommends a centralized query infrastructure which can be used to retrieve all events relating to a particular EPC from all accessible EPCISs worldwide [EPCglobal, 2009]. The retrieval process has two steps: first, the EPCIS Discovery Service (DS) is queried for a set of references to all EPCISs which have stored events involving a particular EPC. Upon receiving this set, the query interfaces of all EPCISs in the set can be directly queried for particular types of events, i.e. the range of events searched for can be restricted to the information of interest. This architecture is well suited for situations when there is no ex-ante knowledge about the applications which will use it. In principle, it allows for the retrieval of EPCIS events based on arbitrary search criteria which have previously been stored in any EPCIS; therefore, it can also be used to realize SCEM. The weak spot of the EPCglobal architecture is its centrality. On the one hand, the EPCIS DS represents a potential bottleneck which threatens reliability; furthermore, there are continuing political debates about who should be in charge of the central components of the worldwide communication infrastructure [Fabian and Günther, 2009]. On the other hand, keeping all the reference data stored in the EPCIS DS up to date will be a major challenge.

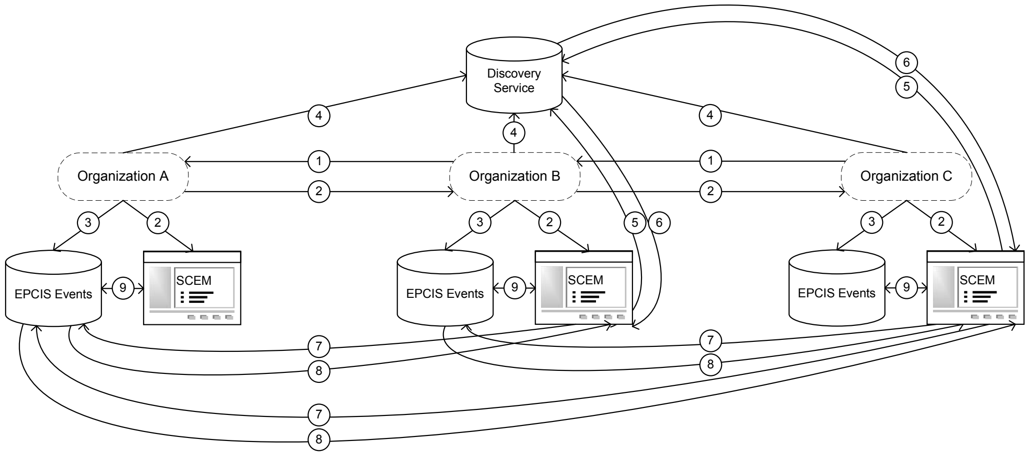


Figure 3.23: Event Pull in a three-tiered supply chain

Figure 3.23 describes how the event sharing mechanism works in the context of SCEM if the architecture approach of EPCglobal is followed. The concrete steps are as follows:

1. The last organization (Organization C) in the supply chain places an order with its supplier (Organization B) which in turn places an order

with its own supplier (Organization A).

2. The first organization in the chain (Organization A) schedules activities, translates the schedule into expected events, stores these events in its SCEM application and sends the set of expected events downstream. The next organization in the supply chain schedules its own activities relating to the order, adds the corresponding expected events to the set, saves all events in its SCEM application and sends the extended set downstream and so forth.
3. Actual events are continuously captured by the EPCIS.
4. Each time an actual event is captured, the organization publishes the event's availability to the EPCIS DS: in this case a key-value pair of EPC and EPCIS reference.
5. If the SCEM application wants to request the status of an EPC, it has to query the EPCIS DS to receive the address of the relevant EPCIS repositories; alternatively, a so-called standing query can be saved so that a foreign EPCIS does not need to be polled continuously.
6. The addresses of the EPCIS repositories which contain event data related to the EPCs of the order are sent to the SCEM application.
7. The SCEM applications separately and directly query each EPCIS repository which contains relevant events.
8. The EPCIS repositories send the event data requested by the downstream SCEM applications.
9. The SCEM applications constantly compare scheduled with actual events.

EPCIS-based SCEM using Event Push

An alternative to EPCglobal's architecture for event sharing is to rely on existing bilateral relationships in a supply chain, e.g. between a manufacturer and its suppliers. Instead of replying to concrete requests from downstream organizations, upstream organizations can simply push all events relevant for SCEM to them (we refer to this approach as Event Push). These events can be forwarded downstream without a previous request because upstream organizations know which events are relevant from previous interaction, e.g. the sharing of schedules. In this alternative architecture, the supply chain also serves as a type of communication network at the same time; therefore, data only needs to be exchanged by parties which are already involved in a business relationship. Apart from other advantages regarding security and trust issues, the Event Push mechanism does not require a centralized query infrastructure.

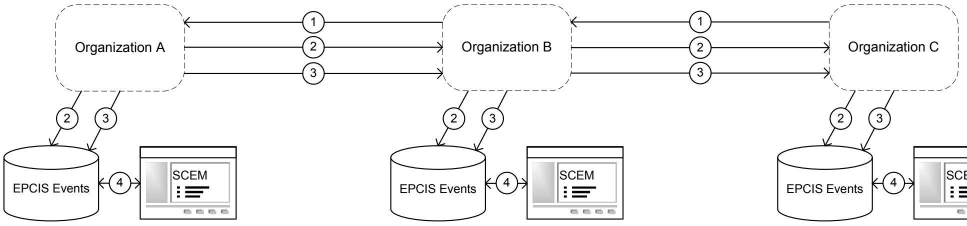


Figure 3.24: Event Push in a three-tiered supply chain

Figure 3.24 describes the Event Push. Steps 1 and 2 are the same as Event Pull above. The following steps are:

3. Actual events are continuously captured and immediately sent to the adjacent downstream supply chain organization, which does the same and so forth.
4. The SCEM applications constantly compare scheduled with actual events.

3.3.5 Evaluation

In order to allow for a rigorous comparison of the two architectures, we outline how they work in detail in the following sections. In spite of a number of qualitative criteria which may also have an influence on which of the proposed architectures will be preferred in practice, we will focus on quantitative measures for evaluating and comparing the two system architectures presented in Section 3.3.4. The performance criteria we use refer to three of the most frequently mentioned performance characteristics of information systems [Bocij et al., 2005] [Garcia et al., 2006]: efficient use of network capacity, efficient use of storage and system reliability. These performance criteria were operationalized by quantitative performance metrics based on the number of data objects stored along the supply chain and the number of messages exchanged between supply chain stages.

The performance metrics depend on several parameters which characterize the structure of and the flow of material in the supply chain; thus, the evaluation of the EPCIS-based SCEM architecture depends on performance metrics which inherently reflect the particularities of the supply chain context. Parameters and performance metrics will be formally defined in the following sections.

Parameters

A supply chain is composed of at least two organizations, tiers, sites or stages which work together in order to provide one product to the end customer. The number of tiers in each supply chain is denoted by $l \in N^+ \setminus \{1\}$. The number of supply chains which are monitored by the SCEM application is denoted by $d \in N^+$. Note that for the sake of simplicity, we do not consider intermeshed supply chains; intermeshed supply chains come into existence if at least one company takes part in two different supply chains and the organizations in these supply chains are not the same. The last parameter which is considered in our analysis is the number of tagged components or products which move through each supply chain during a fixed period of time. This parameter is denoted by $p \in N$.

Efficient Use of Network Capacity

The efficient use of available network capacity is measured in terms of the absolute number of messages exchanged during a fixed period of time. A message in this case is defined as a temporarily enclosed and distinct exchange of data between the information systems of different organizations. Since the two system architectures to be compared do not differ regarding the way in which order data as well as schedules (or expected events) are forwarded along the supply chain, these steps are not included in the number of messages exchanged.

In the Event Push approach, the actual events which are forwarded along the supply chain are the only remaining messages. The amount of messages exchanged grows multiplicatively with the depth of supply chains; events are managed separately for different supply chains.

Consider, for example, a supply chain involving two organizations A and B, one message is sent from organization A to organization B when an event related to one product has been captured by A. If the supply chain is extended by one organizational tier (Organization C), not only the captured events of B, but also those captured by A are sent from B to C (B serves as a communication hub in this case). The number of exchanged messages in Event Push can be calculated in the following way:

$$M_{push} = d \cdot \sum_{k=1}^{l-1} k \cdot p = \frac{1}{2} \cdot d \cdot p \cdot (l^2 - l) \tag{3.1}$$

In the Event Pull approach, captured events are not forwarded to subsequent organizations in the supply chain but rather pulled from upstream organizations on demand. Again, the amount of exchanged messages grows multiplicatively with the number of supply chains the organizations are involved in. For each EPC that is read by an organization, the corresponding key-value pair has to be published via the EPCIS DS (step 4). In order to compare an expected event with the corresponding actual event, an SCEM system has to query the EPCIS DS for the reference to an EPCIS repository (steps 5 and 6). For each received reference, SCEM systems have to query the EPCIS repository for the corresponding EPCIS event (steps 7 and 8); therefore, the number of exchanged messages in the Event Pull approach is:

$$M_{pull} = d \cdot \left[l \cdot p + 4 \cdot \sum_{k=1}^{l-1} k \cdot p \right] = d \cdot p \cdot (2 \cdot l^2 - l) \tag{3.2}$$

Event Push dominates Event Pull in terms of the number of exchanged messages. The factor with which the push approach performs better can be calculated using the following formula:

$$\delta_M = 4 + \frac{2}{l-1} \tag{3.3}$$

As expression (3.3) indicates, the number of supply chains d and products p do not play a role when comparing the performance of the two proposed architectures with respect to their use of network capacity: the performance advantage of Event Push only depends on the length l of the supply chains. The number of exchanged messages produced by Event Pull is six times higher than the one produced by Event Push for supply chains with two participants ($l = 2$), 4.5 times higher for $l = 5$, 4.2 times for $l = 10$ and approaches 4 times higher for high values of l.

Efficient Use of Storage Capacity

The efficient use of storage capacity by the two architectural approaches is measured in terms of the number of stored data objects which refer to the flow of goods. We initially compare the number of events saved in the EPCIS repositories at the different supply chain participants.

In Event Push, each supply chain participant stores its expected and actual events at its own and all subsequent sites. The number of supply chains affects this number multiplicatively. The number of saved EPCIS events can be calculated using the following formula:

$$O_{push} = 2 \cdot d \cdot \sum_{k=1}^{l} k \cdot p = d \cdot p \cdot (l^2 + l) \tag{3.4}$$

In Event Pull as proposed by EPCglobal, schedules would not be stored in the form of events within the EPCIS repositories but would be directly exchanged by the SCEM applications; therefore, the number of stored EPCIS events can be calculated according to formula (3.5).

$$O_{pull} = d \cdot p \cdot l \tag{3.5}$$

However, Event Pull requires the storage of other data objects. Both the key-value-pairs used as references in the EPCIS DS as well as the expected events stored separately by the SCEM applications have to be taken into account. Thus, a fair basis for comparison regarding the number of stored data objects in the pull approach is given by formula (3.6).

$$\bar{O}_{pull} = 2 \cdot d \cdot p \cdot l + d \cdot p \cdot \sum_{k=1}^{l} k = d \cdot p \cdot (\frac{1}{2}l^2 + \frac{5}{2}l) \tag{3.6}$$

No approach formalized in functions (3.4), (3.5) and (3.6) is dominated with respect to the number of stored data objects. The relative advantage of Event Push over Event Pull (or vice versa) expressed by formula (3.7) is independent of the number of supply chains and the number of products moving through each of them.

$$\delta_O = 2 - \frac{8}{l+5} \tag{3.7}$$

The number of stored objects is 1.2 times higher if Event Pull is used for two supply chain participants, equal for three participants, 1.2 times smaller for five participants, 1.5 times smaller for ten participants and approaches 2 times smaller for high values of l.

Reliability

The number of data objects stored at each supply chain participant should not be much above the average number in order to minimize bottlenecks and maximize reliability. We operationalize this performance criterion by measuring how dispersed the required data objects are stored in the supply chain. A standard measure of statistical dispersion is the Gini coefficient G. The value of G ranges from 0 to 1; the nearer it is to 1, the greater the dispersion. Since reliability is expected to be greater if data objects are distributed more equally among the databases along the supply chain, a lower Gini coefficient of the number of stored objects indicates higher reliability. We do not compare the Gini coefficients of data dispersion for the two system architectures formally since the derivation of a mathematical expression is highly complex if feasible at all; instead, we base our analysis on a numerical comparison. Table 3.3 shows the relevant results of the numerical

Table 3.3: Numerical comparison of the reliability metric

l	d	G_{push}	G_{pull}	$\frac{G_{push}-G_{pull}}{G_{pull}}$
2	1	0.333	0.381	12.5%
2	100	0.581	0.673	13.7%
2	10000	0.583	0.679	14.0%
3	1	0.444	0.438	-1.6%
3	100	0.609	0.677	10.0%
3	10000	0.611	0.681	10.2%
4	1	0.500	0.478	-4.7%
4	100	0.624	0.678	8.0%
4	10000	0.625	0.681	8.2%
[· · ·]				
10	1	0.600	0.577	-4.0%
10	100	0.650	0.676	3.9%
10	10000	0.650	0.677	3.9%

calculations and provides the relative performance differences between both architecture approaches. The performance metrics are invariant with respect to the number of products p, but depend on the depth d of the supply chains.

When comparing the architecture approaches based on our reliability metric, several impacts of the parameters l and d can be observed. The longer the supply chain becomes, the smaller the advantage of Event Push compared to Event Pull. The more supply chains there are, the greater the advantage of Event Push becomes. Table 3.3 shows that if the number of supply chains is very low, the push approach can have a higher Gini coefficient; however, as Table 3.4 shows, this disadvantage of Event Push only persists up to parameter configuration with $d = 2$, i.e. it should be negligible in realistic settings.

3.3.6 Results

Supply chain wide visibility of the flow of goods is a precondition for supply chain event management. We have compared two possible system architectures that enable the sharing of standardized supply chain event data with respect to a number of quantifiable criteria. According to our evaluation, none of the approaches can be preferred without further consideration.

