Application of the Electronic Product Code EPC to the Product Lifecycle of Electronic Products

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Introduction

According to the Manufuture Strategic Research Agenda 2006[1], the market is increasingly in demand of a business focus which has shifted from designing and selling physical products to supplying a system of products and services ('product/services' or 'extended products') that are jointly capable of fulfilling users' demands, while also reducing total life-cycle costs and environmental impacts. The new focus calls for an integrated system that includes the entire lifecycle of creation, production, distribution and end-of-life treatment of products.[2] This is imperative in particular to the manufacturers of electronic equipment sold in Europe, upon whom increasing regulatory pressure is being applied to provide support for the recycling, reuse and refurbishing of their products. Especially the introduction of the European Community directive 2002/96/EC on Waste Electrical and Electronic Equipment Directive (WEEE Directive) together with the Restriction of Hazardous Substances Directive (RoHS Directive) 2002/95/EC force manufacturers to act with regards to lifecycle management in order to retain the profitability of these products. The directives, which were adopted into European Law in February 2003, oblige the EU member states to transpose their provisions into national law by August 2004. In Germany, for example, both directives have been implemented as national law *(Elektro- und Elektronikgerätegesetz - ElektroG)*, which regulates the restriction of hazardous substances and the end-of-life treatment for electrical and electronic equipment.

In this paper, the authors explore how Radio Frequency Identification (RFID) technology can be leveraged in combination with the Electronic Product Code (EPC) standard to provide full product lifecycle information management support for electronic products, with a focus on fulfilling the requirements set by the German implementation of the WEEE directive. This exploration is based upon the practical example of a real-life exemplary product which comprises of multiple, individually identifiable electronic components. It examines the design, development and deployment of an Electronic Product Code Information Service (EPCIS) based information management system and analyses how EPCIS Events can be used to model business processes along a product lifecycle. A prototypical solution for the exemplary product is presented, which represents one of the first EPCIS showcase

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[1] Manufuture SRA Executive Summary,
http://www.manufuture.org/documents/Manufuture%20SRA%20web%20version.pdf
[2] Hribernik, K.; Schumacher, J.; Thoben, K.-D.; Rabe, L. (2006). The Product Avatar as a Product-Instance-Centric Information Management Concept. International Journal of Product Lifecycle Management, Vol. 1, No. 4, pp.367-379.

implementations. The paper concludes with an evaluation of the described solution from both business and technical perspectives.

Applying EPC to the Product Lifecycle

In order to suitably explore the subject matter, a product was chosen which exemplifies the product information management challenges which arise along the lifecycle of electronic products. The product chosen is a computing device which consists of a number of distinctly identifiable electronic sub-components, each of which need to be dealt with individually when the overall product reaches its end-of-life phase. The device is designed to be deployed in terminals outside in urban areas.

The electronic product is comprised of a chassis upon which a mainboard, a processor, an ISDN modem, a mains unit, a display and a hard drive are mounted. Each of these components need to be handled separately in the end-of-life phase, thus dictating the requirement of an individual tracking and tracing of each component throughout the product lifecycle. Furthermore, the management of the aggregation of these components comprising the main product needs to be taken into account, allowing for the management of parts replacement and maintenance in the middle, usage phase of the product's lifecycle.
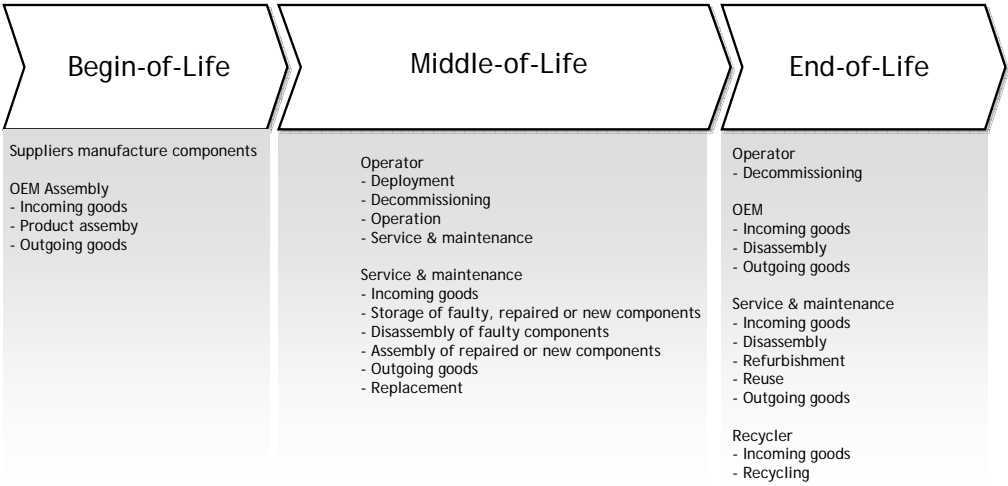

