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RFID-BASED INDIVIDUALIZATION OF EXTENDED PRODUCER RESPONSIBILITY AND RECYCLING FOR WEEE

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Abstract

Recycling of ICT and other electronic products is gaining in importance due to both ecological and economic reasons such as the shortage of resources contained in electronic devices. European legislation has handed the responsibility for recycling electronic products to the producers. However, the WEEE directive (waste electrical and electronic equipment) and its national transpositions have been criticized for failing to reach the original goal of promoting design for recycling. In this paper we analyze how detailed object-related information can support recycling processes. We propose a distributed RFID-based waste management information system for electronic devices which enables individualizing producer responsibility but also supports other goals of waste management by providing detailed object-related information. We first analyze deficiencies in current practice and then conduct a requirements analysis for the proposed system. Based on this we create a system design model, consisting of data and object model and system architecture.

1 Introduction

The environmental impacts of the use of information and communication technology (ICT) are getting increased attention by research and practice in recent years. A multitude of terms have been coined to describe research and practice activities in this area such as *Green IT*, *Green IS* or *Sustainable Computing* (Ijab et al. 2010). A consensus regarding the definitions of these relatively new concepts has not yet been reached in the scientific literature. One major difference of the definitions corresponds to the scope of these concepts: Whereas some authors limit Green IT to minimizing negative environmental impacts of IT infrastructures (Murugesan 2008, Watson et al. 2010), others define the term more broadly, also incorporating the use of information systems for environmental purposes (Molla et al. 2009, Murugesan 2010). The latter is sometimes referred to Green IS, but some authors consider Green IS to deal with maximizing positive impacts as well as minimizing negative environmental impacts of the use of IT (Watson et al. 2010, Dedrick 2010).

Regardless of these differing definitions, two major areas are of interest when analyzing environmental impacts of IT: IT infrastructures can be the subject matter of research with the objective of minimizing energy consumption, emissions and waste, or IT can be seen as an enabler for green processes. Clearly, these sets are not disjoint. The research we present in this paper belongs to the intersection of these sets, which deals with using IS in order to minimize negative environmental impacts of IT infrastructures.

More specifically, we focus on the recycling of ICT waste and other WEEE (waste electrical and electronic equipment) and propose an RFID-based information systems supporting waste management processes. We refer to the goals of WEEE regulation and point out ways to support these by using object-related information obtained by RFID. Special emphasis is given to the concept of producer responsibility, which in its current implementation in European systems for WEEE recycling fails to meet its original goals (Lindhqvist and Lifset 2003, Sander et al. 2007, Roller and Führ 2008). Several authors have proposed RFID-based systems as remedy for these shortcomings (see Section 2), however, a detailed system concept for an integrated RFID-based WEEE recycling information system is lacking, which we address in this paper, following the design science approach (Hevner et al. 2004).

The rest of the paper is structured as follows: in Section 2 we briefly summarize related research in the context of RFID and WEEE recycling. We then elaborate on the concept of producer responsibility in more detail and discuss current implementations in Section 3. Requirements analysis and system design of our proposed system is described in Section 4 and evaluated in Section 5. The paper ends with a brief discussion and conclusion in Section 6.

2 Literature Review

The use of RFID to support logistics processes with detailed object-related information has been analyzed extensively (e.g. Gaukler and Seifert 2007, Baars et al. 2009, Sarac et al. 2010). Benefits of RFID applications along the entire supply chain have been the subject of research and practice. Some works, however, also go beyond the traditional supply chain by addressing the post-usage phase of products tagged with RFID. Some articles analyze potential negative impacts of widespread item-level RFID on waste management (i.e. RFID transponders as electronics waste which cannot be treated separately but could contaminate other waste streams and disturb existing recycling processes, e.g. Kräuchi et al. 2005, Schapranow 2010). There are also quite a few articles dealing with benefits of RFID-based information in waste management application scenarios: One of the early contributions in this area is by Saar and Thomas (2003). They broadly point out several ways to increase the efficiency of recycling processes using barcode and RFID tags. Dubovska-Popovska et al. (2010) discuss RFID in support of Green Supply Chain Management. Some articles deal with concrete potentials in more detail: Parlikad et al. (2003) analyze requirements for object-related information in the context of reuse and recycling of end-of-life products. Kulkarni et al. (2005) discuss the same topic in more detail. In their article, the authors present two case studies dealing with electronics product recovery