The parameters we used to evaluate and compare the two architectures are realistic variable values for length, depth and number of products. Iyengar [2005] calculated the average length of supply chains using the U.S. Benchmark Input-Output tables published by the Bureau of Economic Analysis. Based on data from more than 1 million supply chains, he found that in 1997 the average U.S. supply chain had a length between 3.4 and 4.1 de-

Table 3.4: Numerical comparison of the reliability metric for small values of d

l	d	G_{push}	G_{pull}	$\frac{G_{push}-G_{pull}}{G_{pull}}$
2	1	0.333	0.381	12.5%
2	2	0.458	0.471	2.8%
2	3	0.500	0.531	5.8%
3	1	0.444	0.438	-1.6%
3	2	0.528	0.530	0.4%
3	3	0.556	0.575	3.4%
4	1	0.500	0.478	-4.7%
4	2	0.563	0.562	-0.1%
4	3	0.583	0.598	2.5%
$[\cdots]$				
10	1	0.600	0.577	-4.0%
10	2	0.625	0.624	-0.2%
10	3	0.633	0.641	1.2%

Table 3.5: Relative advantage of Event Push over Event Pull

Length of supply chain l	Network capacity	Storage capacity	Reliability
2	83.3%	14.3%	14.0%
3	80.0%	0.0%	10.2%
4	78.6%	-11.1%	8.2%

pending on the industry. Length was defined as the number of echelons of the supply chain. On the basis of these figures, it seems realistic to consider supply chains consisting of two to four participants.

Estimating a realistic number of supply chains, which would benefit from SCEM applications, and the number of products flowing though these supply chains is considerably more difficult, but can be expected to be very high. Kürschner et al. [2008] state that the EPCIS Discovery Services will have to be able to handle queries from millions of clients. Against this background, our estimation of 10,000 supply chains, which are monitored using an SCEM application, should be realistic.

Table 3.5 summarizes the relative advantage of Event Push compared to Event Pull with respect to the quantitative metrics defined in Section 3.3.5 and based on realistic parameter values. In spite of the typical trade-off between usage of data storage and network bandwidth, Event Push appears to be the preferable architectural choice for short supply chains: up to a supply chain length of three echelons, the push approach dominates the pull approach according to our criteria.

3.3.7 Conclusions and Further Research

We have presented a business application and a corresponding information system architecture that provide the basis for the short-term coordination of a multi-organizational assembly network. The proposed system architecture was chosen for a number of reasons, each of which can be attributed to the requirements of short-term decision support in dynamic multi-organizational business environments, in particular system interoperability and the inter-organizational management of EPC context data.

We have chosen to address the informational needs of our business application in order to derive concrete requirements. The concept we describe comes near to what is known as SCEM. SCEM has found general approval in practice since it addresses a number of pressing problems in today's competitive environment. To the best of our knowledge, this work represents the first attempt to suggest possible ways to realize SCEM applications based on the EPCglobal specifications while taking their specific requirements regarding interoperability and systems integration in multi-organizational environments into account.

From an operational point of view, an obvious shortcoming of the proposed architecture is that it does not address dynamic scheduling. Although it allows for order cancellation, the schedule of other orders encoded in the form of ExpectedEvent objects throughout the network cannot be changed in response to such an event. Certainly the protocol layer could be extended in order to deal with dynamic scheduling, but it remains to be seen if such an extension is feasible in practical circumstances. Another limitation of the architecture results from its decentralized structure. Messages are forwarded along the supply chain, i.e. if an organization in the middle of the supply chain does not implement the protocol, our approach will not work. This problem could be solved by a third party willing to act as a trusted communication intermediary.

The proposed architecture supports interoperability in two ways: first, due to its two-layered design there is no need to standardize any components on the application layer which facilitates the development and integration of the EPC/SCEM components. Second, one common way to describe event data and its context based on the EPCglobal event data specification is used both for intra- and inter-organizational communication.

Regarding the use of the EPCglobal specifications for SCEM applications, we come to the following conclusions: first, although EPCglobal provides a very good starting point for the format of event data, the specifications would need to be extended semantically to include the expectation of events. Second, an implementation of the EPCIS query interface is optional for the application described in this chapter. We do not use the EPCglobal core services, which are designed to search and retrieve EPC-related event data, for our application either; however, we acknowledge that the distribution of actual events (phase 5 of our protocol) could also be realized by querying the EPC Discovery Services for events related to all EPCs known to be involved in the processing of the order.

In our application, up-to-date context data required by downstream nodes and organizations gets distributed without former request as soon as it becomes available. This approach relieves the burden of downstream organizations from the need to maintain a comprehensive up-to-date internal process view of other organizations. Furthermore, ex-ante knowledge of the organisational structure of the assembly network is not required, which represents a crucial advantage in today's dynamic and complex supply chains. Synchronization of data and context is assured by design since data and context are sent via the same communication channel.

The second research question has been whether the current proposal for the distributed system architecture of the Internet of Things is suitable for SCEM applications. Based on three quantitative criteria, we come to the conclusion that an alternative approach based on the idea of pushing EPCIS events downstream could be the preferable choice. We have also mentioned some qualitative advantages of the latter architecture, such as taking advantage of existing business relationships in the supply chain and not requiring a central authority for data management and authentication which speak for Event Push.

Our quantitative measures are coarse and based on simplistic assumptions; however, they provide an objective means for initial comparison of Event Pull and Push. Further research on the topic is definitely warranted: in order to make an informed decision, the relative importance of different performance criteria and metrics will have to be determined (e.g. based on the available network and data storage capacity as well as the variable costs of storing and transmitting data). Furthermore, additional criteria and metrics should be defined to obtain a more detailed picture of possible cost-benefit trade-offs. For instance, operational properties such as latency and throughput could be measured and compared using supply chain simulations as soon as implementations of the proposed architectures are available. Moreover, the evaluation of security properties of the two architectures calls for the development and evaluation of authentication mechanisms. Finally, economic translations of the somewhat technical performance measures used in this work have to be defined in order to enable a sound investment decision by adopters of EPCIS-based SCEM.

We see a number of promising areas for further research on the proposed architecture. First of all, the architectural design needs to undergo further validation. Secondly, it needs to be extended to cope with dynamic rescheduling. The business logic of the actual decision support system, i.e. the development of algorithms used to optimize courses of action based on action path data, are a promising research direction. Still another issue that needs to be dealt with is authentication and security. The communication taking place on the protocol layer needs to be secured against malicious behaviour, e.g. by using dedicated public key infrastructures.

3.4 Storing Data on RFID Tags: A Standards-Based Approach

3.4.1 Introduction

The potential of Radio Frequency Identification (RFID) for increasing supply chain efficiency has been repeatedly stressed by practitioners and researchers alike [Niederman et al., 2007]. The most widely spread practice of using RFID tags on components, products and logistical units as they move through the supply chain follows the GS1 EPCglobal approach [EPCglobal, 2009] of storing only an identifier on the tag and all related data in the supply chain participants' information systems (either using the official EPC or a company specific ID). The main advantages of this approach are that RFID tags are relatively cheap if they only have to store an identifier and do not need memory for user generated content; that it is easy to standardize the identifier, e.g. on the basis of the European Article Number (EAN), which is uniquely assigned by GS1; and that there is no need to encrypt a simple identifier because the access to the data on the network is restricted.

On the other hand, there are several factors that support storing data on the tag [Günther et al., 2008]. The first factor addresses the need for fast data access – when the IT infrastructure must meet real-time requirements and bottlenecks happen during back-end queries. For such cases, data on tags may help ensure quick access to the required information. The second factor concerns the dependency of the business process, including production, on the back-end system. Storing relevant data on the tag can help production to be kept up without being connected to the back-end system – at least temporarily. The third factor refers to the reliability of the back-end system: storing data on the tag facilitates decentralization and helps avoid single points of failure. This can be relevant if the existing IT infrastructure is not optimized for reliability, e.g. if no redundant system is in place.

The advantages described for both approaches for data storage serve as the disadvantages for the other concept at the same time. But especially because of the differences, Diekmann et al. [2007] claim that these methods are not antithetic but complementary and should be integrated into a consolidated approach; this guarantees that the relevant data is always accessible. In their work, two case studies that employ a combined data-on-network and data-on-tag approach were presented.

When extending RFID applications to inter-organizational processes, the standardization of data formats and data content becomes crucial [Hasselbring, 2000]. For the data-on-network approach, researchers and companies respectively founded the Auto-ID Center and EPCglobal consortium and have developed the Electronic Product Code (EPC) to uniquely identify physical products [Brock, 2001]. The data format specification includes a 96-bit code with a fixed, 8-bit header. The standardization of data content is achieved by relying on existing standards (e.g. the Serial Shipping Container Code). The most famous usage of this EPC combines the European Article Number (EAN) with a serial number for each object.

The cross-company usage of data on RFID tags can also only work if the collaborating companies agree upon the syntax and semantic used. Standardization initiatives have taken the first steps in this direction. The German Association of the Automotive Industry (VDA) published a recommendation on the usage of RFID for container management in the automotive supply chain [VDA, 2008]. The syntax in the user memory is specified by the alternation of data field identifier and value. The semantic of the data fields (IDs, description, data type, etc.) are described in a table in the recommendation, e.g. vehicle identification, maximum quantity of parts, purchase order number, etc. A similar approach for tracking tyres individually has been proposed by the Automotive Industry Action Group (AIAG). In this recommendation, the auto-industry-specific data such as the global location number that identifies the facility where the tyre is made; the tyre cure date and the country of origin should be stored in the user memory [RFID Journal, 2005].

Both recommendations to store data on RFID tags will minimize the coordination effort as well as the emerging interoperability or integration problems for all companies in the automotive industry that want to introduce these kinds of applications. However, many different, possibly competing standards for numerous applications within and across industries are not desirable; therefore, to guarantee the wide-spread adoption of the data-on-tag approach, it is advisable to build on existing standards for the storage of data on RFID tags.

In this work, we recommend applying the part libraries (PLIB) standard ISO 13584. This standard has been widely discussed as a reference model for developing product classification systems and standardized property lists [Leukel et al., 2006b]. Major industry consortia have incorporated this standard into their specifications for B2B data exchange (e.g. BMEcat 2005), product classification systems (e.g. eCl@ss, UNSPSC) and property dictionaries (e.g. DINsml). Implementing the PLIB concept for the storage of data on RFID tags promises to avoid heterogeneity and maximize interoperability in cross-company RFID applications.

In Section 3.4.2, we conceptualize the usage of ISO 13584 for storing data on RFID tags. In Section 3.4.3, we define a methodology to extract

ISO 13584-compliant properties from existing data models. A case study of a German kitchen furniture manufacturer is applied in Section 4.2.6 to develop a scenario for the storage of data on RFID tags. The company took part in a joint research project on using RFID tagged components in a cross-company application with its suppliers. Finally, Section 3.4.4 concludes this section.

3.4.2 Property-Based Concept of ISO 13584

For our purpose, Part 42 of ISO 13584 (ISO 1998), which describes its conceptual model, is of primary interest. ISO 13584 was originally developed to describe technical product data, i.e. functional and physical characteristics, on the basis of unambiguous, semantically well-defined, globally unique properties. Its usage for commercial product data has been proven to be useful as well [Leukel et al., 2006a]. To describe how the conceptual model of ISO 13584 has to be implemented, the definition and usage of properties have to be distinguished.

Definition of ISO 13584-compliant Properties

The goal of defining ISO 13584-compliant properties is to make them available and accessible in standardized online dictionaries. For instance, the German Institute for Standardization (DIN) Properties Dictionary is based on ISO 13584 (http://www.dinsml.net). That means that each property:

- is identified with a global unique identifier;
- is described with a set of mandatory and optional attributes (e.g. description, unit, data type), which are specified in the ISO 13584's information model;
- is assigned to a set of references to product classes which define context the properties can be used;
- is defined following a standardized process.

The number of properties in the dictionary is continuously growing. Any company can submit new properties to the standardization procedure to be included in the dictionary. The read access to the online dictionary is free of charge, but companies that want to use it without restriction have to purchase a license. This license includes the passing of the properties used to other companies that are involved in their business process (e.g. suppliers and customers). When describing products on the basis of properties, it can happen that the property values are dependent on each other. For instance, if a liquid is described with the property "volume", it depends on the temperature of the liquid. The property "temperature" is called the condition in this context. To solve this issue, ISO 13584 defines three different types of properties: non-dependent properties, dependent properties and conditions.

Usage of ISO 13584-compliant Properties for the Storage of Data on RFID Tags

RFID technology in supply chain management can be used to track components, finished products or logistical units (e.g. containers, pallets, cases). These objects have certain characteristics which might be stored on their respective RFID tag. Following ISO 13584, all data have to be expressed in form of property-value pairs. This information has to be very precise, e.g. concerning meaning of the property or unit of the value, but to minimize the amount of data storage needed on tags, only the ID of the standardized property (which includes this precise information) and the value should be stored.

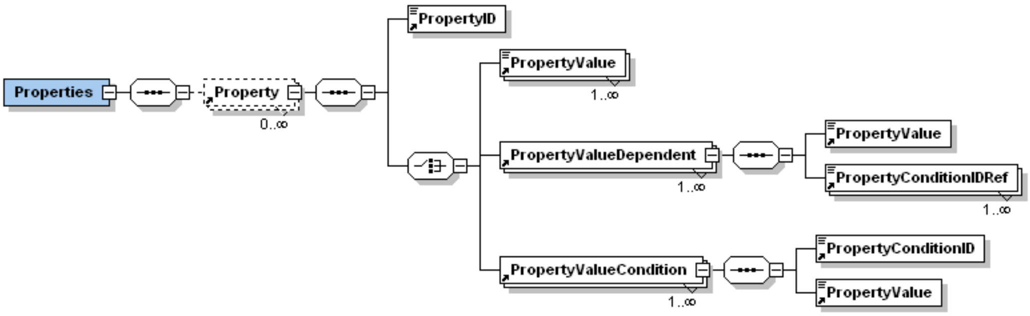


Figure 3.25: Logical model for property usage in XML Schema format

When storing these property-value pairs on tags, the syntax and semantic layers have to be distinguished. Semantically, all three different types of properties have to be supported; therefore, it is not enough to provide only the property id and value for a property: for a dependent property, the reference to the value of the condition has also to be given. One option for this usage of property-value pairs is described in Figure 3.25, which uses a graphical representation of an XML Schema. The reference to the value of the condition is called "PropertyConditionIDRef" in this model.