Figure 1: Lifecycle of the Exemplary Electronic Product

The product lifecycle is by nature a dynamic cooperation across organisational borders, as shown in Figure 1 above. The overall unit is commissioned by an Original Equipment Manufacturer (OEM). Each of the components is manufactured by different enterprises, and then the product is assembled by at a subcontracted assembly plant, and deployed and maintained by the operator and subcontractors. Finally, according to the WEEE requirements, the product needs to be taken back by the OEM or a subcontracted disposal service provider, dismantled, and the component parts recycled, reused or refurbished respectively. It follows that any tracking, tracing and information management of the product along with its component parts needs to take place in a standardised, flexible and platform independent manner.

In this respect, RFID in combination with EPC and especially EPCIS offer a suitable solution. Each of the component parts can be assigned a unique identifier (an EPC), which, stored on an RFID chip applied to each component part, can be used to track and trace the product components throughout the lifecycle. EPCIS is a specification for a standard interface for

accessing EPC-related information. On its basis, each individual object can be tracked independently and real-time information about each individual object can be collected, stored and acted upon. By providing a standard interface to that information, EPCIS enable cooperation partners to seamlessly query such information throughout the supply chain and product lifecycle. This leads to an increased product information transparency throughout the lifecycle, despite the individual organisations storing product-related information in decentral and heterogeneous information systems.

An Introduction to EPCIS Events

This section describes the event concept proposed by the EPCIS specification, and takes a look at each individual event type.

EPCIS Events

The specific EPCIS Events described below all inherit the basic structure of the parent EPCIS Event according to an Object Oriented concept.

Object Events

Object Events represent the simplest type of EPCIS event, and are used to capture and communicate information about EPC tagged objects. It can, for example, be used to document that a specific object has been read at a specific position and time, or capture changed to the status of that object.

Aggregation Events

Aggregation Events are used to document events in which an object identified by an EPC is brought into relation with a number of other such objects. In the example presented in this paper, it is used to capture which component parts of are installed into which overall product. It can be used to both create and destroy such relations.

Quantity Events

Quantity Events can be used to document events which influence a set of objects which can be identified as belonging to a common class. An example for such an event could be the change of price for an entire assortment of products. This event was not found to be applicable to the processes outlined in this paper.

Transaction Events

Transaction Events can be employed whenever an event triggers a business transaction. The mapping of these events is facilitated by means of a business transaction list, which is a core element of the suggested specification of this event.

Mapping the Product Lifecycle to EPCIS Events

The following sections illustrate how EPCIS events can be utilised to provide seamless tracking and tracing of products and their subcomponents throughout their entire life-cycles.

