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# Information management in the product lifecycle — The role of networked RFID

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*Abstract*

***Radio Frequency Identification (RFID) is receiving significant attention at present through its low cost deployment in the retail supply chain. This paper introduces the concept of Networked RFID developed by the Auto ID Center, and examines its role in supporting more effective Product Lifecycle Management (PLM). In particular, the product tagging approach initiated by the Auto ID Centre has centred on ability to access complete and accurate information about a product in a timely manner and is demonstrated to be important for decision making at different stages along its lifecycle.***

## 1. Introduction

Radio-Frequency Identification (RFID) is a technology which allows remote interrogation of objects using radio waves to read data from RFID tags which are at some distance from an RFID reader. This has several advantages over manual scanning using optical barcodes, since many tagged items (or embedded sub-components of a composite product) could be simultaneously identified in an automated manner, very quickly and without the need for line-of-sight to each item.

However, RFID itself is only part of the solution – it is merely an input device for connecting physical objects with computer systems. For many years, the major stumbling blocks to widespread deployment of RFID were the substantial costs of tags and readers and the proliferation of mutually incompatible RFID solutions operating at different frequencies and using different protocols (for further details, refer to Hodges & McFarlane [1])

A recent breakthrough in enabling affordable widespread global deployment of RFID is the emergence of the so called *EPC Network* as a means of connecting a product tagged with RFID to a network. The EPC Network has been developed by the Auto-ID Centre - a collaboration between six of the world’s leading universities and over 100 industrial sponsors, ranging from end-users to technology solution providers and systems integrators [2]. The Auto ID Center vision is to enable the automatic unique identification of any object anywhere and to synchronise what happens to the object in the physical world with flows of data about the object in networked databases. Because the EPC Network has not been outlined in the literature in its current form we will review it here, before going on to discuss its role in Product Lifecycle Management (PLM).

## 2. Networked RFID

The networking of an RFID system was critical to the Auto ID Center developments for two reasons.

- **Cost:** In seeking a very low cost tagging solution, it was decided that all information - apart from a unique identifier - be held on a database, the database being accessible through the RFID readers' network connection.
- **Globality:** A single, open, global strategy for RFID was advocated. This involves being able to access product information (linked to the RFID tag) at different (networked) locations along the supply chain.

In order to achieve this networked RFID solution, the EPC Network consists of six fundamental technology components, which work together to bring about the vision of being able to identify any object anywhere automatically and uniquely. These are:

- The Electronic Product Code (EPC)
- Low-cost Tags and Readers
- Filtering, Collection and Reporting
- The Object Name Service (ONS)
- The EPC Information Service (EPCIS)
- Standardised vocabularies for communication

### 2.1 The Electronic Product Code (EPC)

The aim of the EPC [3] is to provide a unique identifier for each object. Designed from the outset for scalability and use with networked information systems, the EPC typically consists of three ranges of binary digits (bits) representing (refer to Fig. 1):

- an EPC Manager (often the manufacturer company ID)
- an object class (usually the product line or SKU) and
- a unique serial number for each instance of a product.

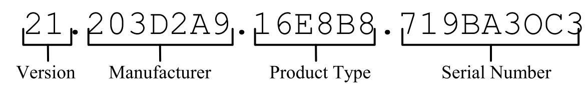


*Fig. 1: Electronic Product Code*

As well as being the lookup 'key' to access the information about the tagged object, the EPC concept has also been an important factor in driving down the production costs of tags and readers [4]; by stipulating that the tag need only store the unique EPC identity number, it is possible to design tags with much lower on-board memory requirements, since the additional information about the tagged object can be stored in distributed networked databases, tied to the object via its EPC number.

### 2.2 Low-cost Tags and Readers

Radio Frequency Identification (RFID) is a key technology enabling automatic reading of multiple items simultaneously, without requiring manual scanning of each individual item. The reader emits radio waves of a particular frequency. When passive tags (called passive because they lack their own power supply) enter the range of a reader, their antenna absorb energy from the radio field, powering the microchip which stores the unique EPC identity code — and returning this information back to the reader via a modulation of the radio waves.