To illustrate the usage of the three different types of properties, the example in Figure 3.26 shows the independent property "colour" and the dependent property "optical density", which is dependent on the condition "optical glass type". The representation format follows the model in Figure 3.25.

Although we have used an XML format based on the developed XML Schema to describe the semantics of using property-based product descriptions, it is not necessary to utilize this format as the syntax. The main disadvantage appears when comparing the payload of this short example with the XML element names etc. – which make up 91% of the characters and symbols – which are not essential for the content.

Benefits of Using ISO 13584

Standards in general contribute to the harmonization of interfaces between heterogeneous systems and, for this reason, increase interoperability. This may result in decreasing coordination efforts and wider usage. In the context of storing data on RFID tags, besides technical interoperability, data interoperability is of great importance. Typical problems include the following:

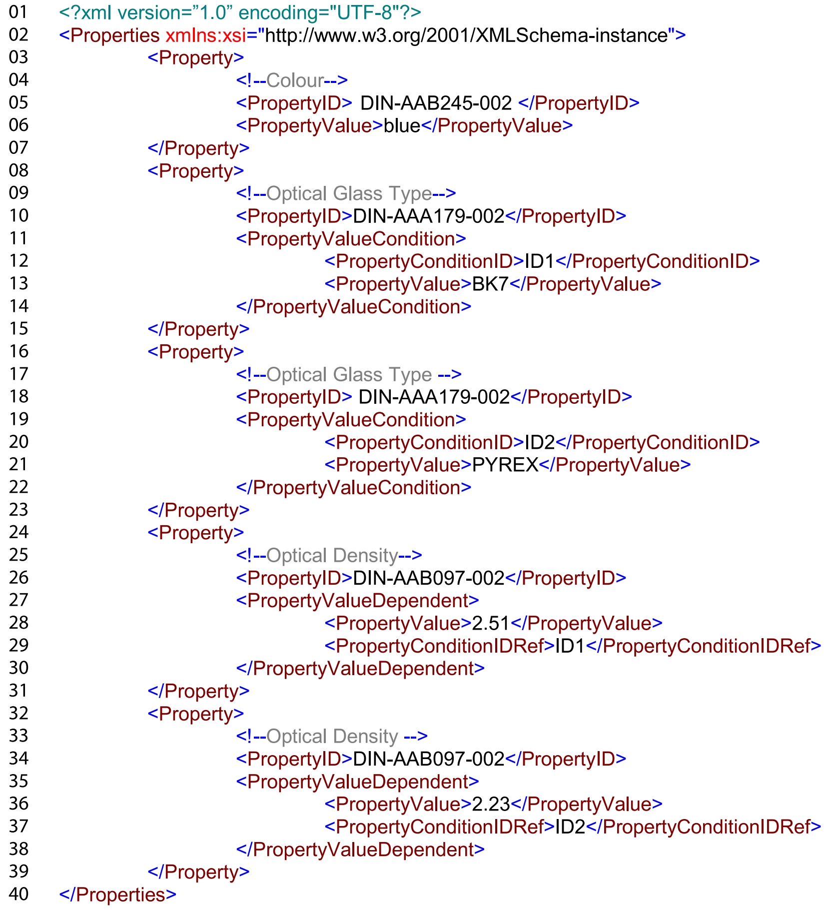
- data could be misinterpreted because the information is not understandable;
- different data models could describe the same information;
- and different information could have the same description in individual data models.

For the mapping between different data models, a high coordination effort is needed to overcome these problems, if it is at all possible.

From another point of view, competing standards do not solve this issue if companies do not know which standard they should choose. In information systems literature this is known as the standardization problem [Westarp et al., 2000]. The different standardization efforts introduced in Section 3.4.1 for the usage of RFID in the automotive industry highlight this problem.

The property based concept of ISO 13584 addresses both problems. First, the standardized properties are precisely defined according to the ISO 13584 data model, which includes language independent verbal definitions as well as additional information regarding units, data types, etc. This results in easier data exchange via standardized interfaces, higher data quality, and a reduction of data redundancy [Pohn, 2006]. Second, using ISO 13584 implies following a bottom-up approach because with properties, small pieces of information are standardized and so can be applied to very different circumstances. Other standardization initiatives (e.g. AIAG and VDA) can create their own standards based on these standardized properties. In this way, ISO

13584 is not competing with other initiatives and, even more importantly, with EPCglobal's approach.



```
<?xml version=”1.0” encoding="UTF-8"?>
<Properties xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
        <Property>
                <!--Colour-->
                <PropertyID> DIN-AAB245-002 </PropertyID>
                <PropertyValue>blue</PropertyValue>
        </Property>
        <Property>
                <!--Optical Glass Type-->
                <PropertyID>DIN-AAA179-002</PropertyID>
                <PropertyValueCondition>
                        <PropertyConditionID>ID1</PropertyConditionID>
                        <PropertyValue>BK7</PropertyValue>
                </PropertyValueCondition>
        </Property>
        <Property>
                <!--Optical Glass Type -->
                <PropertyID> DIN-AAA179-002</PropertyID>
                <PropertyValueCondition>
                        <PropertyConditionID>ID2</PropertyConditionID>
                        <PropertyValue>PYREX</PropertyValue>
                </PropertyValueCondition>
        </Property>
        <Property>
                <!--Optical Density-->
                <PropertyID>DIN-AAB097-002</PropertyID>
                <PropertyValueDependent>
                        <PropertyValue>2.51</PropertyValue>
                        <PropertyConditionIDRef>ID1</PropertyConditionIDRef>
                </PropertyValueDependent>
        </Property>
        <Property>
                <!--Optical Density -->
                <PropertyID>DIN-AAB097-002</PropertyID>
                <PropertyValueDependent>
                        <PropertyValue>2.23</PropertyValue>
                        <PropertyConditionIDRef>ID2</PropertyConditionIDRef>
                </PropertyValueDependent>
        </Property>
</Properties>
```

Figure 3.26: Example for the usage of different types of properties

3.4.3 Extraction of ISO 13584-compliant Properties

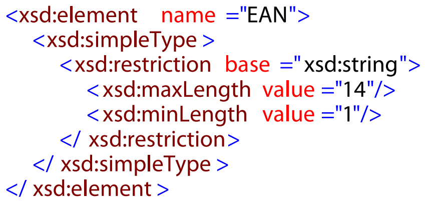
If a company chooses to use ISO 13584-compliant properties for a certain use case, the properties usually do not have to be developed from scratch. The existing data sources in the companies' information systems about the object under investigation can be used as a basis for this: their data models provide a useful basis for the identification of properties because the attributes describing an entity in an ER diagram or a class in a UML class diagram can often be transferred into a property, while associations between entities or classes refer to the type of property (dependent, independent, etc.).

Once the required properties are determined, the corresponding properties in the property dictionary have to be found. Three cases could appear in general: first, a corresponding property in the dictionary exists and the semantic of the usage is the same. In this case, the property ID from the dictionary and the values from the existing instances can be used without further processing. Second, a corresponding property in the dictionary exists, but its property definition differs in usage, e.g. about data type or measurement unit. Here, the property ID from the dictionary can be used if the instances can be transformed into the required semantic. Finally, the company requires properties that have not been defined in the dictionary yet. This is highly dependent on the type of object, e.g. some industries are more actively working together with the dictionary operator. In this case, the new property is added to the dictionary. As already mentioned in Section 3.4.2, this creation has to follow a certain standardization process that has several phases (initiation, evaluation, etc.), which takes 25 weeks at most.

In the remaining section, we define a methodology for extracting properties from an XML Schema. Candidates for properties are all elements and XML attributes in the respective data models.

Simple type elements

Simple type elements can be directly converted into non-dependent properties, if the element is not part of a complex element with a multiplicity greater than 1. For instance, the schema depicted in Figure 3.27 defines such an element for the EAN product identifier (often part of the basic product model; therefore, not deeply nested).



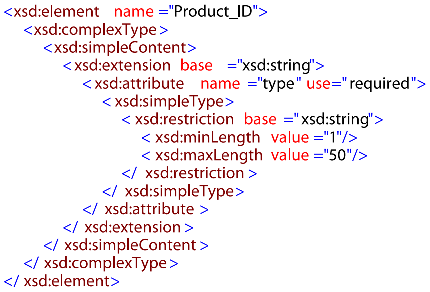
```
<xsd:element   name ="EAN">
   <xsd:simpleType >
      <xsd:restriction  base ="xsd:string">
         <xsd:maxLength  value ="14"/>
         <xsd:minLength  value ="1"/>
      </ xsd:restriction>
   </ xsd:simpleType >
</ xsd:element >
```

Figure 3.27: EAN as a simple type element

We extract the following PLIB-relevant information: property name equals element name; the property is mandatory and univalent; data type is being mapped to `string_type` with the restriction mapped to PLIB's `value format` attribute (cf. Section 3.4.3). The essential `definition` attribute can not be filled automatically, because this information is not part of the schema (i.e., human-language description of the meaning). The compulsory version information can be derived from the schema, e.g., date of the XSD file. If the element has cardinality greater than 1, we allow multiple values for the respective property as well.

Simple type elements with attributes

In XML, attributes can be attached to elements in order to provide additional information on the element and to specify the element content similarly to a type, e.g., the product ID element has an attribute that says whether the ID is that of the supplier, buyer, or a third party. This example is depicted in Figure 3.28



```
<xsd:element  name ="Product_ID">
  <xsd:complexType >
    <xsd:simpleContent>
      <xsd:extension  base  ="xsd:string">
        <xsd:attribute  name ="type" use=" required">
          < xsd:simpleType>
            < xsd:restriction  base ="xsd:string">
              < xsd:minLength  value ="1"/>
              < xsd:maxLength  value ="50"/>
            </ xsd:restriction >
          </ xsd:simpleType>
        </ xsd:attribute >
      </ xsd:extension >
    </ xsd:simpleContent >
  </ xsd:complexType >
</ xsd:element>
```

Figure 3.28: Product ID as a simple type element with attribute

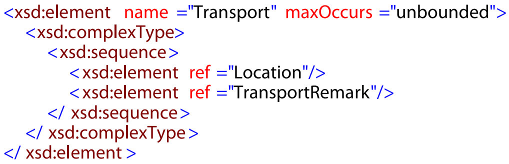
Such attributes require defining a dependent property for the element, and a condition for the attribute; thus, the element value can only be interpreted correctly in conjunction with the attribute value. All other PLIB-relevant information on the attribute-derived property needs to be added manually in the same way as for the elements.

Sequence of elements

The previously described rules concern only a very small part of actual XML schemas, since they do not cover nesting. Nesting is realized by building sequences of elements that again can incorporate sequences.

At first sight, a sequence with the cardinality of 1 could be interpreted as a logical group of its included elements; therefore, the sequence would be used to group related information only, but all included elements are independent from each other, so the respective properties are of that kind, too. However, often semantic relationships exist between these elements, though they can not be extracted on a formal basis. The reason is that this information is not part of the schema, but contained in the supplementing documentation or coded in the element names. For instance, let *OrderInfo* be a sequence of three elements: *OrderUnit* (the unit of measurement for ordering, e.g. box), *ContentUnit* (the unit of measurement of the product itself, e.g. bottle) and *ProductID* (ID of the base product delivered in the bottle). In this case, the latter element must not be confused with a regular product identifier, since its interpretation needs to consider the context of *ContentUnit*. Therefore, *ProductID* serves as a condition for the dependent property *ContentUnit*. All these relationships need to be added manually to the PLIB-compliant property definitions by carefully searching for respective descriptions or names.

Sequences with the cardinality greater than 1 require that all but one of its sub-elements are converted into dependent properties and making the sub-element that had been left out the condition for all other properties. Otherwise it would be impossible to relate property values to each other. The example in Figure 3.29 demonstrates this rule.



```
<xsd:element  name ="Transport" maxOccurs ="unbounded">
   <xsd:complexType>
      <xsd:sequence>
         <xsd:element  ref ="Location"/>
         <xsd:element  ref ="TransportRemark"/>
      </ xsd:sequence>
   </ xsd:complexType>
</ xsd:element>
```

Figure 3.29: Transport information as a sequence of elements

For each product, multiple transportation information can be specified in the *Transport* element, which includes the location of delivery and a remark. The interpretation is that for each location only one remark can be specified; thus, *Location* can be regarded as unique in the context of each *Transport* element. Therefore, we define a multivalent property for *TransportRemark*, which is dependent on the respective (multivalent) *Location* property. The same applies to sequences where two or more elements are unique; hence, the respective properties represent the condition for all other sub-elements. It has to be stressed that choosing the right conditional properties can not be automated, since it depends on the semantics of the sequence, which is not formally described in current message specifications.

Nested sequences

A nested sequence consists not only of simple type elements, but includes at least one complex element; thus, another sequence of elements. In this case, while converting the latter sequence, whether some or all of its elements are dependent on elements (or the derived properties, respectively) of the former sequence must be taken into consideration.

Identification and naming rules

Each PLIB property requires a GUID (`code` attribute) and name (`preferred name` attribute). This information can be extracted from the XML schema as follows: in PLIB, the GUID is defined as a 3-tuple: organization, dictionary item, and version. We choose an ID for the organization that developed the schema, define a range of consecutively numbered IDs for the dictionary items (properties), and add a version ('1.0' for the initial ontologizing process).

XML element names can be mapped to the property name directly if element names are unique in the schema. When parsing the XML schema, the same element may appear more than once (being used in multiple contexts). Then we do not define a new property, but set the cardinality of the already existing property to multiple (if it is 1). However, this procedure depends on the actual schema. If element names are not unique, we have to use the full path instead of the name only.

XML attribute names are often generic and seldom unique (e.g., `type`, `version`, `code`); therefore, we build the property name by adding the respective element name (e.g., `Product_ID/type`).

Data typing and domains

The PLIB ontology contains a comprehensive system of data types for restricting property values. This system includes in total 23 data types that are arranged in a type hierarchy. Since this hierarchy is differently from the XSDL type system, we defined a mapping to enable automated conversion.