Begin-of-Life

For the begin-of-life phase of the exemplary product's lifecycle, this paper's examination begins with the process steps taking place at the Incoming Goods of the enterprise subcontracted to carry out the assembly of the product, as illustrated in Figure 2.
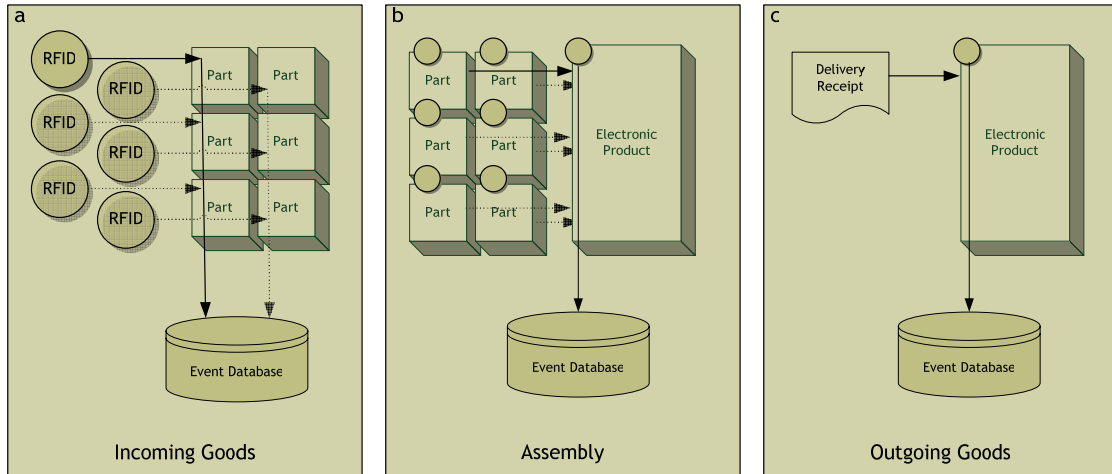
Figure 2: Assembly

Here, in *Incoming Goods* (a), the individual product parts which arrive at the assembly plant are inventoried according to their serial numbers. During this process, EPC-compliant RFID tags are attached to them, the tags are read and the respective EPCs mapped to the serial numbers and stored in the event database. This takes place by communicating an EPCIS "Add" event to the Capture Operations interface. The individual product parts which are thus inventoried are a mainboard, a processor, an ISDN modem, a mains unit, a display and a hard drive. The chassis is tagged with an EPC-compliant RFID just like the individual product parts. Similarly, an EPCIS "Add" event is communicated to register this action.

The next relevant event in the assembly process take place when the product parts are installed onto the product's chassis, as shown in Figure 2 (b). The assembly personnel take each part and manually install them into the chassis. During the installation procedure, the tag on each part is read, followed by the chassis tag. An EPCIS "Aggregation" event is generated, which logically links the EPCs of the product parts to the chassis EPC. From now on, the chassis EPC can be used as the superordinate identifier for the entire product.

After the completion of the product's assembly and the product is to be delivered, it is moved into the *Outgoing Goods* process of the assembly plant. A delivery receipt is created for it and is mapped to the product by reading its superordinate EPC. An EPCIS "Observe" event is generated in which the product's status is changed to reflect the progress of the delivery.
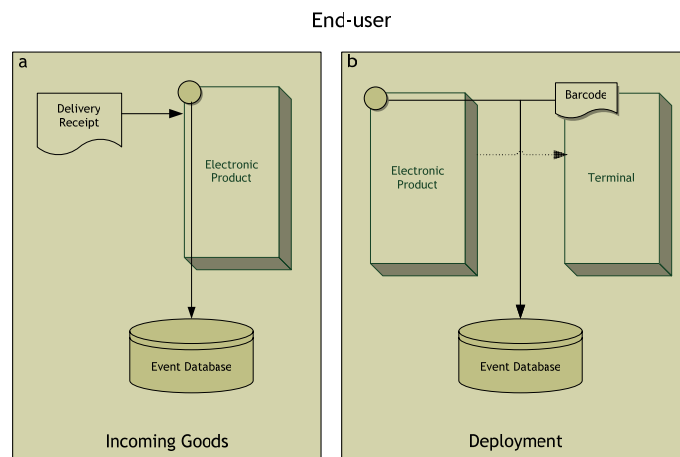

Figure 3: Events Generated by the End-User

As soon as the product is delivered to the end user's Incoming Goods (as shown in (a) of Figure 3), the physical delivery receipt is cross-checked against the data mapped to the superordinate product EPC. This requires reading the product's superordinate tag and checking the event data which was communicated in the assembly subcontractor's *Outgoing Goods* process step. If the delivery is complete and acceptable, the product is moved into the next process step.