and point out the benefits of object-related information provided by RFID-based information systems. Dörsch et al. (2005) and Khan et al. (2006) propose a system for the support of product recovery decisions of vehicle components based on embedded sensor-equipped RFID tags. Parlikad and McFarlane (2010) analyze the value of RFID-based information in vehicle component recovery. Kulkarni et al. (2007) assess the value of RFID in remanufacturing using an analytical single period product remanufacturing model. Binder et al. (2008) focus on the application of RFID to support waste management of batteries and electrical appliances in Switzerland. They assess the benefits of an RFID-based sorting system for these types of waste using material flow analysis and multi-criteria assessment. Luttropp and Johansson (2010) propose an RFID-based recycling information system for household electronics. Several articles discuss RFID in the context of producer responsibility concepts. Most of these propose RFID-based systems for the individualization of collective systems implementing the WEEE directive (e.g. Hicks 2005; Butz 2007; Roller and Führ 2008; Kuhnhenn and Urban 2006; Daniel and Tadatomo 2007).
Although RFID has been recognized as a possible means to enable individual EPR and support recycling of WEEE, a detailed system design of an integrated RFID-based EPR and recycling support system has so far not been proposed. It is this research gap that we address in this paper.

3 Extended Producer Responsibility: Legal Concept and Current Implementations

The principle of extended producer responsibility (EPR) specifies that producers are responsible for the disposal and recycling of the products that they market. This can either be done on an individual basis (each producer is directly responsible for his own products) or collectively (each producer is responsible for a share of the total amount of products, e.g. according to market share). EPR legislation aims at two things (Lindhqvist and Lifset 2003). First, producers should pay the disposal costs in order to relieve government budgets. Furthermore, recycling is to be improved by giving producers an incentive to produce less waste and to design their products to be recycling-friendly and to contain less pollutants. Whereas the first goal can be reached with both individual and collective ER schemes, reaching the second goal in a collective scheme is difficult due to missing incentives for producers to adopt design-for-recycling.
The application of the EPR-principle on the recycling of waste of electrical and electronic equipment (WEEE) in the EU has been discussed since the early 1990s (Cooper 2000, Lindhqvist and Lifset 2003, Castell et al. 2004). Directive 2002/96/EC for electronic and electrical waste was passed in order to harmonize upcoming regulations in the member states. It came into effect in 2003 and stipulates that member states are obliged to establish recycling systems financed by producers. However, the directive only states the goals and framework and member states remain free in how they implement this into national law: “In order to give maximum effect to the concept of producer responsibility, each producer should be responsible for financing the management of the waste from his own products.” However, already the next sentence relativises this: “The producer should be able to choose to fulfil this obligation either individually or by joining a collective scheme” (Directive 2002/96/EC, Recital 20). The result of this freedom in designing national EPR-systems is that most member states have created collective instead of individualized producer responsibility for electronic waste (Sander et al. 2007, Van Rossem et al. 2006). Thus, the individual producers do not pay for the products they sell, but a recycling system is financed collectively. The case of Germany is an example for a collective transposition of the directive. In this paper, we use the German transposition of the WEEE directive as the starting point for our system design. However, as similar systems are in place in other EU countries, adaption to other national systems is possible. In Germany, the Law on Electronic and Electric Products (ElektroG) came into effect in 2005. This law implements both the WEEE directive and EU directive 2002/95/EC on the restriction of the use of certain hazardous substances (RoHS). The ElektroG allows for collectively implementing the EPR, which is also done in practice. Electronic waste is collected at municipal collection points. The appliances disposed of here are roughly separated in containers according to five categories. Beyond this point, producers are collectively

responsible for financing the collection and recycling of the waste. The financing of this system is monitored by a clearing house (‘Elektroaltgeräteregister’, registry for electronic waste, EAR). The share of costs that an individual producer has to pay is not determined by the actual waste and resulting costs, as identification is too complex (Roller and Führ 2008). Instead, the costs are distributed according to market shares. The alternative option granted by the ElektroG (sampling and manual identification of WEEE) is hardly used as it is costly. The result is a system which does not create incentives for individual producers to develop products that are more recycling-friendly.