In addition to predefined types of the XSD namespace, current B2B message specifications make extensive use of restricting standard types and defining customized types, especially enumerative types (e.g., for country codes, currencies, languages, price types, product categories, etc.); therefore, we transformed those domain definitions into PLIB-compliant ones. It has to be noted that the expressiveness of the PLIB type model is lower; thus, not all type-related information can be mapped to PLIB. This – otherwise lost – information could be included in the generic PLIB `remark` and `note` attributes, though these attributes have no formal semantics.

3.4.4 Conclusions and Outlook

A company that considers the introduction of RFID technology has to develop a business case and calculate the related costs and benefits. The business case determines which of the following three scenarios to pursue: (1) the RFID tag stores the identifier only and all object-related data is stored externally (typically a networked databases); (2) all object-related data is stored on the RFID tag; or (3) one uses a hybrid approach using both paradigms for different applications. Due to various reasons, for the company described in the case study the hybrid approach is appropriate.

If companies want to use RFID technology in a cross-company application, standards have to be considered. For the data-on-network approach, the EPCglobal standards provide an appropriate solution. A standard for the data-on-tag concept had been missing.

In this section, we recommended using ISO 13584 for the standardized storage of data on RFID tags. A standard in general contributes to the harmonization of interfaces between heterogeneous systems and, for this reason, increases interoperability, data quality and reduces data redundancy. The properties in our approach are precisely defined according to the ISO 13584 data model, which includes language independent verbal definitions as well as additional information regarding units, data types, etc.

In Chapter 4.2.6, we will show that using ISO 13584 is a suitable approach for the data-on-tag concept by presenting a case study from Wellmann, a German kitchen manufacturer. Within this case study, we will explain how the properties are extracted from the existing information models. For the processes under consideration, all necessary data will be transformed into independent, dependent and conditional properties. Thus, at least for this application ISO 13584 is appropriate.

Although we will use a single case study approach in a very specific industry, the goal of using ISO 13584 is that the approach can be used for all other industries and RFID applications. This is because using ISO 13584 implies following a bottom-up approach. With properties, small pieces of information are standardized and can be applied to different circumstances. In this case study, we applied them to the production of custom ordered kitchen cupboards. Other standardization initiatives (e.g. AIAG and VDA in the automotive industry) can create their own standards for certain applications (e.g. container management and theft prevention) based on these or other standardized properties.

Chapter 4

Empirical Work

The case study method is popular in information system research as it provides an extensive insight into a company's activities and experience. Since the cross-company usage of RFID is a relatively new research field, the case study methodology is suitable for an integrated and extensive analysis of this problem. Case study research can be used for exploratory, descriptive and explanatory purposes [Yin, 2003, p. 3]. In contrast to quantitative research approaches, case studies aim to analyse single or multiple cases while taking into account several dimensions of relevance [Boos, 1993, p. 34].

For the selection of the case study, several dimensions including the complexity of the application, the number of companies involved and the state of RFID usage had to be considered. In addition, accessibility to the relevant data played a critical role [Crowston, 1991, p. 84].

With regard to the companies and cases chosen, different data sources were accessible when building the case studies. On one hand, several publications of practitioners and scientists who dealt with Gerry Weber's initial RFID pilot are available [Loebbecke et al., 2006]; [Tellkamp and Quiede, 2005]; [Tröger, 2008]. On the other hand, the authors had the opportunity to conduct personal interviews with leading participants of Gerry Weber's initial RFID pilot as well as of their current RFID project.

Both companies – Gerry Weber and Wellmann – are currently involved in a joint research project, partly funded from the German Federal Ministry of Economics and Technology. In the next generation media programme, the ministry supports eleven projects in the sector of new technologies and ubiquitous computing. The range of subjects extends from wireless networking of production facilities to the measurement of personal vital functions with the help of radio-based miniaturized sensors [Bundesministerium für Wirtschaft und Technologie, 2009]. The project this study was conducted under – Ko-RFID: Collaboration in RFID-based Supply Chains – is part of the *logistics* track.

The analysis of the first case study provided in Section 4.1 aims at disclosing elements and strategies of cost-benefit sharing in cross-company RFID applications. Based on the findings from the analysis, the approach to cost-benefit sharing – including a categorization of different compensation alternatives and a life-cycle model – was developed in Section 2.3. The second case study on Wellmann is used for an explanatory purpose. The scenarios for using RFID with white goods in Section 4.2.2 and for storing data on RFID tags in Section 4.2.6 are used to show the feasibility of the conceptual reference framework (Section 2.1) and the ISO 13584 standard (Section 3.4) respectively.

4.1 RFID in the Fashion Industry – The Case of Gerry Weber

4.1.1 Company Profile

Founded in 1973, Gerry Weber International AG (Gerry Weber) is a globally operating apparel company based in Germany. Gerry Weber's primary business consists of the design and marketing of women's fashions. The brand portfolio includes GERRY WEBER, TAIFUN-Collection and SAMOON-Collection. Currently about 82% of sales are generated by the wholesale channel, i.e. the lion's share of Gerry Weber's products are sold to end customers by fashion retailers. The remaining 18% are either sold by Gerry Weber's own brand stores or Gerry Weber franchisees, currently exceeding 240 stores worldwide. Gerry Weber plans to increase the revenue generated by its own shops to at least 50%.

With about 2,000 employees, Gerry Weber realized a turnover of over 507 million Euros and an EBITDA margin of 12.2% in the fiscal year 2006/2007, which is well above industry average. Gerry Weber's recent success has been attributed to a fundamental optimization process which, among other things, resulted in the outsourcing of logistics operations ([Gerry Weber International AG, 2008, p. 3 et seq.]; [Gerry Weber International AG, 2007, p. 1 et seq.]).

While the physical operations such as manufacturing, transportation and warehousing have been outsourced, supply chain management activities are orchestrated from the Gerry Weber headquarters [Gerry Weber International AG, 2008, p. 24 et seq.]. These activities include supply chain design issues; the selection of service providers; and planning activities – these three are regarded as the core competence of the group's supply chain management team. Gerry Weber sources globally: 63% of the suppliers are located in the Far East, another 23% in Turkey and the rest in Eastern Europe. Gerry Weber relies on both full package service suppliers as well as cut-make-trim suppliers. As a consequence of the ongoing search for more competitive alternatives, their supplier base is constantly changing.

The most important goals of Gerry Weber's supply chain management are to assure the reliable delivery of products to external retailers and their own points of sale; to guarantee cost efficiency as well as to shorten time spans between design/production and availability at the point of sale. Due to the business model of Gerry Weber, supply chain processes are relatively complex. Their three different distribution channels (large retailers, their own shops and online shopping) require specialized supply chain processes. Logistic operations have recently moved to the centre of attention because it has to keep pace with a recently introduced marketing strategy: product life cycles in the retail channel have been reduced to two weeks in order to improve the customer buying experience and increase the average number of store visits. Gerry Weber has been working on concepts of RFID usage in their supply chain for several years. In 2007 the decision to introduce RFID on the item level was made.

4.1.2 The Supply Chain

The Flow of Goods

Gerry Weber products are designed at the Gerry Weber headquarters. When the major external retailers have submitted their orders, Gerry Weber places manufacturing orders to contract manufacturers around the world. Besides a small number of 'never out of stock'-products (e.g. dark-coloured business suits), which are replenished on a regular basis, all products are ordered in one big rush ahead of their respective selling season and are produced and distributed according to a predefined schedule. Suppliers can be distinguished into two groups (large and small) according to the size of production orders placed with them: large suppliers fill whole sea containers or trucks; whereas the shipments of small suppliers get consolidated and filled into containers at consolidation sites near harbours or airports by the long-haul transportation providers. Depending on the location of suppliers, merchandise is transported by truck, sea or air to distribution centres located in Germany by major long-haul transportation providers. Since long-haul transportation services for apparel are only provided by a small number of major logistics companies, the probability that Gerry Weber uses the same logistics provider repeatedly is relatively high. In places where there are large concentrations of contract manufacturers of apparel, such as in the Shanghai area, long-haul transportation providers operate large consolidation centres where all products destined for overseas are packed into shipment lots.

The distribution centres in Germany are operated by logistics service providers that specialize in the apparel industry. These providers also conduct centralized quality assurance (QA) and picking of shipments destined for wholesale and Gerry Weber's brand stores. Since the consumer segment addressed by Gerry Weber is very sensitive to the quality of products, Gerry Weber closely monitors the QA process in order to prevent negative impacts on revenue. The commissioning process conducted in the distribution centres is demanding due to two reasons: first, the array of selling points being served is very heterogeneous in terms of batch sizes, packaging and accounting requirements. Second, Gerry Weber reserves the right to interfere in the distribution process up to the last minute in order to efficiently steer the distribution of goods. In case of inconsistencies between the actual supply process and schedules, Gerry Weber's management can take immediate action in order to optimize the allocation of the available garments to stores. The actual transportation from distribution centres to stores and between stores is done by several short-haul transportation providers. Gerry Weber products can be divided into two categories: hanging and lying garments. Hanging garments are transported on hangers while lying goods are put into cartons.

The Information Flow

In this section, we outline which data is received and sent by the different members of the supply chain during the production and distribution of Gerry Weber products. We focus on information objects which are directly associated with physical items. In particular, this includes production orders and Advance Shipment Notices (ASNs).

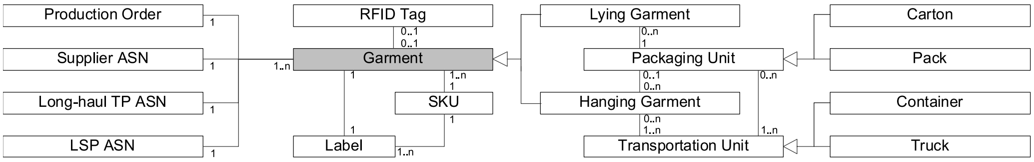


Figure 4.1: Structure of logistical data

Production is initiated by sending a production order to a supplier. The production order contains exact information about the type and quantity of all garments to be produced. Upon receipt of a production order, the supplier incorporates it into its production schedule. The supplier is able to access and modify the order data objects representing the production orders using Gerry Weber's SCM system. Among other things, production progress is recorded in the form of milestones along the garment production process (dyeing, cutting, sewing, washing) while the expected time to finish an order is constantly updated. Finally, when a supplier prepares a batch of finished products for shipment, an Advance Shipment Notice (ASN) is created by Gerry Weber's SCM software. This ASN provides an overview of all items contained in the shipments prepared to leave the supplier's site. The items listed by the ASN can be physically distributed over several containers and/or truck loads and be packaged in cartons and hanging packs. The information contained in the supplier's ASN only refers to the item type, not the individual garments. Without item-level RFID there is no way to tell which carton contains which items and inside which container or truck load a certain hanging pack or carton is shipped. The garment lots received from the small suppliers are consolidated into shipment lots by the long-haul transportation providers. When transportation batches have been determined, the long-haul transportation providers send an ASN via Gerry Weber's SCM system. Changes in transportation status are also recorded by the system. Figure 4.1 describes the structure of the logistical data processed in Gerry Weber's supply chain using a UML notation.

The logistics service providers that operate the DCs receive the ASNs of the long-haul transportation providers as soon as they are available within the SCM system. The DC processes have to be adapted to the type and quantity of incoming deliveries; therefore, the ASN information helps the DC operators to optimize their processes. For instance, if the ASNs indicate that a larger than expected delivery will arrive, capacity can be added in order to deal with the situation. The information that Gerry Weber receives from the DC operators includes the quantity of garments received, the results of the quality control which is conducted shortly after shipments are received, as well as the results of the picking process. The deliveries received by the DC are counted either manually or automatically on a 100 per cent basis, i.e. the data received by Gerry Weber allows them to determine whether the suppliers have shipped the agreed quantity. The information provided on the quality assurance process gives Gerry Weber the chance to react based on the number of production lots which have not passed the tests. For instance, if a significant number of garments are spoilt, the store orders need to be reviewed and scheduled shipment quantities have to be revised. The information about the outcome of the picking process serves to create the ASN of the logistics service provider (LSP ASN) which is sent to customers. It is also used to prove to the short-haul transportation provider how many items have been handed over at the DC in case garments are lost on the way.

The Potential of RFID

Gerry Weber constantly works to improve the efficiency and quality of its logistics. Among many other measures, Gerry Weber was among the first companies to explore the use of RFID in the textile supply chain. The group conducted a pilot project in 2003 in close cooperation with Kaufhof Warenhaus AG (a 100 percent owned subsidiary of the METRO Group) and involving several other partners, such as logistics and IT service providers and research institutions. 13.56 MHz tags where used to identify items and logistic units. Tags were applied at a distribution centre operated by the logistics service provider. RFID was then used to track all tagged objects on their way to two dedicated Kaufhof department stores via a Kaufhof distribution centre. All sites involved, including the stores, where equipped with mobile or stationary RFID readers. The main objective of the pilot was to assess the benefits of RFID for the fashion supply chain and to get a detailed view of costs occurred and technological limits. The pilot was successfully completed and proved that the technology is suitable for the fashion supply chain and a positive business case is possible. Most of the problems identified during the pilot were linked to the technology – e.g. insufficient read rates for bulk reads – or its costs [Tellkamp and Quiede, 2005, p. 143]; [Loebbecke et al., 2006].

Based on the positive experiences from their pilot, Gerry Weber International AG has decided to start implementing RFID to identify and secure merchandise along the supply chain. In the case of Gerry Weber, the main 'hard' benefit expected from RFID is the reduction of incorrect deliveries. The completeness and timeliness of shipments will be monitored by using RFID scanners at several steps in the supply chain. Reaction to delays or mistakes can therefore be carried out more timely and accurately in the future; for instance, mistakes made in the picking processes can be identified promptly, which in turn improves the chances of correcting the mistake before it can cause problems and additional work. Another quantifiable benefit is the reduction of administrative overhead at Gerry Weber's own stores. For instance, sales employees have to count incoming and outgoing goods either manually or by scanning the SKU barcode. With RFID, these processes will take a fraction of the time and enable employees to pay more attention to the customers.

A number of RFID benefits expected by Gerry Weber cannot be quantified in monetary terms but have nevertheless been taken into account. In particular, Gerry Weber's general management perceives the introduction of

RFID as a strategic investment since their wholesale customers may also soon demand tagged products. Gerry Weber will be well prepared for potential RFID mandates by its wholesale customers and positions itself as one of the first movers that has introduced an operational cross-company RFID solution. The second qualitative objective in implementing the RFID system is the improvement of information quality concerning supply chain processes. Since Gerry Weber constantly tries to reduce the time span between production and sales, the importance of information visibility to guarantee the availability of merchandise in stores with fewer out of stocks and more accurate inventory data, increases.