Here, the product is readied for deployment into the end-user's terminals. Each of these terminals is identified by means of a unique barcode. The physical coordinates of the terminal are mapped to this barcode. By additionally mapping the superordinate EPC of the product to the barcode, the terminal into which the product has been deployed as well as its physical position can automatically be identified. This mapping is done by generating a further EPCIS "Observe" event, in which the barcode of the terminal is stored as the *read position*. Furthermore, the status of the product is changed to "deployed" in the event data. A combined EPC-compliant RFID-reader with a built in barcode reader is required to for registering the necessary information during deployment. Alternatively, the barcode identification can be input into a hand-held RFID-reader by the deployment personnel. This operation is illustrated in Figure 3, frame (b).

Middle-of-Life

After the product has been deployed into the end-user's terminals in the field, the beginning of its life has come to an end. With entering its usage phase, the product is now in the middle of its life.

The most common process in this phase of the product's lifecycle is maintenance. In this process, several modifications can be made to the overall product which need to be tracked. These modifications may entail the exchange of specific product parts or indeed the replacement of the entire unit. In order to provide seamless tracking and tracing of the product's and its component parts' stati throughout the entire lifecycle, EPCIS events need to be defined which are capable of capturing such changes.

Replacement parts are kept available in a service subcontractor's warehouse as well as at the end-user's own maintenance department.
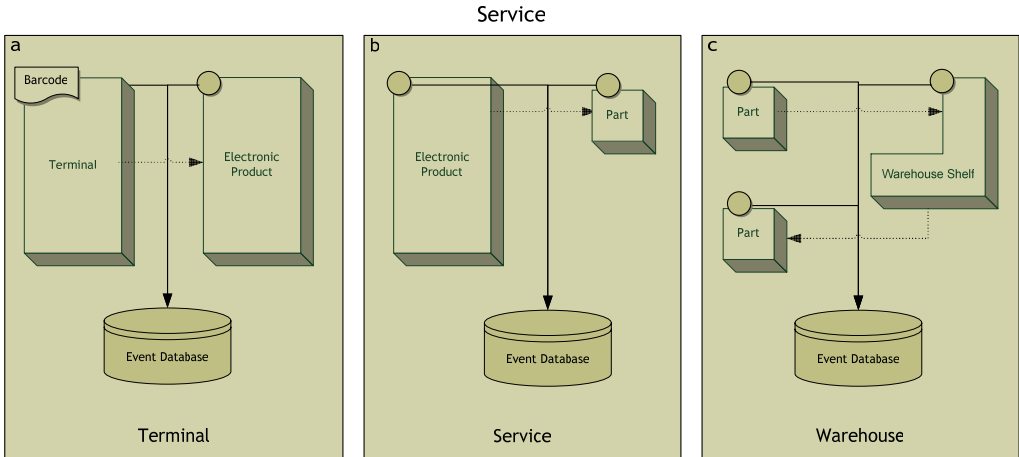

Figure 4: Middle-of-Life with Focus on Service, 1

Should a terminal be reported as defect, a service employee will remove the unit from the terminal. In order to capture this operation for lifecycle management, the barcode of the terminal as well as the superordinate RFID are read and an EPCIS "Observe" event generated

in which the removal of the unit is documented. The service employee then brings the defect unit into service. The unit is analysed and the defect component part or parts removed.