### 2.3 Filtering, Collection and Reporting ('Savant')

A wide-scale deployment of RFID tags and readers could potentially result in overloading of the information network (bandwidth and database storage capacity) with raw data from RFID readers. It is important to ensure that just significant data and 'events' are transmitted. These software 'events' contain information and are able to trigger processes in higher-level applications and information systems.

The role of filtering, collection and reporting is to isolate the physical reader infrastructure from the higher-level applications and information systems which make use of the data, so that:

- applications do not need specific interfacing details for different readers, and
- only significant 'events' and summary data packets are propagated to applications and information systems, rather than every individual tag read.

### 2.4 The Object Name Service (ONS)

The Object Name Service (ONS) is used to convert an EPC into a number of internet addresses where further information about a given object may be found. Currently, the ONS specification deals with a static implementation based on the Domain Name Service (DNS) which provides IP address lookup for the internet.

In order to avoid overloading and degrading the performance of DNS, the static ONS will generally not perform serial- level lookup but rather object-class lookup – e.g. product- line (SKU) granularity for trade items. ONS therefore usually returns a number of manufacturer-oriented web addresses for various services, such as HTML web pages, web services, XML product data, etc.

Recognising that other parties on the supply chain may also hold relevant data about an object and that issues such as traceability require a robust solution, it is likely that static ONS will be augmented with a dynamic ONS counterpart, which is able to provide the serial-level lookup for instances of a given product, pointing to the various other parties across the supply chain, which also hold information.

### 2.5 The EPC Information Service (EPCIS)

While the ONS points to various sources of information, it must be recognised that different companies will use different database vendors and different implementations and that there is currently great reluctance to share information between trading partners. However, in order to obtain maximum benefit from the EPC Network infrastructure, companies need to share some information in order to be able to respond in a more timely manner to the new data available, e.g. allowing manufacturers to adjust production rates to synchronise with actual real-time consumer demand detected by smart shelves with embedded readers.

The EPC Information Service [5] allows trading partners to access and exchange well-defined subsets of their live real-time data, through a standard interface, with full web service security access controls and authentication, while interfacing the back-end to diverse databases and information systems from multiple vendors, without their partner needing to know the details or have direct access to the underlying systems.

### 2.6 Standardised vocabularies for communication

Having obtained the data via ONS and EPCIS, it is important that its interpretation is unambiguous and ideally self-describing. This is the role of standardised vocabularies. The eXtensible Markup Language (XML) is a way of marking up structured data for communication and exchange between diverse applications and different parties. The philosophy of XML is to use open standards for data exchanges, promoting interoperability and multi-vendor solutions and competition rather than proprietary encoded formats which are tied to particular vendors and tend to result in monopolistic practices.

Under the Auto-ID Centre, a Physical Markup Language (PML) [6] was developed as an XML format for communicating data directly captured by the EPC Network, such as readings from sensors, including RFID readers and other identity input devices, such as barcode readers – but also including data from physical sensors (e.g. temperature sensors) either embedded on tags or monitoring the environmental conditions.

### 2.7 The EPC Network

These elements together form the core infrastructure of the EPC Network and provide the potential for automatic and unique identification of any tagged product.

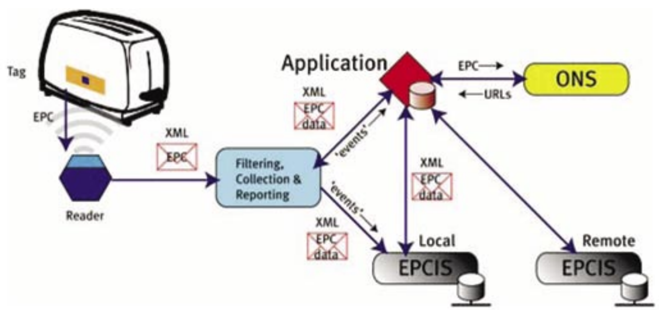


*Fig. 2: Architecture of the EPC Network*

Fig. 2 illustrates a schematic of how the elements interface with each other for the case of an electric toaster. The RF reader detects the presence of the toaster when the toaster returns its EPC code in response to the reader's interrogation. The tag reads from the toaster are collected, filtered and reported to the software application (for e.g.: stock checking software). The application will then query the ONS to obtain the URL corresponding to the EPCIS (which could lie locally or at a database across the Internet) that contains data linked to the EPC code of the toaster. It can then query the appropriate EPCIS to obtain the information required for efficient stock keeping.