The decision to introduce item-level RFID was made based on an economic analysis which considered the 'hard' savings mentioned above, i.e. the reduction of non-conformity costs at the DCs as well as the labour cost savings at the stores – especially through reduced time for counting and identifying items. The initial ROI calculation assumed the use of stand-alone RFID transponders for one-time use. Since this assessment resulted in a less beneficial ROI, Gerry Weber's management searched for ways to increase benefits and/or reduce costs.

4.1.3 Cross-Company Closed-Loop Integrated Use of RFID

Gerry Weber came up with three changes to the initial investment plan:

- Cross-company RFID infrastructure: RFID data will be used along the whole supply chain in order to further reduce non-conformity costs.
- Closed-loop application: RFID transponders will be covered in plastic hard cases so that they can be used several times in order to reduce transponder costs.
- Integration of RFID with EAS: besides the RFID transponder, every hard case will also have Electronic Article Surveillance (EAS) functionality.

Although special transponders that can be reused are more expensive than transponders for one-time use, using the same tags multiple times leads to significant cost savings. Gerry Weber anticipates that each transponder will circulate 8 to 10 times on average. There are three reasons for this conservative estimate: (1) the surface of the plastic tags wears out over time which could have a negative effect on the perceived quality of Gerry Weber's products when displayed on the shop floor; (2) the functionality of the RFID transponders may suffer over time; (3) transponders may get lost in the supply chain.

The savings resulting from the repeated use of transponders are diminished by the additional expenses for shipping the transponders upstream; however, these expenses are comparably small because the capacity of containers and trucks on their way back to the production sites in Eastern Europe, Turkey and the Far East are usually not utilized and therefore relatively cheap.

Another advantage of closed-loop applications is that object identification does not require globally unique identifiers such as Electronic Product Codes (EPCs). Although Gerry Weber is a member of the RFID industry consortium, EPCglobal, and also pays fees for the use of European Article Numbers (EANs), actually using the EPC numbering system with full service would result in additional licensing fees; therefore, the EPC is not being used for now.

EAS tags are currently attached to the garments in the European distributions centres. By combining EAS and RFID, no additional RFID tagging process is required. Moreover, both EAS and RFID functionality can be added at the manufacturing sites where labour is a lot cheaper than in the distribution centres.

The additional benefits realized by the combination of cross-company, closed-loop and integrated use of RFID resulted in a sufficiently positive ROI; however, the additional requirements imposed by the cross-company, closed-loop integrated use of RFID transponders also lead to a number of critical challenges in terms of system and process design. These will be discussed together with the envisaged system design in more detail in the following section.

4.1.4 Design and Scope of the RFID System

The design and development phase of Gerry Weber's RFID project has been almost completed by now. In collaboration with their service provider, IBM, they have specified detailed use cases as well as hardware and network infrastructure for the following processes:

- Virtual association at suppliers, consolidation sites, distribution centres, and retail stores (UC1)
- Goods issue at suppliers, consolidation sites, distribution centres, and retail stores (UC2)
- Goods receipt at distribution centres and retail stores (UC3)

- Localization of unassociated garments at distribution centres (UC4)
- Disassociation of items at distribution centres and retail stores (UC5)
- Stock taking at retail stores (UC6)

All use cases have to comply with the above-average complexity and diversity of Gerry Weber's supply chain processes. For instance, they have to be designed both for automatic and manual distribution centres; for both hanging and lying garments; for the described reusable and also one-time use tags (possible requirement in the future); and for different locations. Figure 4.2 provides an overview of the information flow within Gerry Weber's supply chain, the involved information systems and the scope of the planned RFID system. Due to space limitations, we will concentrate on the two most critical RFID processes: the challenges involved in their implementation and how the system architects plan to cope with them.

The Virtual Association Process

In order to reuse RFID transponders, garments have to be associated both physically and virtually. Physical association means that a transponder gets physically attached to a garment. Virtual association means that with an appropriate database operation, a transponder ID is associated with: a garment stock keeping unit (SKU), the ID of the transportation unit it is transported in and the context data object (e.g. a production order) it belongs to. Whereas the association of transponder ID and SKU ID is a basic necessity for connecting read events with the appropriate context data stored in the IT backend, the association of transponder ID with the IDs of transportation units and context data objects is required to enable the effective tracking of the flow of goods. In particular, these associations can be used to identify tagged items which have not been observed at a particular RFID checkpoint, although they should have been observed there according to the schedule. In addition, Gerry Weber plans to validate the completeness of garment lots early on, during the association process: based on a real-time matching of association data and available business context data, employees will be instructed to take corrective action if necessary.

Both association types (physical and virtual) can be conducted at several sites throughout the supply chain (at large suppliers, consolidation sites, DCs) in order to make sure that 100% of the garments which leave the distribution centres are physically as well as virtually associated (otherwise, the intended store use cases such as stock taking could not be carried out). To this end, the association status of every shipment, i.e. 'untagged', 'tagged',

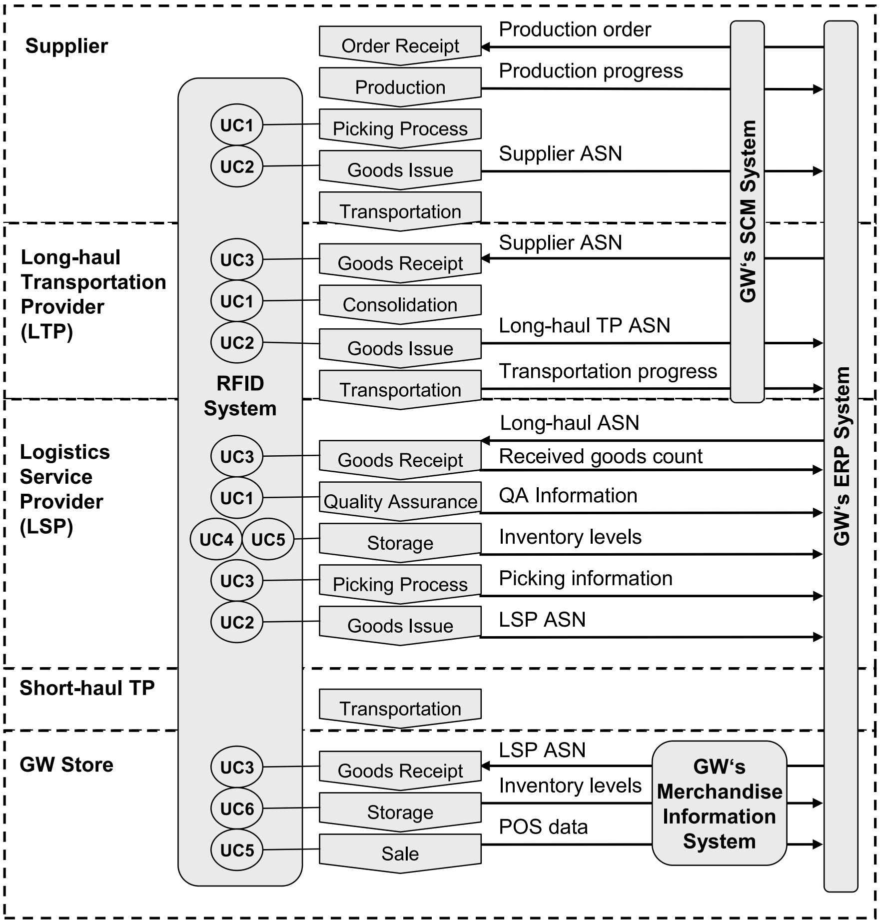


Figure 4.2: Scope of Gerry Weber's RFID system

'tagged and virtually associated', is captured and relayed so that every one of the following supply chain partners can react accordingly.

The RFID reader devices that are used at the work stations responsible for conducting virtual association will be able to read both barcodes and the data stored on RFID transponders. Each station will accommodate a dedicated server which will temporarily buffer RFID-related data such as the business context data required in the association process and the results of the association process. For hanging garments, a handheld device will be utilized; whereas, the virtual association process for lying garments will be performed on a specially designed RFID packing table which enables fast, ergonomic processing. While associating the garments, the items will be merged into logistics units (either plastic bags or cartons); thereby, also virtually linking them to the number of the respective logistical unit.

Physical association is straight-forward since it is similar to other standard labelling processes that are already conducted along the supply chain (such as the application of price labels). There are, however, a number of specific challenges involved in the management of the EAS-RFID hardcase tags as well as in the implementation of the virtual association process.

The RFID implementation strategy implies that transponders are shipped to the large producers, the consolidation sites and the DCs at the right time and in a sufficient quantity. Gerry Weber expects that each transponder is used two to three times per year depending on the country it is shipped to, the transportation mode used, etc. The calculation of the total number of required tags is not straight-forward since it has to take the buffer stock of tags into account.

Concerning the virtual association, the application among other things has to be robust with respect to the following exceptions:

- Non-readable RFID transponders
- Several RFID transponders in detection area
- Non-readable barcode
- Missing business context data
- Bypassing of predetermined processes by employees

Whereas the first three issues can be solved pragmatically (e.g. by replacing an RFID tag; shielding or containment of the detection area; regeneration of barcode label), the remaining two cannot be coped with that easily: if there is missing business context (such as purchase orders, ASN, etc.), immediate access to the central RFID platform is required in order to perform the planned quantity control. If the Internet connection to the RFID system cannot be established, the business logic has to be designed in a way that conducting the virtual association without quantity control is still feasible. Furthermore, the process either has to be able to mitigate the faulty virtual association of garments or at least detect it and notify subsequent stages of the supply chain so that the association process can be selectively repeated later on.

Goods Issue Process

When garments have been prepared for goods issue at an RFID-enabled site, they have to be both physically and virtually associated as well as packaged in plastic bags (hanging garments) or cartons (lying garments). The goods issue marks the last opportunity to ensure the completeness of a shipment and the correct association of RFID transponders with garments. In Gerry Weber's supply chain, RFID hardware has to comply with special environmental conditions. For instance, the goods issue process can be conducted manually, via suspension rails, with pallets or on conveyor belts. In order to satisfy this requirement, different RFID hardware solutions are necessary. Warehouse operators can, for instance, choose to use handheld devices or a fixed RFID gate. Another challenge regarding the RFID-enabled goods issue process is to read the data stored on many transponders at the same time: since reading reliability can still not be guaranteed, ways to make the process robust – to almost 100% read rates – had to be found. To this end the allocation of transponder IDs and logistical unit IDs is used: if all items packaged in the same carton or pack can be inferred from the database, reading one transponder ID suffices to conduct a full count at the goods issue.

Similar to the virtual association process described above, Gerry Weber will realize value added at the goods issue by detecting potential deviations from the distribution schedule. Warehouse operators will have access to the RFID-based real-time loading status and can be alerted if a shipment is incomplete. The RFID system will be able to display to workers which items or logistic units are missing in order to complete a shipment.

4.1.5 Project Management

The design and implementation of the described RFID application will be carried out by one main contractor (IBM) and several subcontractors (hard- and middleware suppliers) that are supervised by IBM. IBM is responsible for the design, trial, rollout, and operation of the RFID system. OATSystems is part of the implementation team and is in charge of the middleware solution. Checkpoint Systems provides tags as well as stationary and Intermec handheld reader systems. The advantage of this organizational model for Gerry Weber is that it has one single point of contact for managing all of its RFID operations.

In order to minimize the financial risk involved in realizing the RFID application, Gerry Weber decided to implement it in four steps. After each of these steps the continuation of the project will be re-evaluated. In the first step, the RFID solution is designed, tested and implemented in four distribution centres and two retail stores. In the second step, the solution is rolled out in all of Gerry Weber's retail stores. The international rollout of the solution is initiated in the third step by equipping two consolidation sites in China and Turkey with RFID technology. In the final step, all remaining consolidation sites in the Far East and at the sites of main suppliers will be included, which will enable the maximum item-level visibility that can be achieved using RFID [Tröger, 2008].

4.1.6 Necessity for Cost-Benefit Sharing

The fashion industry as a whole is seen as one of the leading industries regarding the cross-company use of RFID. Many companies have successfully completed pilot projects and are now starting to implement the technology (see e.g. [Berger, 2006], [O'Connor, 2006], [O'Connor, 2007], [O'Connor, 2008], [Swedberg, 2006], [Swedberg, 2007]). Gerry Weber's approach differs in scope from that of many competitors as it encompasses the whole supply chain; thus, supply chain partners – especially logistics service providers which operate distribution centres in Europe and consolidation facilities in sourcing countries – are involved in this cross-company project. With respect to power structures, Gerry Weber can be characterized as the most powerful company among the partners within the supply chain under consideration.

Implementing the RFID solution is associated with considerable costs at each stage. These include costs for developing, testing and installing the RFID solution; investment in hardware; recurring expenses for tags and tag returns; the operation and maintenance of the RFID infrastructure; and service charges for the RFID platform.

During the cost-benefit analysis, savings and increased revenues have been identified that will exceed those costs – from the supply chain point of view – once stage three has been successfully concluded. Benefits encompass, among others savings generated by automated scanning and handling processes, increased information quality which leads to higher flexibility and enhanced delivery quality. In addition, a change in the current EAS tagging process – combining RFID and EAS and outsourcing the tagging to the suppliers – counters most of the tag-related RFID costs.

While implementing RFID is profitable for the whole supply chain, this is not necessarily the case for the logistics service providers. On the one hand, a considerable share of the RFID installation can be allocated to their facilities. On the other hand, most of the logistics service providers lack the understanding of how to generate benefits for their operations from the technology. In order to win their support for the project, Gerry Weber has developed a cost-benefit sharing scheme.