4 RFID-based Individualized EPR and Recycling System for WEEE

The system concept is based on attaching RFID-transponders on electric appliances (during production) and on creating a network of data collection points within the chain of waste disposal in order to improve recycling via object-related information. In the following, we will examine requirements and present the system design. The system design is modelled using the object-oriented language UML (Unified Modeling Language). Due to the page limitation, we can only present a brief overview of the system’s structure and only simplified examples for the interaction and behaviour of the systems components. The complete object model is much larger and contains approx. 70 classes and dozens of sequence, activity and state machine diagrams.

4.1 Requirements Analysis

This Section gives a brief overview of functional and technical requirements for the proposed system. The functional requirements are derived from the goals of general and specific waste management legislation, such as the Council Directive 75/442/EEC of 15 July 1975 on waste and the WEEE directive on the EU level and their German counterparts, the ‘Kreislaufwirtschafts- und Abfallgesetz’ and the ‘ElektroG’. Regarding the technical requirements, we focus on application- and domain-specific aspects; general requirements such as scalability, response time etc. are not discussed here.

4.1.1 Functional Requirements

The designed system focuses on the following functions:

- Individualization of producer responsibility by billing producers for the actually incurred recycling costs for their products
- Facilitation of recycling through detailed and recycling-relevant product data
- Promotion of reuse of products and/or components

The results of the use case analysis are summarized in Figure 1.

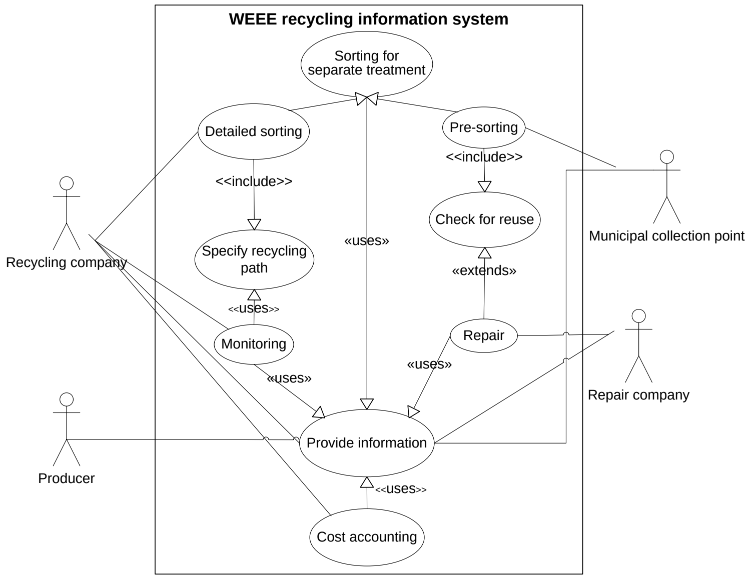

Figure 1 Use case diagram for the proposed system

Providing information is a necessary precondition for the successful implementation of the other use-cases. Repairs made during the usage phase must be recorded in the product history. Authorized repair services therefore need access to the data in the producer's information system. Repairs can also be carried out during the disposal phase. This allows for recycling of the entire appliance or its parts. The other use-cases are specified with a use case template (Table 1).

Use case (main actor)	**Aim**	**Activating event**	**Description**	**Extensions**
Pre-sorting (municipal collection points)	Automatic sorting including inspection of reutilisation, transport of old appliances to the respective collection container, updating of the signal to the EAR	Arrival of the device at the municipal collection point	Access master data, determine collection group, access product history and reutilisation criteria, inspection of reutilisation, locate collection container, transport device to container, documentation	Inspection of redistribution activity, inspection of self-marketing, report to EAR
Detailed sorting (recycling company)	Automatic identification and documentation of the recycling-path, including dismantling instructions	Arrival of the device at recycling company	Access master data and product history, determine requirements of recycling systems, documentation	---
Cost accounting (recycling company)	Automatic calculation and allocation of disposal costs, costs per device, update of cost charges per producer	Arrival of the device at recycling company	Access master data, track basic costs and cost changes, calculate disposal costs, update producer cost charges	---
Monitoring (recycling company)	Automatic update of notifications to producers on disposal amounts	Determine the device's recycling-path	Access and analyse data, determine system input, determine system output fraction and weight, calculate amounts recycled, search for and update corresponding notifications	Forward notifications to producers