## 3. Product Lifecycle Management

In this section, we will provide a brief introduction to product lifecycle management (PLM), the various stages in a product's lifecycle and the important decisions that are made at each stage.

Product lifecycle management is viewed as a holistic approach to product development and product management from cradle to grave (i.e. from product conception through product retirement) and spans a wide range of functions within a business ranging from product designers and engineers, through manufacturing and logistics to sales, customer support, maintenance and ultimately decommissioning [7]. PLM has been gathering importance in the past few years as companies have started seeing this as a means to gather useful information about their product throughout their lifecycle for efficient management and control [8]. In addition, environmental degradation has become a big concern and governments all around the world are formulating "producer responsibility" laws to put pressure on businesses to manufacture products that minimise eco-burden [9,11].

The various stages in a product's lifecycle are shown in Fig. 3.

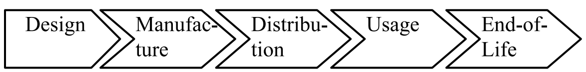


*Fig. 3: Product lifecycle stages*

### 3.1 Decisions at each stage

We will now discuss the various decisions that play an important role in the different stages of a product's lifecycle.

*Design:* The product lifecycle begins with the conception and design of the product. During product design, while drawing up the functional specifications of the product, the designer has to ensure that the product satisfies the rapidly changing customer expectations. The designer also needs to design the product and choose the constituent materials so as to satisfy the product's intended function, and also ensure that they are environmentally benign.

*Manufacturing:* At the manufacturing stage, there is an increasing trend towards mass customisation [10], where each product is manufactured uniquely to suit the requirements of individual customers. This requires the manufacturing facility to be flexible and responsive enough to frequent changes to product design. This will reflect on raw material procurement decisions as well, where orders will have to be placed according to the bill-of-materials for each order, as compared to batch procurement decisions using EOQ models in traditional manufacturing.

*Distribution:* When the products are shipped out of the manufacturing facility into the distribution channel, decisions pertain to logistical issues such as storage, transportation, inventory management, and replenishment. There could be a gain in being able to handle inventory at a higher granularity, i.e., less than pallet/case level. Such a capability is definitely important, as mass customisation is becoming an accepted practice in today's industries.

*Usage:* When a consumer purchases a product, the manufacturer in most cases will still be tied to the product through maintenance/warranty contracts and will have to make decisions throughout its usage life regarding maintenance, repair and replacement. In addition, the consumer will have to ensure that the product is used in conditions that it was designed for (such as ambient temperature, humidity, shock, etc.).

*End-of-life(EOL):* Every product is designed to operate for a particular life span. When a product reaches the end of its useful life, it is often discarded or returned to the manufacturer. Products may also be discarded in lieu for better products with increased functionality long before they reach the end of its useful functional life. Government regulations such as the WEEE directive [11] stipulate the maximum proportion of the returned/discarded product that can be land-filled. Hence, a major portion of discarded products needs to be recovered for reuse or recycled for material recovery. Now, collected products need to be sorted according to product type/potential recovery value, and the best recovery option (such as reuse, refurbish, recycle, etc.) needs to be chosen [12]. Products may also be disassembled for harvesting components/sub-assemblies that maybe reused. In this case, the best disassembly sequence needs to be determined. If the product or some parts of it cannot be recovered, it has to be disposed of in a proper way as required by government regulations on waste disposal.

As can be seen, these decisions pertain to each product (as opposed to a batch of products or a product type) and thus would critically depend on the quality of information available. In the next section, we will discuss the information requirements for making these decisions effectively.

### 3.2 Information requirements for lifecycle decisionmaking

We will now take a brief look at the information required to support the various decisions to be taken along a product's lifecycle as described in the previous section. Fig. 4 outlines the decisions that are made at the different stages of the product lifecycle as discussed in the previous section, and the information required to support these decisions. It highlights the fact that the decisions depend on information associated with the product collected from all stages of the product lifecycle.