4.1.7 Cost-Benefit Sharing Model

According to the cost-benefit sharing scheme depicted in Table 4.1, Gerry Weber will bear all costs occurring during stages one and two. This does not

Table 4.1: Gerry Weber's cost-benefit sharing approach (based on Tröger [2008])

Stage	One: pilot	Two: run-up	Three: operations
Costs (paid for by Gerry Weber)	development, testing, piloting	roll-out services, infrastructure: investment, infrastructure: service/maintenance, operations: RFID platform, operations: tag cycle	operations: RFID platform (proportionally), operations: tag cycle
Costs (paid for by partners)	none	none	operations: RFID platform (proportionally), infrastructure: service/maintenance, tagging/initialization of tags
Benefits (to Gerry Weber)	none	lessons learned	flexibility/event driven supply chain management, visibility, enhanced, store processes (e.g. inventory, fewer out of stocks), savings through combining EAS and RFID
Benefits (to partners)	none	evaluation of benefits of the technology for own operations, evaluation of technology-related services	reduced costs for counting and handling merchandise, visibility, revenues through RFID-related services

only include hard- and software-related costs, but also training measures. To enable the logistics service providers to take part in those stages and allow them to evaluate the use of the technology for their operations, their basic RFID equipment will also be covered by Gerry Weber. Once stage three is operational, the service providers are expected to co-finance a share of the RFID solutions' operating costs. They should be able to derive additional benefits from the technology themselves at that time and also partially profit from the enhanced supply chain visibility that Gerry Weber is willing to share. Service providers will be remunerated for additional time and effort resulting from the use of RFID – for example re-tagging garments if not done properly by suppliers [Tröger, 2008] –, at least in the first two project stages.

Categories of Compensation

In Section 2.3.6, monetary, tangible and intangible compensations are differentiated. In the case of Gerry Weber, several of the monetary measures for the cost compensations mentioned above were applied; however, benefit sharing was not implemented. Gerry Weber is paying the operational expenses and is willing to pay a premium for RFID-related services (e.g. tagging of goods, association of transponder and product information); at least in the first two project stages. There is no monetary compensation since Gerry Weber provides their suppliers and service providers with the required hardware and does not reimburse them for their expenses; however, there is some other tangible compensation made.

Regarding the tangible compensation, it was mentioned that providing infrastructure equipment requires a certain degree of stability in the buyer-supplier-relationship and that this measure is not suitable for volatile procurement markets. To avoid this problem in the early stage of the RFID rollout, only a few of Gerry Weber's established suppliers and service providers with long running contracts will be integrated.

The case study reveals several instances of intangible compensation. It is shown that Gerry Weber assists its service providers in site assessment and technology selection by providing its own staff and hiring consultants. Furthermore, the gathered information will be accessible not only to Gerry Weber, but also to its partners. Beside these, the assistance during the run-up phase and training are also potential areas where Gerry Weber can help its partners.

Temporal Dependencies

The kind of cost-benefit sharing evolves over the different implementation stages. In Section 2.3.6, general recommendations about which type of compensation should be used in which phase are given. In the Gerry Weber case, all expenses resulting from the pilot are paid by Gerry Weber. Additionally, Gerry Weber supported its partners in applying the technology to their own processes. These measures were chosen to guarantee the participation of the key partners. In general, all the measures of compensation were suitable for the pilot phase. Because of the difficulties in estimating the potential benefits, a combination of tangible and intangible compensation measures is likely to be preferred to a financial payment.

After the realization of a pilot project, it is expected that the service providers will expand their own RFID activities and become financially involved during the RFID run-up by investing in additional RFID equipment. It is for this reason why tangible compensation measures will not be applied in the run-up phase. More likely, intangible measures such as knowledge transfer, training courses and exclusive contract terms will be offered to the partners. Furthermore, Gerry Weber will pay its service providers and producers extra money for RFID-related services, such as tagging and information provision.

4.1.8 Conclusions

This section described the current state of Gerry Weber's RFID project. Gerry Weber is one of the first companies in the apparel industry that has decided to introduce RFID on the item level. Based on the description of the flow of goods and information, our case study disclosed the benefits Gerry Weber expects from the introduction of RFID. The case description gives insights into the processes taking place along Gerry Weber's supply chain and the data being exchanged between the supply chain partners. Gerry Weber has outsourced most of their logistics operations, but at the same time has to face the increasing complexity of their supply chain; therefore, they are interested in monitoring the flow of goods more closely in order to diagnose possible exceptions remotely. Besides typical RFID benefits, such as labour costs and error reduction, RFID is expected to play a key role in providing accurate monitoring data, which will be used by sophisticated decision support systems.

The case shows how the ROI of RFID hardware can be improved by closing the tag loop and efficiently combining RFID with existing technologies such as EAS. Two RFID use cases that play a crucial role in the implementation of Gerry Weber's RFID strategy were analysed: the virtual association and the goods issue process. The corresponding advantages and challenges were outlined.

The approach of using RFID in a closed loop and integrating it with existing EAS processes is not necessarily restricted to the apparel industry. It could also be applied to other retail products of relatively high sales value (e.g. consumer electronics). In our opinion, the approach of increasing the ROI of item-level tagging outlined in this section has the potential to foster the diffusion of large-scale item-level RFID applications. If more RFID transponders are sold their price will eventually drop due to the economies of scale realized in their production. This in turn will eventually make open loop applications economically viable. Although Gerry Weber will start to use RFID transponders in a closed loop, the system architecture that is currently being implemented can easily be expanded to an open-loop application: when Gerry Weber's wholesale customers start calling for RFID tagging, Gerry Weber will be ready to serve their request.

4.2 RFID in the Kitchen Furniture Industry – The Case of Wellmann

4.2.1 Company Profile

Wellmann GmbH & Co. KG (Wellmann) based in Enger, Germany, is a kitchen manufacturing specialist. Founded in 1953 by Gustav Wellmann, the company was taken over by Alno AG in 2003. In its supply chain, Wellmann's position is that of the Original Equipment Manufacturer (OEM). The structure of its suppliers is very heterogeneous and varies from small factories to industrial producers and logistics service providers. The kitchens produced are offered by several retailers – mostly under their own brand names. The business goal of Wellmann is to provide high quality, complete kitchens on schedule for competitive prices, despite numerous variants and a high share of individual and special parts.

Both following case studies cover all processes, including procurement and production, that are relevant for introducing RFID at Wellmann.

4.2.2 Scenario Description for Using RFID for White Goods

Wellmann offers kitchen furniture, major kitchen appliances (white goods) as well as all the accessories needed to assemble the kitchen as units. For equipping kitchens with these appliances, Wellmann operates an intermediate warehouse with inventory for frequently ordered items. Demands that can not be supplied from this inventory are bought from a manufacturer that has its distribution centre in the same building. A logistic service provider is commissioned with operating both inventories. The focus of this case study is the electronic data interchange (EDI) for the sourcing of electronic appliances between Wellmann and the service provider and has the goal of identifying the relevant EDI structures that are affected by an RFID introduction. As soon as the route planning for the customer orders is finished, the orders for the appliances are automatically released by the ERP system. An electronic order of kitchen devices is always related to customer orders and separated into Wellmann's inventory, devices from the contractual manufacturer, and special devices that have to be ordered just in time (JIT). The electronic transfer of the orders to the logistics service provider happens once a day for each category. The service provider retrieves the order data from an FTP server.

The service provider attaches Wellmann's customers' shipping labels to the devices; therefore, additional data (customer data, shipping bar code, shipping lot, etc.) are transferred to the service provider. For the picking process, the service provider consolidates the order data with the label data and creates the picking order; this contains, besides the internal picking data, Wellmann's shipping data. In the case of large electric appliances (fridge, stove, etc.), one single shipping label is attached to each product. An order of smaller devices (such as wiring) are put into a box and one combined label is attached to the box.

To uniquely identify a shipment, the logistic service provider creates a number (called SLB), which is then transferred to Wellmann as part of an electronic avis. For the receiving certificate, the service provider prints a delivery note, which has a list of all items within the delivery. Additionally, the delivery note includes the generated SLB number as a bar code. In the incoming goods area at Wellmann, this barcode is scanned and the items previously transferred in the avis are retrieved from Wellmann's ERP system. The arrival of the items is entered into the ERP system by scanning the shipping label's bar code. At the same time, this controls for completeness as the scan is matched with the data from the avis. When this process is finished, the shipping manager signs the delivery note and returns it to the logistics service provider via the next truck driver.

4.2.3 Data Structures

To support the ordering process with RFID, an analysis of the structure of all business documents that are exchanged electronically is necessary. With regards to the item level identification, which is enabled by RFID in particular, the currently used identification numbers are of primary interest.

Figure 4.4 depicts this structure, which can be explained as follows:

- A customer order can consist of several categories of electric devices.
- The order number uniquely identifies the order within one category.
- One order can include several positions per category.
- For each position, Wellmann creates a unique shipping barcode.
- The uniqueness of the positions is independent of the categories.
- The shipping barcode is, consequently, the unique identification criterion for objects in an order.

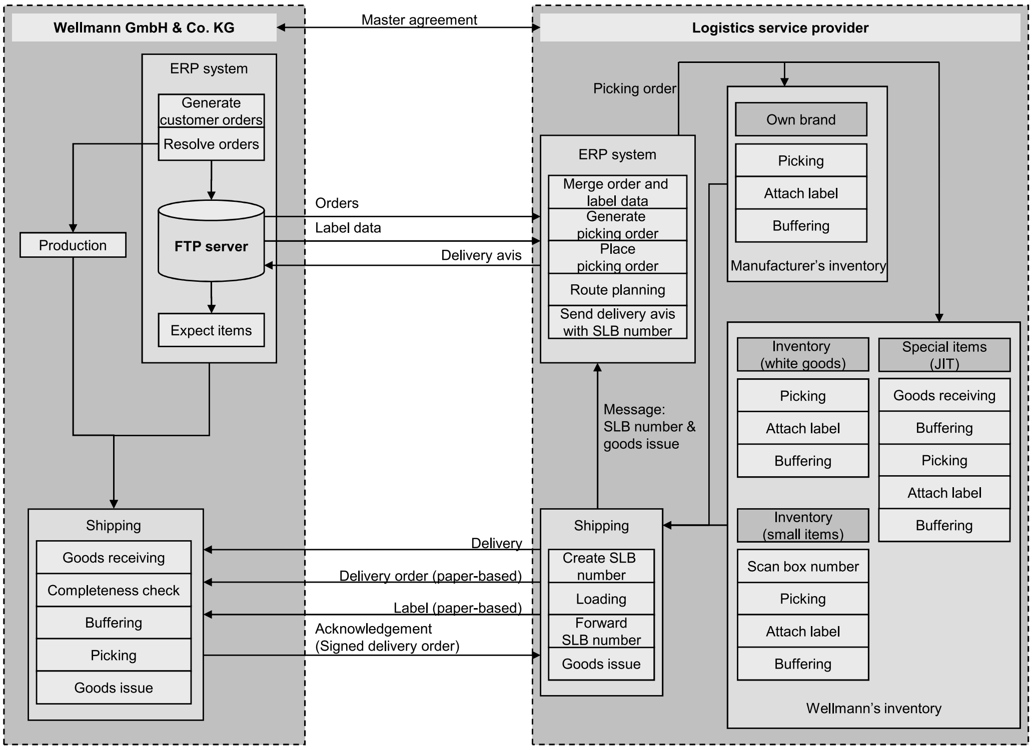


Figure 4.3: Data exchange between Wellmann and the service provider

4.2.4 RFID-caused Process Changes

As already mentioned earlier, in contrast to bar code technology, RFID allows for the automatic identification of several objects without line of sight and human interaction. Because of these characteristics, RFID technology allows for: improvements in the receiving and shipping processes; earlier information about missing components in a delivery; and a reduced number of mistakes in (manual) transactions. A prerequisite for gaining these benefits is a binding agreement on RFID-based data structures and identification criteria between all participating companies in general, and between Wellmann and the logistics server provider specifically in this case.

For this relationship, an EDI solution based on neither EDIFACT nor XML standards, but a custom solution has been used. The main reason is the legacy hardware and software system at Wellmann and the logistics service provider, which has been modified over time. The cost-benefit relation in changing to a standardized solution is unclear. In general, the spread of EDI standards for production logistics (in contrast to distribution logistics) in the furniture industry is quite small because of the heterogeneous sup-

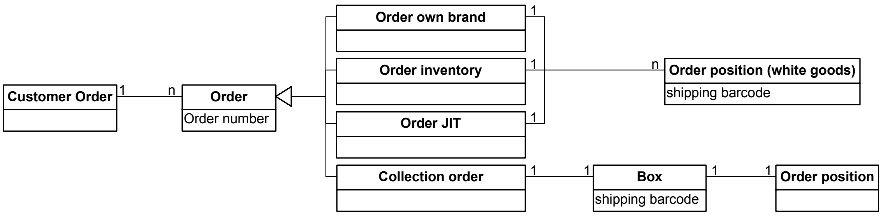


Figure 4.4: Structure of an order

plier structure; hence, no network effects could be gained with a change to a standardized solution. Concerning identification, the use of an EAN-based barcode is not beneficial because of the uncountable variants, single and special components. In this situation, every single component would constitute a product class of its own.

To keep the effort needed to change from barcode to RFID technology relatively small, the current custom solution will also be used for the RFID-based data exchange and the unique identification number will be the shipping barcode. This number will be stored on a passive RFID transponder and attached with an adhesive label, which also contains the existing data in a written format. In order to realize this, an RFID printer has been installed at the logistics service provider. At Wellmann, RFID handhelds are used to automate the goods receiving process as well as the completeness check. In future, this handheld will be replaced with an RFID gate. After identifying the delivery order and the items, the completeness check will be performed automatically by the ERP system. When this process is completed, the delivery acknowledgement is sent to the logistics service provider. Currently, this acknowledgement is represented by the signature on the delivery receipt by the shipping manager. With the new system, this acknowledgement will be based on the RFID data. The ERP system will store the electronic document on the FTP server where it can be accessed by the logistics service provider.

4.2.5 Data Standards for Cross-Company RFID Applications

An important aspect considering cross-company RFID applications – as opposed to local applications – is the use of standards. The main argument of using standards in local applications is future proofing it against technological changes. For cross-company applications, the relative importance of hardware related standards is declining; instead, the importance of standards for the electronic data interchange is increasing. The most frequent used standard used for EDI in Germany is by far EANCOM, which is a subset of EDIFACT [QW03].