Table 1 Use case specification

4.1.2 Technical Requirements

The technical requirements result from the implementation of the functional requirements examined in Section 4.1.1 and from the operation conditions. The parameters and capacity features, such as the working frequency, installation place, reading range and power supply are the main focus. The material of the device case and the place where the transponder is fitted strongly influence the reading quality. It is advisable, if possible, to attach the transponders inside the device's case in order to make it more robust. This requires different laboratory tests for each type of device which determine the optimal position. Metal cases are a challenge because of shielding effects. In this case, weaknesses in the shield have to be determined and/or special tags have to be used with an antenna-design allowing for reading under these circumstances. Furthermore, the RFID transponder has to last and be readable beyond the device's end of life. As there may be decades between the production and disposal of a device, robust tags have to be chosen, which do not require batteries, but acquire their energy solely from the reading device (passive tags). Longevity of electronic devices also affects aspects of standardization: Even after 20 years, different companies still have to be able to read, understand and process the transponder data. The EPCglobal infrastructure is used for the utilization of established standards with regard to the transponder and reading infrastructure, as well as data storage and exchange. A four-layer-model is chosen for the exchange of data within and between companies: infrastructure level (hardware-components and hardware infrastructure for pre-processing of data), integration level (collecting, compressing and analysis of data and integration of RFID in existing systems), application level (usage and processing of information for the support of business processes) and network level (internet based platform which expands the existing internet infrastructure by different standardized services).

4.2 System Design

The system design is presented with the help of the following models: the data model roughly specifies data requirements and points of data collection. The subsequently presented object model is developed using UML. It specifies the system structure and behaviour in detail. The technical system architecture is presented at the end of this section.

4.2.1 Data Model

A mixed approach of data-on-tag and data-on-network is chosen for the dispersal of the object-related data in the RFID-system (Diekmann et al. 2007). The tag standard EPC Gen 2 is chosen. A Serialized Global Trade Item Number (SGTIN), which uniquely identifies the electronic device is stored on the transponder. Furthermore, in order to meet the legal duty to supply information, a reference is stored on the transponder to the so-called recycling passport as a Global Document Type Identifier (GDTI). This recycling passport transmits article-specific recycling data (see below). All other object-related data are stored in the network in order to enable data access without the objects presence.
The following master data are necessary and are partly stored redundantly in the databases of the parties:

- Company data: EPC manager (access key), contact data and optional further information of each relevant party.
- Article data: contain the EPC's object class (access key), the producer's EPC manager, article description, device category and device type.
- RFID reading device data: include reading device number (access key), location, EPC manager of the producer responsible for the operation and administration of the reading device.
- Recycling passport: GDTI is used as an access key. In accordance with (PAS 1049) the recycling passport contains recycling information such as disassembly information, structure of the device, hazardous materials, measurements and graphical depiction, etc.
- Component data: includes GTIN (access key) and characteristics. The component is described with the aid of the properties that are deposited in the IEC 61360 Data Base.
- Substance data: the list is created according to the specifications of the EICTA (European Information, Communications and Consumer Electronics Industry Technology Association). It contains the ID number (access key), the name of the chemical substance, usage limitations, harmfulness to the environment or to humans.

Data sources and collection points are now analyzed along the process chain: The producer is the most important data source of the system. He generates recycling passports and is responsible for creating, monitoring and saving the product histories of each electronic device. The information given by suppliers in the form of component recycling passports, as well as internal information sources such as CAD, ERP and PDM systems are of great importance for generating recycling passports. The product life documentation begins with equipping the electronic device with an RFID tag. Right after the transponder is put into place, the first RFID data are read out by a reading device which is integrated into the installation complex. This data is augmented with further information such as the reading device number and time of reading, and then entered into the product history. Further entries important for the disposal process are collected with the aid of repair services, which have authorised and limited access to the database of product histories. The repair services are equipped with mobile RFID reading devices. The identification of the defective component, the spare parts and the utilised connection method are added manually to the collected data and transferred to the producers.

The municipal collection point is equipped with an RFID reading station and a conveyer belt. The conveyer belt transports the discarded electrical appliance across the RFID reading station to identify the appliance. The read RFID data make it possible to retrieve corresponding article data and to access the product history (synchronously – pull-service or asynchronously – push-service). The information thus retrieved allows identifying the corresponding device category, checking the device for reusability and updating the corresponding collection registry.

