ENVIRONMENTAL LIFE CYCLE INFORMATION MANAGEMENT - NEEDS FOR STANDARDISATION

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Abstract: The overall aim of the EU funded project ELIMA is to enable eco-efficient management and acquisition of product life cycle data by closing the information loop in different phases of product life cycle including design, manufacture, distribution, use, service-support, maintenance, and end-of-life product recovery. Information systems that can integrate information about products from all stages of the product life cycle are needed to manage the product life cycle, to reduce costs, to improve the design of future consumer products and to minimise environmental impact. The data must be communicated to the relevant stakeholder for action; all actors in the supply chain must share data. Only through the use of standards the interconnectivity and interoperability can be assured.

1. INTRODUCTION

New regulations and legislation in the EU, such as producer responsibility and priority waste stream actions, have been introduced to help protecting the environment, to minimise resource consumption and waste as well as to meet customers' demands for reliable and efficient products.

Specifically, producers need to be able to track their products in manufacture, distribution, in use and at the end-of-life, which implies collecting more information over the life cycle. The intention is that current technologies can be used for this, for example sensors, memory devices and communication systems in products. The availability of life cycle data for their products brings benefits such as easier maintenance tasks, better service support, resource efficient operation and more efficient recycling. The acquisition and management of life cycle data is of interest to government and public bodies as well as to retailers and consumers alike, demanding a change in attitudes, expectations, policy and standards.

Industry therefore needs information systems that can provide information about products during the whole life cycle of the product. This information can then be used to manage the product life cycle, to reduce costs, such as maintenance costs, to improve the design of future consumer products and to minimise environmental impact by modifying product operation, use pattern or by recovering more resources at end-of-life.

The data must be communicated to the relevant stakeholder for action; all actors in the supply and value added chain must share data. This presents a major information processing challenge; any solution needs to be provided at extremely low cost and with low environmental impact.

2. THE ELIMA PROJECT

2.1. Objectives of ELIMA

Taking extended producer responsibility the manufacturer of a product should have data on the whole life cycle of a product available. This calls for an integrated information system, with databases and management tools under the control of the manufacturer but open to access by other parties such as those involved in the supply of components, the maintenance or the recycling of the product. Therefore the ELIMA project has been established.
The main technical objectives are to:

- Design ELIMA information systems and prove their operation with two application tests;
- Produce specifications and standards, including design guidelines, reference architecture and associated product/service life cycle management tools;
- Develop and validate life cycle models for the assessment of cost and environmental benefits of product life cycle management activities;
- Evaluate the economic and environmental benefits of the ELIMA concept and to investigate consumer attitudes to the new products and services.

2.2. Approach of ELIMA

The integrated ELIMA system is being prototyped for two cases: consumer electronics and domestic appliances. It is a composition of hardware, software, communication and management tools, integrated so as to optimise the product life cycle from economic and environmental aspects.
The ELIMA system combines so called static environmental data programmed during the manufacturing stage e.g. materials used, together with dynamic data acquired from sensors active throughout the life cycle of the product. The rapidly changing nature of information technologies means that ELIMA systems must be robust and flexible; if well designed they can exploit emerging technologies to bring the manufacture, component supplier, user and recycler together as a unit.

3. STANDARD ISSUES

3.1. General

Requesters for environmental life cycle information could be retailer, distributors, customers, consumers, service companies, waste collectors, recyclers, governments, or public organisations. Data must be communicated to the relevant stakeholder for action and all actors in the supply chain must share data. The type of data depends on transfer and analysis requests. Currently mainly paper written or electronic recorded databases as stand alone solutions are in place, a few intranet-based solutions are provided. The required accuracy of data is quite differed and varies for the material declaration from 1% of all materials to 10ppm of requested substances. Only through the use of standards the interconnectivity and interoperability can be assured. Most of the requesters are mainly driven by upcoming legislation. In order to identify which environmental information/parameters are needed environmental standards and proposals have been studied like WEEE, RoHS, EEE, ISO14000, TCO, ECMA, and EICTA.

3.2. Worldwide Activities

In most cases a material declaration is required. Therefore several standardisation activities have been started to simplify the declaration process. These activities are driven from industrial voluntary associations e.g. automobile and the IMDS system [1]. In 2000 the EICTA Environmental Supply Chain Management (ESCM) task force had been established. So far an agreement could be achieved on:

- Reporting on subassembly level
- 99% of material of the product has to be reported
- List of 34 predefined materials (rest declared as others)
- List of 35 predefined substances have to be reported up to 10ppm.

ECMA [2] has focused on standardisation of several environmental information beside materials like power consumption, radio frequency emissions, chemical emissions packaging, batteries, take back information etc. This standardisation effort is focused on declaration and not on limits.