The technical innovation of RFID and EPC is their ability to uniquely identify items individually. For a cross-company application, it is important to clarify which company will be assigning the identification number. In a recommendation by GS1 [Kuhl08-ol], the supplier generates the ID and transfers it within the despatch advice message (DESADV) so that the goods can be received from the customer. In this recommendation, the segments that have to be used are described in detail for the EANCOM 2002 S3 version. Alternatively, the exchange can be done on the basis of GS1 XML.

In the second alternative, the customer will generate and assign the ID instead of the supplier. This option was used in this case study, but no GS1 recommendation exists for this case. To realize this case based on EDIFACT, the message type order (ORDERS), where a certain product class can be ordered with a certain quantity, would be affected. So, for each individual product with a unique ID a new element would have to be transferred.

At Wellmann, standards for the electronic data interchange are only used to a limited degree. Reasons are primarily the high costs for the system customization, which would be caused by the custom legacy system and the missing pressure from business partners. In general, the challenges of item identification are also valid for Wellmann's internally developed messages types. All items are related to one specific order from the beginning of the order and production process. This simplifies the problem because the shipping number is unique for white goods and for boxes with small items.

Figure 4.5: Electronic Product Code based on an EAN

Different identification numbers can be coded in the EPC. Figure 4.5 shows an EPC that is based on an EAN (at the top of Figure 4.5 in barcode notation). The difference between EAN and EPC is that not only a class of items, but every individual item can be differentiated. Another standardized ID that can be used in the EPC is the serial shipping container code (SSCC) for logistical units. The codes have been developed and are assigned by GS1. If the ID is solely used in an intra-company context or in a well-defined inter-company application, which is the case in this case study, and the companies want to avoid paying GS1 for an assignment, a self generated identification number can be used instead of an assigned one. This is standard compliant if the number starts with the numeral 2.

4.2.6 Scenario Description for Storing Data on RFID Tags

The implementation of RFID in Wellmann's logistical and production processes is done in several successive steps. In the initial steps, only parts with the most critical logistical importance [Strassner, 2005b], i.e. parts of high value, are tagged with RFID transponders. Besides the white goods, they consist of kitchen cupboard fronts that are custom ordered; produced by an external supplier; and delivered just-in-time for assembly at Wellmann.

The production of cupboards with fronts follows a structured process that consists of ordering parts, picking parts, drilling fronts, assembling components and assembling whole cupboards. The process starts with a customer who plans his or her kitchen at a retailer which in turn creates a custom order for Wellmann. As soon as the route planning for the custom orders is finished, the orders for the externally sourced parts are automatically placed by Wellmann's Enterprise Resource Planning (ERP) system once a day to all affected suppliers. Each position in the electronic order is always associated with its corresponding position in the custom order. In this case study we focus on fronts, which can either consist of wood or glass. Glass fronts are either framed in wood on all four sides or only have wood on the top and bottom. The combination of individual dimensions, different types of handles and other characteristics makes the production of cupboards vary greatly.

Parts are moved through the factory in special containers, which are identified with a unique twelve digit Transport Group number (TG number). Within this container, the parts are identified with a twelve digit Transport position number (TG position number). Additionally, each part is identified with a twelve digit Transport order number (TA number). All numbers are newly assigned before each production step. To control all production steps, the numbers of all objects are stored in Wellmann's ERP software. The data model for identification numbers is depicted in Figure 4.6.

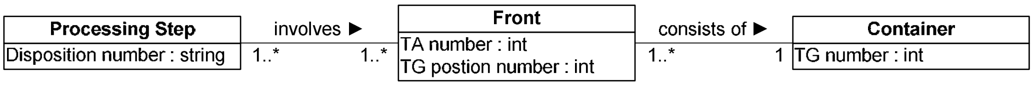


Figure 4.6: UML model describing the identification scheme

The supplier produces the fronts ordered and supplies them just-in-time when the assembly of the kitchen is scheduled. The delivery of the fronts is scheduled for two working days before the cupboards are sent to the customers. The supplier prints a delivery note, which contains only the TG number and the supplier's delivery note number as a bar code. Additionally, all parts are listed with their corresponding TG position numbers, TA numbers and characteristics (e.g. dimensions and colour). On an attached negative delivery note, all parts from the order that could not be delivered are listed in the same way. Besides these delivery notes, each front has a label attached that contains the TA number for its first processing step as a bar code and the description of its characteristics as well as its production and delivery date.

When the fronts are received at Wellmann, the receiver first scans the TG number on the delivery note or the TA number off of a label attached to one of the fronts. With either of these possibilities, the list of ordered parts is received from the ERP system and displayed. To check the completeness of the delivered parts, the receiver can scan the barcodes (TA number) of each front label and compare the lists. Additionally, the receiver could enter the TG position numbers or the TA number of the parts that have not been delivered into the system. The receiving process is finalized by storing the delivery note number in the ERP system. This triggers a rescheduling of the downstream activities, where the undelivered fronts are removed from further processing steps.

For further processing, the fronts have to be buffered directly in front of the next work station. In this case, the fronts are drilled at a CNC (Computer Numerical Control) jig boring machine. Each bore program is retrieved from a central server over the network and always relates to one special front. This program determines the bore template as well as the depth of the drill holes and the components that have to be assembled (e.g. hinges and cushion for the doors). During the production of one batch, which consists of several front containers, changes with the bore program might occur. For this reason, the boring machine is loaded with programs once a new container arrives; therefore, the TG number barcode of the container is scanned from the picking list that was created for this work step. The operational sequence of the boring programs depends on the position of the fronts in the container; therefore, the picking process of fronts into the container has to be done very accurately. If there is one front missing, the bore program for this front has to be removed manually. The operator, who equips the machine with fronts, removes the missing front by selecting the position on the display of the CNC machine. Because the machine works automatically after the operator has equipped the machine with the custom fronts from a container, mistakes have a great effect on the overall process if they are destroyed. In such a case, a complete delivery of the kitchen to the customer at the scheduled time is no longer possible.

After this processing step, a new picking list is printed. This contains the next processing step, the container ID (TG number) and lists the fronts in this container (TG position and TA numbers). After each processing step, this data is retrieved from the ERP system. Additionally, the completion of the processing step is recorded. This acknowledgement is necessary because the production order has to follow the planned and scheduled production process. After the acknowledgement in the ERP system, the next processing step is unlocked.

For transport to the following processing step, the fronts are put into a new container, which depends on the type of cupboard and the new TG position numbers that are assigned for their following processing step. At the final working station, the fronts are assembled with their bodies that have the same TG position number. The bodies are then delivered to an assembly line. For a smooth process, the sequence of the fronts plays an important role again: avoiding downtime of the assembly line. Cupboards whose fronts have not been delivered have to be set aside. The bodies are buffered until the fronts are produced and provided.

4.2.7 RFID Process Benefits

Because RFID offers the possibility to simultaneously identify several objects without contact, without line of sight and without human interaction, two general effects are again achieved in this scenario: first, manual effort can be decreased (e.g. faster receiving and shipping processes); and second, costs incurred due to errors (e.g. at the boring machine) can be reduced.

The general potential from using RFID at Wellmann can be achieved with the data-on-network approach; however, in the production environment where components are tagged and not consumer products, the usage of the EPC is not suitable. Instead, the TA number, which is assigned by Wellmann and pushed to the supplier, is stored as a unique identifier. All manual process steps described in the scenario above are positively affected by the introduction of RFID: the registration of fronts at the receiving business step, the manual deletion of missing fronts at the boring machine as well as the control of the fronts' sequence. An automatic matching of front and bore program ID helps reduce costs incurred by errors (the higher price for emergency orders for fronts, etc.) and reduce the risk that a kitchen can not be completely delivered to the customer.

Additional to the benefits that can be reached with the data-on-network approach, there are advantages for Wellmann in storing data on the RFID tag. First, the data related to the processing step can be accessed without connection to the network. Second, the bore programs for the boring machine including the specific parameters and characteristics of the fronts can be stored on the transponder. These bore programs can be accessed directly before a front is processed. Furthermore, the completion of the processing step, the retrieval of the following steps and the printing of this plan can be omitted when all necessary data are stored on the RFID tag. The processing progress can be stored on the tags as well as a trigger to release it for the following processing step. In case of a failure or breakdown of Wellmann's local network, the production is not affected.

For Wellmann's supplier in this case study, the introduction of RFID in cooperation with Wellmann offers benefits, too. Certainly, the supplier also benefits from the reduction of manual effort (e.g. the shipping process and creation of delivery notes). Additionally, the conflict potential in the transferring of title and risk can be reduced.

Wellmann wants to establish a standardized approach for storing data on RFID tags instead of developing a separate solution with every business partner. Although the prototype described in this case study encompasses only the business relationship to the front supplier, it is Wellmann's intention to expand the RFID solution to other suppliers, logistic service providers and retailers. They, in turn, work together with other manufacturers and will benefit from a standardized approach as well. Searching for a prospective solution not exclusively for this use case, Wellmann chose to store the data on RFID tags in the form of ISO 13584-compliant properties.

4.2.8 Extraction of ISO 13584-Compliant Properties

The effects of the RFID introduction described in the scenario above affect the existing processes only. In this case study, RFID does not act as an enabler for new processes with a transformational effect [Straube et al., 2007]; that is why all relevant data that should be stored on RFID tags are implicitly contained in the current business processes and should be extracted from them instead of being newly created. To define the properties compliant to

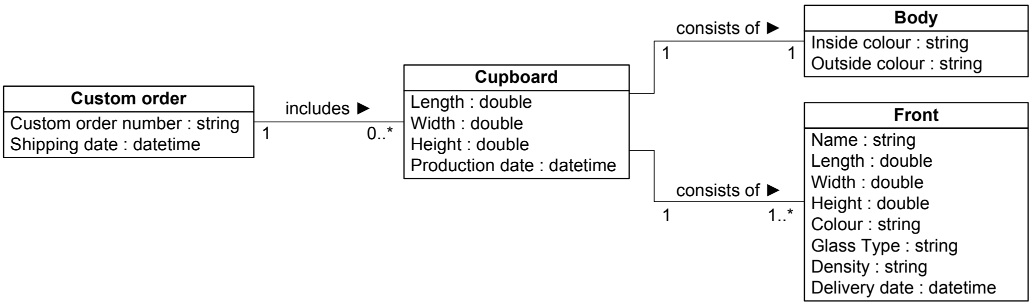


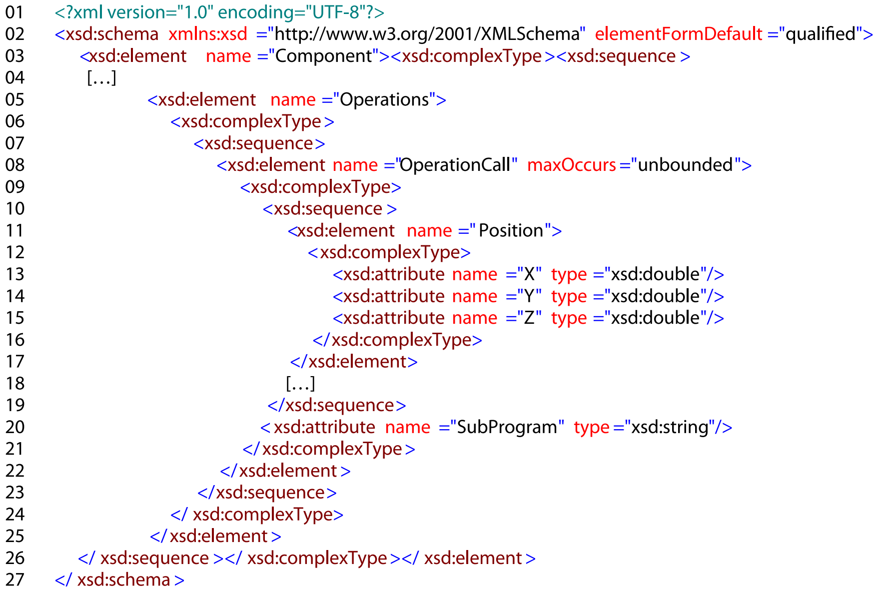
Figure 4.7: UML diagram showing the objects' characteristics

the ISO 13584 specification, at least the name of the property, the type of the property and the data type have to be extracted. Further information, such as IDs and units, can be manually added later. The needed information can be found in the information model of Wellmann's ERP system.

The processing steps of the fronts, which are the objects of investigation in this case study, are receiving, producing and assembling. The identifiers related to the fronts as well to the containers the fronts are transported in have already been described in the information model depicted in Figure 4.6. Following this model, the RFID tag is put on the fronts, which means that the TA number and TG position number can be extracted as properties (compare Table 4.2). Because of the association of the class `fronts` to exactly one container, the TG number can be added as a property as well. Attention has to be paid to the `one or more` association to the processing steps. This indicates that all three properties are not unambiguous, but depend on the ID of the disposition number of the processing step. For this reason, the disposition number builds the condition for the three dependent properties.

Further characteristics of fronts and their related objects are depicted in Figure 4.7. In this information model, coming from the class `front`, all other classes are connected with an association multiplicity of exactly one. That is why no dependent properties have to be created because of multiplicities in the class diagram. Other dependencies (e.g. glass type and density) have to be manually detected. The attributes of the class `front` can be extracted as independent properties along with their corresponding data types. The attributes of the related classes can be extracted as well, but if the names of the attributes are not unambiguous for the front, the class name has to be added to the property (e.g. cupboard length). The extracted characteristics are shown in Table 4.2.