Upon arrival at the recycling company, the discarded electrical appliances are identified by an RFID gate reader. Identity data are then augmented with the accessed master data, evaluated and processed in order to fulfil the company's tasks. Producer-specific cost accounting is one issue. The information on the article makes it possible to assign it to a disposal cost class which determines the basic costs for the devices. Criteria relevant for recycling such as joining techniques, disassembly-friendliness and the need for selective treatment, material mix etc. influence the calculation of additional charges or reductions. This information is available to the first handler via the recycling passport shortly after the device is introduced in the market. The recycling passport, the product history and the information on the up-to-date recycling methods are needed for establishing the optimal recycling path including the creation of disassembling instructions. Once the recycling path has been established, the monitoring function related to the amount of recycled material can be realised. For this task the same data as for the establishment of the recycling path are needed.

Another data collection point is located at the disassembly station. It is equipped with a mobile RFID reading device and work station. The appliance is identified when it comes to the disassembly point. The SGTIN allows to retrieve the corresponding disassembling instruction and to display it on the screen. In the case of automatic disassembly, a disassembly algorithm is used which steers the work of the disassembly robots (Kuhnhenn et al. 2006).

4.2.2 Object Model

The distributed IS consists of three types of packages (see Figure 2). The package 'producer' represents the subsystem at the producer and includes two more packages containing the classes required for the fulfilment of the producer tasks. The package 'Document object life' imports the recycling passport from the package 'Create recycling passport'. The recycling passports created at the producer and the product history are needed for the other subsystems, which are installed at municipal collection points or recycling companies. The package 'Sorting', containing the classes responsible for the automatic sorting, is at the centre of the package 'Municipal collection point'. However, the discarded electronic product has to be checked for reusability before a decision on sorting can be made. For this purpose the classes of the responding packages have to be used. The results of the sorting are passed on to the collection registry which also administrates the reports to the EAR. The last subsystem contains three packages which are needed to fulfil the tasks assigned to the recycling company. This is the package 'Cost accounting' providing classes to automatically create the producer-specific cost sheet. The classes of the package 'Disposition' determine the recycling path of the appliance. In a last step, the amount of material to be recycled has to be established on the basis of the recycling path identified. The package 'Monitoring' is available for this step; it allows determining the recycling output using the classes of the package 'Calculation Tool' and take them into account in the relevant report (package ‘Reporting’).