The removal of the parts is documented by reading the superordinate product RFID and then the tag or tags of the compromised part or parts. An EPCIS "Aggregation" event is triggered in which the EPC of the compromised parts are "deleted" from the list of aggregated EPC. This decouples the broken component part from the overall unit.
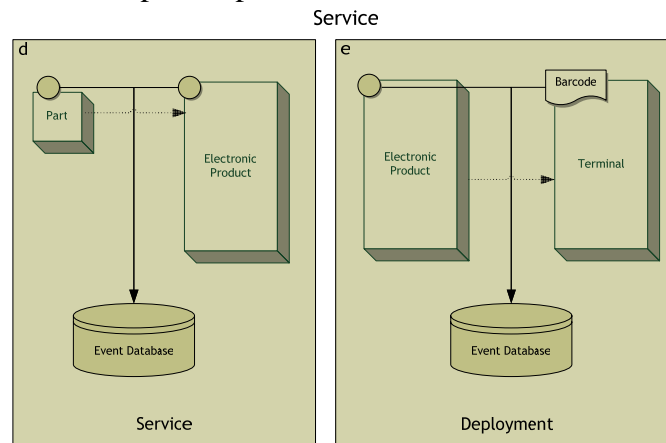

Figure 5: Middle-of-Life with Focus on Service, 2

The compromised parts can then be stored in the service department's warehouse. In order to be able to track the parts, the warehouse shelves may themselves be identified by EPC using RFID. When putting a part into storage, an EPCIS event can then be used to record which shelf the part has been placed on. This takes place using an "Aggregation" event, "adding" the part's EPC to the list of codes aggregated to the shelf's own EPC. The same operation can also take place in reverse, for the identification and retrieval of a suitable replacement part. Both operations are shown in Figure 4, (c). Alternatively, a defect component part may be judged irreparable and be moved directly into the beginning of its respective end-of-life phase.

After identifying a suitable replacement part, the service employee repairs the unit by installing this part into the chassis. Again, this operation is documented by an EPCIS "Aggregation" event. The new part's EPC is added to the list of codes aggregated to the superordinate EPC. This is illustrated in Figure 5, (d). Once repaired, the entire unit may either be put into storage as a replacement unit, in which case the superordinate EPC needs to be aggregated to a suitable shelf's EPC for location purposes. Otherwise, the unit may be deployed back into a terminal in the field. In this case, the operation as shown in Figure 5, frame (b) is carried out, which is identical to the operation for the initial product deployment.

End-of-Life

Once a unit can no longer be maintained, it enters its so-called "end-of-life" phase. In this phase, it is decommissioned, decomposed, and its individual product parts selected for recycling, refurbishing, reuse or disposal. The latter can take place in Germany, for example, according to the *Elektro- und Elektronikgerätegesetz - ElektroG*, by the involvement of a disposal service provider. The precise identification of the component parts disposed of, the type of disposal along with the time need to be documented in order to fulfil legal requirements. A system based on EPC supporting tracking and tracing in this phase of the product lifecycle should be required to satisfy these information management needs.
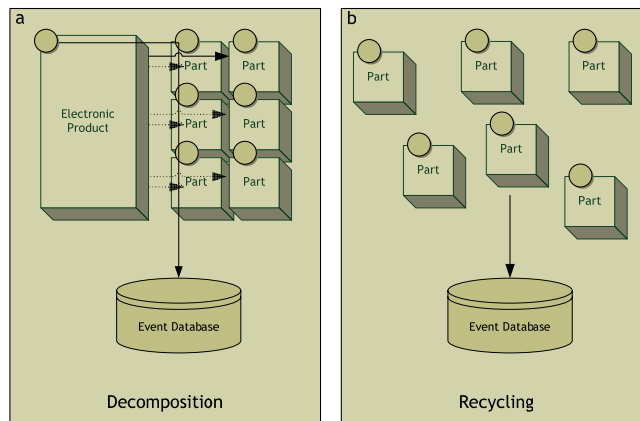
Figure 6: Events during End-of-Life

By once again leveraging EPCIS "Aggregation" events, the precise time, location and responsibility details of the decomposition operation can be recorded, along with information regarding the type of disposal (for example recycle, refurbish, or reuse). The event information can be used by the manufacturer and the part suppliers to document their fulfilment of their legal obligations to provide suitable disposal services which satisfy their legal obligations.