As an example, we will look in detail at the items of information which should be collected at each stage of a product's life in order to be able to make appropriate decisions about how to handle it at its end of life (EOL) and how to extract maximum value from the components and materials of which it is composed.

At the design stage, much of the information, such as the product recipe and bill or materials is often generic, applying across all instances of the product. At subsequent stages, from manufacture, through distribution and retail to usage, it is much more useful to collect unique data about each individual object, i.e. at a serial-number level of granularity.

Such serial-level data includes date of manufacture, measurements from sensors, such as temperature history, number of operation cycles, total time in operation, as well as details of any maintenance, whether preventative, routine, such as the replacement of cartridges – or to fix specific problems arising during its use. The reader is referred to Parlikad *et al.* [13] for a detailed review of information requirements for EOL decision making.

It is desirable that product lifecycle information that supports decisions at the various stages of the product lifecycle should have the following characteristics:

**Uniqueness** — to enable individual information trails for each unique object throughout its lifecycle and across the whole supply chain.

**Completeness** — to ensure that all the relevant information is available for optimising decisions.

Timeliness — to ensure that information is readily available in a format that is required for decision-making and execution process.

**Accuracy** — to reduce or eliminate inaccurate representations of current and historical product information.

Hence, a product lifecycle information management (PLIM) system that supports decisions pertaining to a product over its lifecycle should be capable of proving information with the qualities mentioned above. The next section describes how the collection of technologies which form the EPC Network are ideally suited to managing the information about products throughout their lifecycle.

| Decisions | | Information: Design | Manufacture | Retail | Usage | End-of-Life |
|---|---|---|---|---|---|---|
| **Manufacture** | Planning & Scheduling | Recipes<br>Design Drawings<br>Handling Constraints | | | | |
| **Retail** | Distribution | Handling Constraints | | Fulfilment Requirements | | |
| | Store Reordering | Product Identity | "Due by" Dates | Storage Costs<br>Sales Price | | |
| | Shelf Replenishment | Product Identity<br>Storage Constraints | "Due by" Dates | Shelf Locations | | |
| **Usage** | Usage | Usage Instructions | "Due by" Dates<br>Possible Recalls | | | |
| | Repair/Replacement | Reliability data | Disassembly recipes | Warranty details | Maintenance history<br>Usage History | |
| **End-of-Life** | Sorting | Product Identity<br>Design changes | | | | |
| | Recovery option | Reliability data | | Replacement history<br>Sale price | Usage sensor data<br>Maintenance history<br>Parts replaced | Reason for return |
| | Disassembly sequence | | Disassembly recipes<br>Irreversible processes | | | |
| | Disassembly level | Bill of Materials | | | | |
| | Recycling | Hazardous materials | | | | |

*Fig. 4: Information requirements for lifecycle decisions*

## 4. Towards PLM Using RFID

This section highlights the significance of each of the EPC Network components in achieving an effective PLIM system.

The EPC introduces mass-serialisation, giving each instance of a product a *unique identity* and allowing information systems to store accurate, complete and relevant individual data (an individual life history) of each unique object. Furthermore, the EPC encapsulates the unique identity in a single numeric code. This is particularly important for enabling more selective product recalls, since each individual object can be tracked independently, rather than relying on cumbersome combinations of GTINs, SSCCs, lot or batch numbers etc. and recalling more items than just those which were known to be defective. The purpose of the EPC is that this

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single identifier can be used throughout the supply chain to track and store data about a specific object, rather than having to rely upon connecting various transactions between each party.

RFID technology (tags and readers) is key to being able to automatically read the EPC and thereby track each individual item, wherever it travels in the supply chain. Without a technology such as RFID, there is much manual scanning, which introduces delays and human errors, rendering the PLIM system impractical or inaccurate. RFID technology provides the ability for automated and efficient method for collecting product information in a *timely and accurate manner*.

The filtering, collecting and reporting layer, or ‚Savant', is essential in order to be able to deploy large quantities of RFID tags and readers without overwhelming the network capacity or business applications and information systems with a cacophony of ‚blips', of which only a few actually contribute to significant ‚events' with any meaning for the applications. This is essential for converting the stream of raw data emerging from RFID tags into meaningful information that could be used to support decisions.