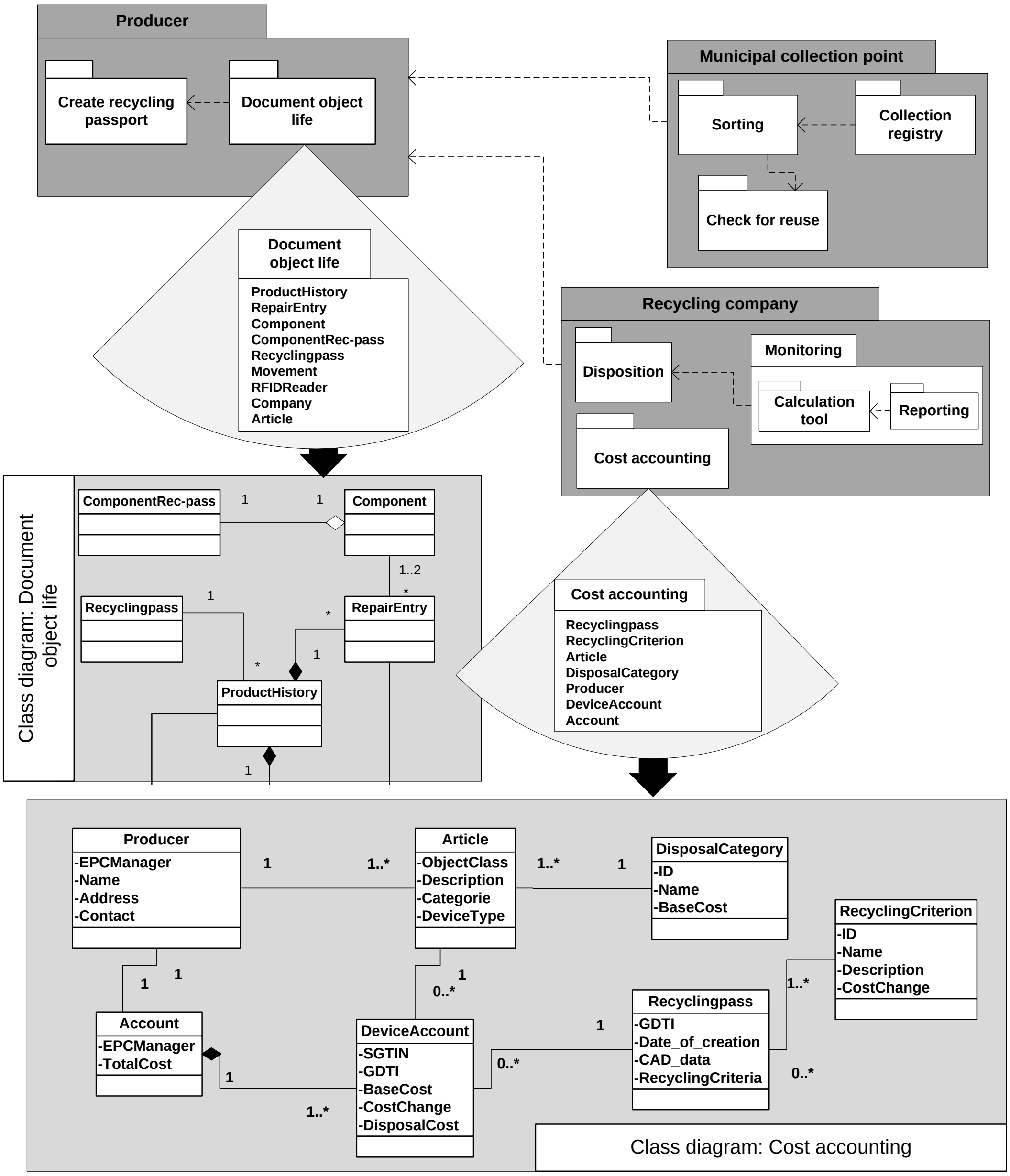

Figure 2 Package diagram of the system

Figure 2 does not only show the individual packages, but also the more refined break-down into classes for selected packages. The class ‘Product History’ (package: Document object life) is at the centre of the creation and maintenance of a product history; it encompasses instances of more classes such as movement, article and repair entries. Movement includes the RFID data that were read and enhanced during production, while repair entries are created during the usage phase. Figure 3 shows which instances are accessed and in which sequence they are accessed. The package 'Cost accounting' contains several classes. The most important ones are ‘Device account’ containing the disposal costs of the individual appliance and ‘Account’ calculating the overall disposal costs. The class ‘Device account ' has two important attributes for calculating the disposal costs: basic costs and cost changes. Both attributes can be determined using the accessed master data mentioned above (article data and recycling passports). Figure 2 shows the corresponding class diagram on a highly abstract level. Figure 3 shows the interactions between the instances of the classes over time.