Showcase Specification and Implementation

Figure 7 illustrates the system architecture specified for the showcase implementation. It represents a core EPCIS system and is oriented closely towards proposals made by the EPCGlobal Special Action Group on EPCIS. As the showcase was primarily developed as a proof of concept on the use of EPCIS Events for tracking and tracing of products throughout the product lifecycle, the complexity of the showcase architecture was kept as low as possible. For example, only direct capture and query requests are handled by the system, whereas a full EPCIS implementation may be specified to handle direct and indirect requests.
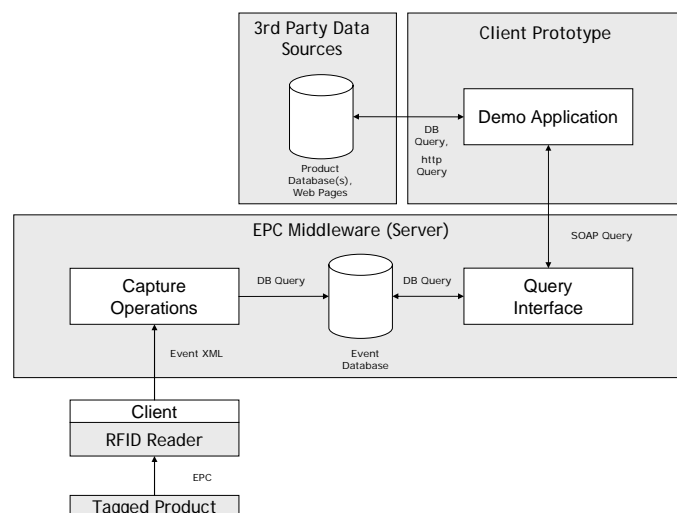

Figure 7: Showcase Implementation Architecture

At the heart of the architecture, a simple MySQL database was specified as a storage container for the EPCIS Events. This can be viewed as a simulation of real-life enterprise systems equipped with the respective interfaces. The data storage exposes a Web Service interface realising key elements of the proposed EPCIS query interface. It follows the proposal for http/SOAP-bindings of the EPCIS. This interface allows the showcase

application to retrieve information about events previously stored in the database, according to queries over any of the EPCIS Event attributes. The demo application visualises these queries and can be used to effectively show how EPCIS events correspond to process steps along the product lifecycle, and serves as a proof-of-concept of this tracking-and-tracing approach.

The Capture Operations interface is likewise specified and realised as a low complexity realisation of EPCIS specification suggestions. It simply monitors whether new Event files have arrived, which are communicated according to the proposed XML format, parses them and stores the respective event data in the database. By either wireless connection via Bluetooth or Wi-Fi, or USB leveraging synchronisation mechanisms, events gathered by the RFID reader can be communicated to the Capture Operations interface. The RFID reader used in the showcase is a commercial model which is EPC-compliant and runs Windows CE. An application was developed for the showcase which is capable of guiding the user through the operations described in *Mapping the Product Lifecycle to EPCIS Events* and creating the respective EPCIS Events and communicating them to the Capture Operations interface.

Conclusion

To conclude, EPCIS Events can be said to be a promising and adequate tool for the facilitation of tracking and tracing throughout the lifecycle of electronic products. The development, demonstration and evaluation of the showcase system can be said to provide a proof-of-concept that EPCIS Events are indeed suitable for this task. Using this approach, a standardised, inter-organisational communication of identification-related events throughout the product lifecycle can be achieved. Obviously, the showcase remains a low complexity, laboratory demonstrator which doesn't fully anticipate the full spectrum of difficulties which will arise in a real world deployment of such a system. However, the basic design can be used as a template for such developments.

Acknowledgements