Standardised vocabularies for sharing structured data are essential for avoiding ambiguities in the information in a PLIM, especially where items cross countries with different human languages and pass between multiple trading partners who manage their internal data systems differently. This is the essential role of XML schema generally, of which PML Core [14] is one example, specifically developed for marking up data captured from the EPC Network of sensors and RFID readers. Without standardised vocabularies, human intervention is required to interpret the data exchanges, leading to delays and greater potential for errors affecting *accuracy and completeness* of information.

As well as a set of common vocabularies for communication, a common protocol for accessing that information is required. This is the role of the EPC Information Service (EPCIS), effectively providing a web service gateway to the underlying data, while insulating trading partners from needing direct access to each other's databases. Information systems and databases used by companies are supplied by diverse vendors and companies are naturally very nervous about sharing information with each other. Provision of a secure web-service access route to a controlled subset of the data makes information sharing viable. Effective lifecycle decisions often rely on accessing information fragmented across the supply chain. EPCIS makes this a practical possibility by providing a uniform interface supported by each party.

Such a distributed database tied with a dynamic ONS registry that provides pointers to all the EPC Information Services on the individual supply chain followed by each individual object in a more robust manner would help in collecting and retrieving *complete* lifecycle information associated with a product.

In summary, each of the six technology components present in the EPC Network is indispensable if we are to achieve an effective PLIM solution with instance-level tracking and information.

## 5. Illustrative Example: PLIM For A Domestic Toaster

This section will illustrate the role of RFID-based product lifecycle information management for the case of a simple domestic appliance such as a toaster. Here, we will concentrate on the key operations and decisions made along a toaster's lifecycle and the information requirements for making those decisions.

### 5.1 Toaster description

A toaster, which is one of the most commonly found domestic appliances, comes under the purview of the Waste from Electric and Electronic Equipment (WEEE) directive [11], which forces its manufacturer to be responsible for managing the product's entire lifecycle from design and manufacture, to product recovery or disposal at its end of life.

Fig. 5 shows an exploded view of a domestic toaster showing the major subassemblies i.e., the main body, the element assembly, the control box, and the slide carriage assembly. The main body is often made of plastic and the other components are made from different types of metals.

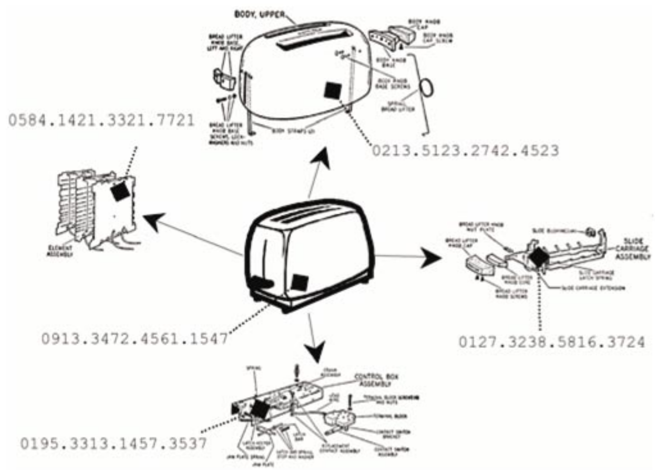


*Fig. 5: Exploded view of a domestic toaster*

In the next section, we will explore the important decisions made along the various stages of the toaster's lifecycle and the information requirements for making those decisions effectively.

### 5.2 Key decisions and information requirements

The product lifecycle begins with the design of the toaster where in addition to the mechanical design, the designer has to choose appropriate materials for the different parts and components. The emphasis here, in view of regulations such as the WEEE directive [11], is to design the product in such a way that it is environmentally sustainable. The designer also has to ensure that end-of-life handling of the toaster is as simple as possible by using design for disassembly principles. Information regarding material processing capabilities and component reuse from recyclers and remanufacturers who handle toasters at their end-of-life would be critical in improving future designs. For example, certain types of plastics might be better suited for recycling than others. Standard components that can be used in different types of toasters will have a higher reuse value than others. Maintenance history data from the usage and maintenance stage would also help in improving the reliability of the critical components such as the heating element and the control box.