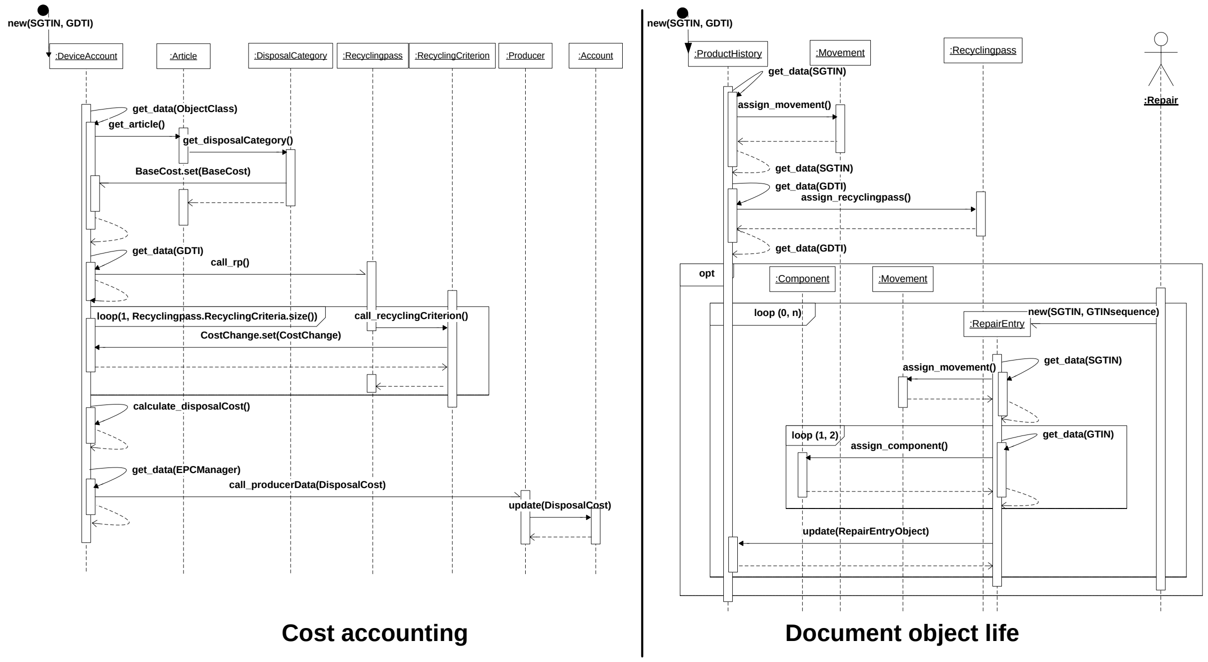

Figure 3 Selected sequence diagrams

4.2.3 System Architecture

The technical system architecture is based on the four-layer model presented in Section 4.1.2. The infrastructure layer includes read/write units (producer), RFID-gates (municipal collection point and recycling company) as well as mobile handheld reading devices (repair shop). Furthermore, there are the device-controllers connecting the hardware components with the software components. RFID middleware provides a bridge between the collection of RFID data and their integration into business processes. It does not only serve as an interface, but it also receives and processes business data provided by the device-controller to feed into the applications.

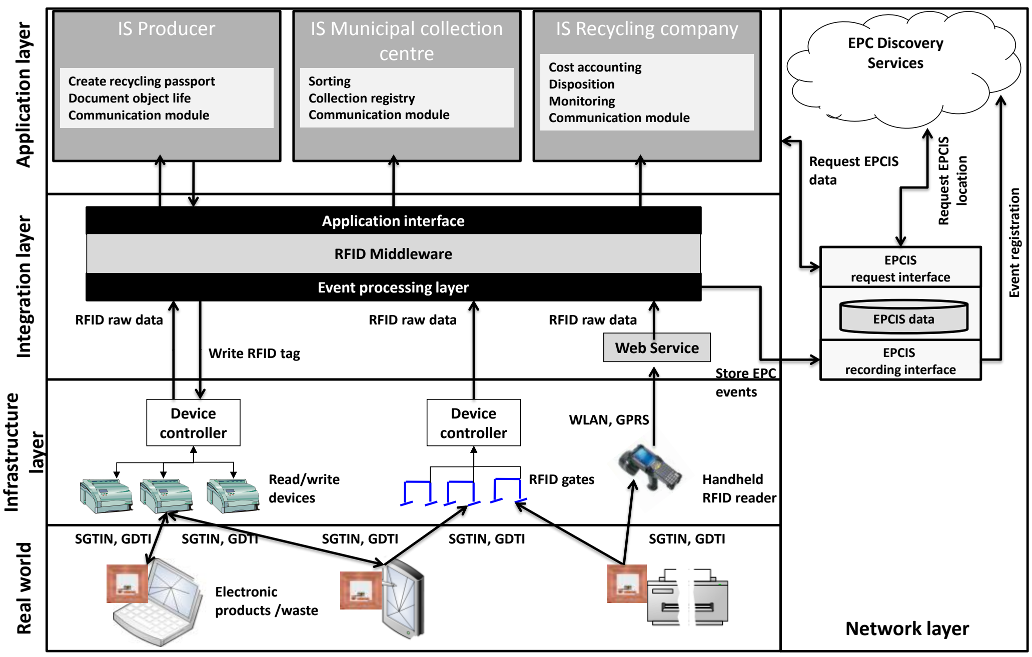

Figure 4 System architecture

The enhanced RFID data (events) are stored in the EPC Information Services (EPCIS). EPCIS also ensures the connection of companies to the EPCglobal network. Through the information retrieval interface, data can be provided to internal company applications and network participants. Other important components of the EPCglobal network are EPC Discovery Services, enabling the network participants to locate the EPCISs which store the required information. The nodes described in chapter 4.2.2 belong to the application level. The packages of the individual nodes shown in Figure 2 represent the most important system modules. However, for each participant, a communication module has to be added providing the procedures for communication with the authorities and other participants. Figure 4 shows the system architecture of the designed system.