The properties of the bore program for the fronts can be extracted from Wellmann's manufacturing execution system. In general, there exist two options: first, the whole bore program could be stored as one property that has the data type BLOB (binary large object). Second, the properties for the bore program can be extracted from the bore program. The bore program is encoded in PrimeFact's XNC format [Smeerdijk, 2006]. The subset of this XML Schema, which is used by Wellmann, is depicted in Figure 4.8. The ISO 13584-compliant properties are extracted with the methodology proposed in Leukel et al. [2006a] and added to Table 4.2 (where the attribute `SubProgram` is renamed to `bore program ID`).



```
<?xml version="1.0" encoding="UTF-8"?>
<xsd:schema xmlns:xsd ="http://www.w3.org/2001/XMLSchema" elementFormDefault ="qualified">
  <xsd:element  name ="Component"><xsd:complexType ><xsd:sequence >
   [...]
        <xsd:element  name ="Operations">
          <xsd:complexType >
            <xsd:sequence>
              <xsd:element name ="OperationCall" maxOccurs ="unbounded">
                <xsd:complexType>
                  <xsd:sequence >
                    <xsd:element  name =" Position">
                      <xsd:complexType>
                        <xsd:attribute name  ="X"  type ="xsd:double"/>
                        <xsd:attribute name  ="Y"  type ="xsd:double"/>
                        <xsd:attribute name  ="Z"  type ="xsd:double"/>
                      </xsd:complexType>
                    </xsd:element>
                    [...]
                  </xsd:sequence>
                  < xsd:attribute  name ="SubProgram"  type ="xsd:string"/>
                </xsd:complexType >
              </xsd:element >
            </xsd:sequence>
          </ xsd:complexType>
        </xsd:element >
  </ xsd:sequence ></ xsd:complexType ></ xsd:element >
</ xsd:schema >
```

Figure 4.8: XML Schema for bore programs based on PrimeFact's XNC format

4.2.9 Prototypical Implementation

To realize the RFID project at Wellmann, special requirements and challenges have to be considered. First, only one type of RFID tag has to be used for applications in logistics and production. A combined approach of the data-on-tag and data-on-network concepts has to be applied. Second, passive RFID tags are preferred over active ones because of the price differences. For the data-on-network approach, RFID tags according to EPC Gen 2 (ISO/IEC 18000-6) in the UHF frequency range have succeeded in the market and should also be used at Wellmann for this reason.

Nevertheless, most RFID tags that comply with these specifications are only produced with the 96 bit memory for the EPC. To reasonably use the

Table 4.2: Extracted ISO 13584-compliant properties

Ser. No.	Preferred Property Name	Example of Value	Unit	Property Data Type	Type of Property	Dependent on Ser. No.	Possible Identification in DINsml
1	Name	Front		String	Nondependent		DINAAA054-002
2	Length	0.625	m	Double	Nondependent		DINAAA357-002
3	Width	0.02	m	Double	Nondependent		
4	Height	0.2	m	Double	Nondependent		DINAAB517-003
5	Colour	Blue		String	Nondependent		DINAAB245-002
6	Glass Type	BK7		String	Condition		DINAAA179-002
7	Optical Density	2.51	D	Double	Dependent	6	DINAAB097-002
8	Delivery Date	2008-11-24 08:24:19		Datetime	Nondependent		
9	Custom order number	VD234		String	Nondependent		
[. . .] Figure 4.7							
10	Disposition number	34K13Z3		String	Condition		
11	TA number	1234003		Integer	Dependent	10	
12	TG number	1234		Integer	Dependent	10	
13	TG position number	003		Integer	Dependent	10	
14	Bore Program ID	98735123		Integer	Condition		
15	X-axis Value	482.5	mm	Double	Dependent	14	
16	Y-axis Value	563.0	mm	Double	Dependent	14	
17	Bore Depth	5.9	mm	Double	Dependent	14	DINAAA080-002
18	Bore Diameter	8.0	mm	Double	Dependent	14	DINAAA788-002
19	Bore Program	0110010 0101001		BLOB	Nondependent		

data-on-tag approach, at least 1024 bits of additional memory is necessary. The additional cost of this type of RFID tag is currently about 20 Eurocents. Individual companies have to decide for their own RFID business cases whether such a solution is economically reasonable or not. In the case of Wellmann, between 20,000 and 30,000 fronts have to be tagged each year (253 working days). The extra costs of 5000 Euro per year at Wellmann can be justified by the reduction of costs incurred due to errors at the boring machine. Assuming that only 25% of the ca. 5 cupboards per day (1265 per year) that are mis-bored can be saved from errors, which saves about 20 Euro per cupboard for recycling, material and extra logistics, the annual savings add up to 6325 Euro. The qualitative benefits, such as the reduced dependency on the backend system and the number of additional satisfied customers, can also be added, but it is not very easy to evaluate them monetarily. In this costs consideration, only the extra costs and savings of using a combined data-on-tag and data-on-network approach were considered, not general RFID benefits and the costs for implementation, maintenance and training.

To prepare for the introduction of RFID at Wellmann, technical tests in the laboratory were first conducted with RFID tags with 512 bits of extra memory. Later on, RFID tags with 1024 bits were chosen because of, as already stated above, the memory needed. For this prototypical implementation, a proprietary syntactical format – following the VDA recommendation [VDA, 2008] with a separator – was chosen to store the data on tags. Since the ISO 13584 standard, which is recommended in this work, only covers the semantics layer, further research on the syntactical layer is necessary.

4.2.10 Conclusions

In the second part of the empirical chapter, we conducted two case studies with the kitchen furniture manufacturer Wellmann. While the first case – concerned with tracking white goods in the cross-company RFID application with the logistics service provider – focused on organizational issues, the second case proved the feasibility of storing data on RFID tags using standardized properties.

The focus of the first case study was on production logistics in contrast to distribution. The use of RFID tends to result in a greater benefit as the length of the supply chain where the technology is being used grows. The reason is that the investment into the RFID tags has only to be done once and, theoretically, the costs are split among all participants. Besides usual network effects, this is one reason that the greatest potential of RFID can be seen in cross-company applications. If the transponder is attached in those applications after the production, the realization of benefits will be restricted to processes in distribution, especially in logistical and retail processes. The main benefits of this cross-company application were on more efficient goods receiving and delivery processes. If RFID-tagged components are assembled to make a final product and new associations between the ID of the RFID tags and the product are set in the information systems, end products can also be identified. This way the same transponder can be used for all stages in the supply chain, provided it is technically feasible. However, the efficiency for each individual tag goes down if all of the components are tagged as only one tag is needed after the product is assembled. In the second case concerning Wellmann, only one component of the cupboard, namely the fronts as they are the most expensive, was tagged.

The degree of integration into the existing IT infrastructure of the participating companies is low, similar to the described applications in Section 2.1.2. At the site of the logistics service provider, only the handling processes for printing the RFID labels had to be changed. At Wellmann, the process for incoming goods had to be adapted. Because of the already existing identification of individual items, neither the formats for the electronic data exchange had to be changed, nor was access to the single read events in the business partner's information systems necessary. Furthermore, both companies that participated in this cross-company RFID application already had a very close relationship. Taken all aspects mentioned together, this case study fits into the first category of applications regarding the developed framework in Section 2.1, in which the technological requirements and standards for an RFID introduction is mature. Eventually, it is up to the participating companies to decide whether to use them or to use individual solutions, such as the ones the companies in the case study used.

For the other category of RFID applications from the framework (Figure 2.1), the following development path for the future can be determined. As the practical examples show, a standardized infrastructure for the discovery and processing of RFID read events on the item level and the integration of this data into existing information systems is of enormous importance for future applications. One piece for this infrastructure is the EPCIS Discovery Service, which is currently under development. Beyond that, application specific standards or best practices have to evolve, e.g. for supply chain event management and against product counterfeiting.

This case study described the optimization of the order processing between the kitchen furniture manufacturer Wellmann and its logistics service provider with RFID technology. The order processes are so general that they are not only valid for the kitchen furniture industry, but also for other industries. Specifically, companies that are interested in introducing a cross-company RFID application can benefit from Wellmann's experiences in integrating RFID into the existing electronic data exchange.

In the second case on storing data on RFID tags, we explained the various reasons why a hybrid approach between data-on-tag and data-on-network is appropriate for Wellmann. As they are using RFID technology in a cross-company application, standards become important. While EPCglobal standards provide an appropriate solution for the data-on-network approach, a standard for the data-on-tag concept was missing. In this case study, we have shown that using ISO 13584 as described in Section 3.4 is a suitable approach. We started by explaining how the properties were extracted from the existing information models. For the processes under consideration, all necessary data could be transformed into independent, dependent and conditional properties. Thus, at least for this application ISO 13584 is appropriate.

The next steps for a successful implementation of ISO 13584 consist of standardizing those properties that have not yet been included in the DINsml property dictionary. Subsequently, and after gaining experience with RFID technology, the scope of the application will be expanded. Although we used a single case study approach in a very specific industry, the goal of using ISO 13584 is that the approach can be used for all other industries and RFID applications.

Chapter 5

Conclusions

RFID technology promises to improve a broad range of processes in supply chain management, so this is why the attention of researchers, practitioners and politics is still persevering; however, the market acceptance of RFID is developing slower than expected. Previous research on RFID adoption found several aspects that might explain this. These include high investment costs; uncertain and missing benefits; and missing standards among others. The focus of most of those studies was on RFID technology in general, which is why the first part of this thesis dealt with the question of factors that are perceived to influence the adoption of *cross-company RFID*.

The results of our cross-sectional study with 153 participants showed that the impact of all factors considering costs and benefits was statistically significant. These cost-benefits factors include the expected overall profitability of RFID across the supply chain; the uncertainty of costs and benefits; and the asymmetry of profitability. In contrast, the influence of the considered organizational factors could not be proven. This indicates that the existence of a powerful player; the existence of an RFID instigator; and the extent of RFID experience in the supply chain may be overrated in the given context – at least in direct comparison to cost-benefit factors.

Based on these results, we recommend that future non-technical RFID research should focus on effective and more reliable ways to estimate and measure RFID costs and benefits across the supply chain and to share costs and benefits in an incentive-compatible way. We delved into the latter aspect and explained why the sharing of cost and benefits is particularly important for RFID applications: the benefit generated by a network technology such as RFID is related to the diffusion of the technology among the participating partners. Often, the overall success of applications depends on the participation of a single player. For an economically reasonable decision, the benefits of each participating company have to be higher than the investment and operating costs. Since the distribution of costs and benefits usually is not economically equal, the necessity of redistribution arises.

Against this background, we elaborated on the concept of *cost-benefit sharing*. For the design of a cost-benefit sharing model, influencing factors – such as the power structure or the progress of the technology – have to be kept in mind. Since the benefits of an RFID deployment are difficult to forecast, the reliability of ex-ante calculation is low; hence, a cost-benefit analysis has to be conducted several times during the rollout. The rollout should be structured into phases: the pilot, the run-up and the transition to the operational environment. The design of the cost-benefit sharing changes from phase to phase. The analysis of the case of Gerry Weber has shown that in the pilot phase a combination of tangible and intangible measures are preferred. In the run-up phase each partner has to contribute financially. In the final phase, partners get paid for RFID-related services and profit from intangible compensation measures, such as the assistance in site assessment and technology selection or the sharing of information.

The second part of this thesis dealt with the technical challenges related to the use of RFID in supply chain operations, in particular with the often criticized lack of technical standards for RFID. While the main argument of using standards in local applications is future proofing it against technological changes, the relative importance of hardware related standards is declining in cross-company systems; instead, the importance of standards for the exchange of RFID data is increasing. The industry consortium EPCglobal and associated research institutions have developed a stack of standards for the Internet of Things: objects that are equipped with an RFID tag that contain an EPC are identified at several steps in the supply chain and information about the movement of these objects (things) can be accessed via the Internet. This thesis explored three open problems on different layers of the EPCglobal architecture: the management of context data, the application layer and the option to store additional data on RFID tags.

This thesis presented an in-depth analysis of the requirements for event capturing applications. Our results show that the connection between the different data sources required to generate EPCIS events is very demanding. The required data ranges from rather static process descriptions to highly dynamic state signals from the physical infrastructure. We have detailed the specification of the ECA by providing the required interfaces, data model and event assembly algorithm. To demonstrate the correctness of our specifications, we have developed a prototype that implements them and tested it in our RFID laboratory. The architectural layers interacting with our ECA prototype were represented by solutions accepted in the market (CrossTalk and Fosstrak) in order to assure its usability. Experiments showed that, in connection with the mentioned software components, our developed prototype has sufficient performance.

The adoption of the RFID-based Internet of Things in general and specifically the EPCglobal network can only take place if business applications can be realized based on it. We presented a business application for Supply Chain Event Management for the short-term decision support in dynamic multi-organizational business environments. This work represents the first attempt to realize SCEM applications based on EPCglobal's specifications. Beyond that, we analysed whether the current proposal for the distributed system architecture of the Internet of Things is suitable for SCEM applications. Based on three quantitative criteria, we came to the conclusion that an alternative approach based on the idea of pushing EPCIS events downstream is the preferable choice. This result was confirmed with some qualitative advantages of the latter architecture, such as taking advantage of existing business relationships in the supply chain and not requiring a central authority for data management and authentication.

The concept of storing only an EPC on the RFID tag and all object-related data in an external database is the foundation of the EPCglobal network. Some use cases can demand additional data to be stored on the RFID tag. A standard for this data-on-tag concept was missing. In this thesis, we recommended using ISO 13584 for the standardized storage of data on RFID tags. A standard in general contributes to the harmonization of interfaces between heterogeneous systems and, for this reason, increases interoperability, data quality and reduces data redundancy. The properties in our approach are precisely defined according to the ISO 13584 data model, which includes language independent verbal definitions as well as additional information regarding units, data types, etc. We showed that using ISO 13584 is a suitable approach for the data-on-tag concept by presenting a case study from Wellmann. In this case study, we explained how the properties were extracted from the existing information models; thus, ISO 13584 is appropriate at least for this application. Although we used a single case study approach in a very specific industry, the goal of using ISO 13584 is that the approach can be used for all other industries and RFID applications. This is because using ISO 13584 implies following a bottom-up approach. With properties, small pieces of information are standardized and can be applied to different circumstances. Other standardization initiatives (e.g. AIAG and VDA in the automotive industry) can create their own standards for certain applications (e.g. container management and theft prevention) based on their own standardized properties that follow ISO 13584.

This thesis dealt with selected organizational and technical factors that were identified as essential for the adoption of RFID technology in cross-company applications. Another aspect that should not be completely disregarded in this context is the concept of trust and power constellations among supply chain participants – although this aspect did not turn out to be a significant factor for a successful introduction of RFID. On the technical side, securing data access in the Internet of Things is a still unsolved problem, which is currently being investigated by researches and standardization bodies.

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Selbständigkeitserklärung

Ich bezeuge durch meine Unterschrift, dass meine Angaben über die bei der Abfassung meiner Dissertation benutzten Hilfsmittel, über die mir zuteil gewordene Hilfe sowie über frühere Begutachtungen meiner Dissertation in jeder Hinsicht der Wahrheit entsprechen.