In addition to this, consumer tastes and preferences also have to be taken into account. Here, feedback from retailers about popularity of new product introductions, customer demand data and customer returns would lead to design changes that are more suitable to the fast-changing customer expectations.

At the manufacturing stage, due to the trend towards *mass customisation,* a customer might place an order for a toaster with a light brown body with a capacity for five slices of bread that could be tailor fitted into existing kitchen furniture. This means that the manufacturing process needs to be extremely flexible to produce such a unique toaster in a cost-effective and timely manner. More importantly, each component and the processes used may potentially be exclusive to this particular toaster and hence all these information must ideally be captured. Referring back to Fig. 5, all the four major subassemblies of the toaster have RFID tags embedded with unique EPC number. Note that information *richness* about the toaster will increase as more components within the toaster are tagged.

The availability of these EPC numbers will enable automatic identifications and product information updates for the subassemblies throughout the lifecycle of the toaster. For example, if the control box fails during usage, a replacement control box with the new EPC number will be updated to reflect the changes in the PLIM system. This new control box may be of a different model than the one that failed and such information will be useful for future maintenance and end-of-life management. With EPCIS, subassemblies within the toaster could be determined without the need to disassemble the product.

If all the subassemblies within the failed control box are tagged, we could then determine exactly which component failed and trace the component history back to the original manufacturer and re-evaluate the use of that component. One may then make an informed decision to stop using the component altogether in future toaster design, anticipate which customers may have problems with their toasters or even recall all the toasters that use that component.

Fig. 6 shows how information about the toaster is stored in a distributed manner in various EPCISs across its lifecycle. It also describes clearly how, for example, a recycler could find the toaster’s date of sale (possibly to find out how long it has been used). Without a product-oriented information system similar to the one provided by the EPC network, it might be impossible for the recycler to obtain that kind of information.

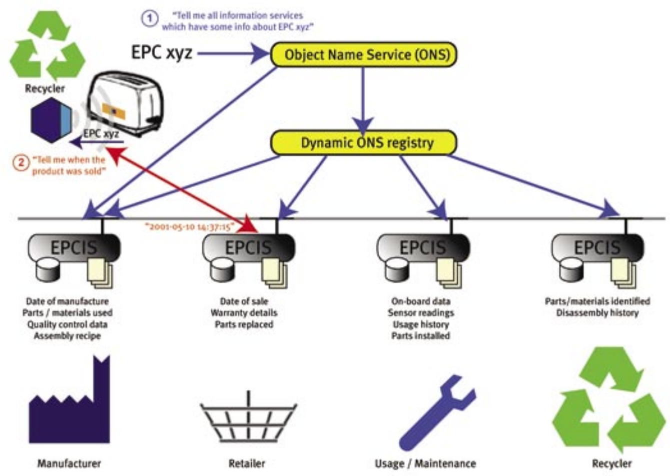


*Fig. 6: EPC based PLIM for an electric toaster*

Although we use an illustration of a simple product such as a domestic toaster, the concepts are similar for other potentially more complex product (refer to [15]) such as a refrigerator, computer servers, vehicle or even an aircraft. Clearly, the benefit of having PLM using RFID will increase with increased product complexity.

## 6. Conclusion

This paper discussed how a networked RFID could be used to manage information in the product lifecycle. A unique EPC identifier supported by other fundamental components will enable PLIM system to track and trace instances of a given product across multiple actors throughout the whole supply chain. The use of RFID will also provide an automated and efficient information collection capability that will improve accuracy, timeliness and completeness of information pertinent to that particular unique product — corresponding to the concept coined as the *Level 1 Intelligent Product* introduced in Wong et al. [15].

More importantly, a networked RFID provides the opportunity for each instance of a given product to enhance decision- making process along the supply chain in a timely and coherent manner. Such a capability will potentially enable mass customisation as each and every instance is capable of assessing and influencing its function in an automated manner - corresponding to a *Level 2 Intelligent Product* [15,16]. The intelligent product has information content that is permanently bounded to its material content enabling automated decisions that may in the long term, require a radical change in the operational structure of the supply chain. The role of Level 2 intelligent product in product lifecycle management is currently under investigation.

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