5 Evaluation

According to Hevner et al. 2004, evaluation is a crucial component of the design science process in IS research: "The business environment establishes the requirements upon which the evaluation of the artifact is based. […] evaluation includes the integration of the artifact within the technical infrastructure of the business environment" (Hevner et al. 2004). Accordingly, we evaluated our system concept with regards to the business environment (functional requirements) and the technical infrastructure (technical requirements). A brief summary of this evaluation analysis is presented in Table 2, containing the most important requirements, their implementation in our concept and respective challenges/prerequisites.

Requirement	Implementation	Challenges / Prerequisites
Functional requirements		
Pre-sorting at municipal collection points	Implementation completely conformable to law; goes beyond legal requirements with regards to sorting for reuse	• Provision of demand data regarding used devices and/or components
Detailed sorting at recycling companies	Waste management processes are supported and documented automatically beyond legal requirements	• Information on recycling facilities, optional recycling paths • Detailed data regarding recycling costs and revenues need to be obtained • Data base for automated recycling decisions (e.g. recycling depth) needs to be set up
Individualized EPR / cost accounting	Implementation enables individualization of EPR, setting incentives for design for recycling	• Detailed data regarding recycling costs and revenues need to be obtained • Cost changes depending on recycling criteria have to be determined
Monitoring	System enables detailed monitoring data beyond legal requirements	• Data on recycling quotas
Technical requirements		
Parameters of the RFID system	EPC Gen2 UHF-WORM Tags, EPC Gen2 UHF-Reader	• Development of tags for domain-specific operating conditions • Testing of tag location inside the devices and tag performance
Standardization	EPCglobal specifications; PAS 1049; EICTA terminology; IEC 61360-1 to 6	• Uncertainty regarding adoption of PAS 1049 • Other Standards need to be developed, e.g. repair data format
Intra- and inter-company data exchange	Implementation of the four-layer model	• Cost-benefit analysis and distribution of costs • SaaS as an option for integrating small parties

Table 2 System evaluation

6 Discussion and Conclusion

Detailed object-related information and closely linked flows of material and information are the basis for control of all logistics processes in procurement, production and distribution of goods. In contrast, processes in reverse logistics and waste management are mostly not controlled by object-related data yet, they are unplanned, unwanted and remain largely uncontrolled. In the face of the rising significance of these processes and the shift of responsibility from municipalities to producers, IS for reverse logistics process control gain in importance.

In order to implement a system such as proposed in this paper, various issues need to be resolved: Cost and benefits of the system need to be analyzed. The costs of the RFID tags are considerable, would however for many electronic products only be a small fraction of the product's total production costs. Reader infrastructure costs for the distributed system are a more serious issue considering that thousands of municipal collection centres and recycling and repair companies would have to be equipped with RFID readers. Legal obligations and/or financial incentives would have to be established in order to achieve participation from all parties involved. Alternatively, the system could be implemented on a smaller scale with limited benefits in comparison to the complete system described in this paper. E.g. only a small set of approved collection centres could be equipped with RFID infrastructure or the identification of WEEE could be limited to the recycling facilities, thus leaving out the collection centres entirely. Data privacy and security are often sensitive issues when RFID tags on consumer products are discussed. It is often feared that unnoticeable reading of RFID tags may be used to identify and track people unknowingly. Whereas this fear is obviously unfounded for some categories of WEEE, such as desktop computers or washing machines, portable devices such as mobile phones may indeed be the target of unauthorized readings for potentially malicious purposes. Therefore, privacy measures have to be implemented, especially since optional permanent deactivation of the RFID tag after purchase of the tagged good (which is often discussed as a solution for RFID applications in distribution logistics) is not a viable solution for applications in waste management.

Although these challenges are severe, the growing importance of reverse logistics calls for research and practice to analyze how to better support these processes with IS. The recent growing pressure of e-waste challenges such as the shortage of precious metals and rare earth elements and the widespread illegal export of European electronic waste to Africa calls for future research to explore advances in technologies such as RFID in order to better control recycling processes.

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