3.3. Elima Specifics

ELIMA will directly contribute to effective implementation of the WEEE and future EC Integrated Product Policy (IPP). In a first step the application independent issues shall be focused. The approach has to ensure a soft- and hardware independency. In summary there is a need for standards of:

- Definitions
- Unique Identifier
- Data structure
- Configuration of the ELIMA system

For all monitoring activities or objects a unique identification is required. A common data syntax has to be tackled. Specifications for the technical environment have to be covered. The size and location of fields inside the data structure must be fixed. Mandatory and optional data fields have to be named as well as data field requirements. The names

for the addressed data fields must be the same for all partners. A further step is the definition of configuration files, similar to configuration sets for field bus systems.
Once the frame is fixed, the content inside this frame has to be specified. Monitoring events, schedules and their structures have to be standardised in that way that a device and software independent development is possible. Therefore, the data monitoring structures have to be defined as well. Finally standards for data protocols and their applications can be applied to the data structure and monitoring device.
The proposed strategy for the ELIMA project is to:

1. Apply existing standards
2. Adapt existing standards
3. Cooperate with existing standards initiatives
4. Develop new standards

4. DATA CONTENT

4.1. Static data

Studying the data requirements we can summarize that external requesters ask for static data mainly:

1. Hazardous materials
2. Material declaration
3. Emissions
4. Resource consumption (e.g. power,...)
5. Take back information
6. Disassembly attributes (e.g. sequence, tools,..)
7. Recycling information

This information is applicable to the whole product family. The static data will be stored in a separate database for the product itself (see chapter 5). At the moment the use of the EICTA material and substance list seems to be a good approach to include these information into the database.

The serial number of the product can be used to get access to the information. For most of the electronic products only the barcode has to be scanned. For over twenty-five years, the Universal Product Code (UPC or "bar code") [3] has helped streamlining retail checkout and inventory processes. As one of the most successful standards ever developed, UPC coding and labeling methods have grown to include numerous elements of the supply chain. In response to the UPC system already in operation in the USA 12 European countries formed an ad-hoc council for developing a uniform and standard numbering system for Europe. As a result, a UPC compatible system called "European Article Numbering" was created [3].

4.2. Object Identification

The main intention for the ELIMA system is to identify each single item in a bulk of similar objects over a long period of time. Especially in the field of product identification a lot of standards already exist. Because of the importance of product identification within the ELIMA system this issue has been studied in detail.
Different methods for object identification are already applied, e.g. vehicle identification numbers (VIN) [4], Global Trade Item numbers (GTIN) [3], Media Access Control (MAC) numbering systems [5], or International Standard Book Numbers (ISBN) [6]. Most systems does not allow to track to a single physical unit, the code distinguish only the types of items. In some cases the code contains information about production site and date.
For electronic equipment in a network like modems a one-to-one identification is possible using the IP address [7] and can be used. However, no information about the manufacturer is included, which could be important for example for the take back payment, taxes, etc. For mobile phones the International Mobile Equipment Identification (IMEI) [8] coding is already in use and ensures the one-to-one identification including manufacturing information. However, the IMEI system can be used for this branch only.
The unified identification has to serve different purposes, (e.g. product identification, tracking, sorting, take back control etc.), identification by machines or humans as well as interpretation by manufacturer, service company or customer. Therefore the following information is of interest:

- Country information,
- Company information,
- Product name information,
- Version and Serial number
- Electronic identification in a network,

To ensure the requirements of an ELIMA system the following unified identification system is proposed by applying existing standards.

Information	Applicable Standards
Country	International area code [9]
Company	GTIN EAN UCC 13/14 [3]
Product	GTIN EAN UCC 13/14 [3]
Version number	Serial version number
Serial number	Item based serial number
Manufacturing date	
Electronic identification in a network	Internet IP, Server IP [7]
Specific IDs of application areas (optional)	(e.g. IMEI, MAC ...see above) [8,5]

Table 1: Proposal for Unified Identification

4.3. Specific WEEE requirements

The proposal of the WEEE requires several information from manufacturers. The treatment facilities has to be informed in an appropriate way to identify the different electrical and electronic equipment components and materials, and the location of dangerous substances and preparations in the electrical and electronic equipment. For the information of consumers a marking of certain items of small electrical and electronic equipment has to be applied to avoid disposal. Additionally the WEEE also sets limits for some environmental attributes especially the recycling rates. For the material specification the EICTA material and substance list could be one common approach. Other information like disassembly information needs to be standardized as well. As long as the disassembly is mainly a manual process, drawings and bill of materials should satisfy the requirement. If more and more automated systems are established the CAD data exchange on the base of the STEP [10] standard should be used.

Material data and disassembly information are static data and should be stored in a database. The object identification allows access to these stored data.

4.4. Dynamic data

Dynamic data will be stored on the device in a memory chip. This data will be used for predicting the remaining lifetime of the device or components if it is disposed by the user and received at a recycling firm. Failure causes can be investigated and maintenance operations facilitated. At least the data will give valuable input for product designer and specification of new devices.

Environmental conditions have a major impact on the functionality and reliability of electronic components, equipment, and systems. International functionality and reliability standards for relevant applications in international standards [11] have been studied in order to settle a useful data set. Such standards specify stress limits and test conditions, among others for heat (steady state, rate of temperature change), cold, humidity, precipitation (rain, snow, hail), radiation (solar, heat, ionising), salt, dust, sand, noise, vibration (sinusoidal, random), shock, fall, and acceleration. For brown goods the following important parameter have been identified:

- Time related
- Temperature
- Humidity
- Vibration
- Mechanical shocks
- Supply voltage
- Current
- Electric field

5. DATA BASE AND MANAGEMENT

The key role for the ELIMA Data Management System includes support of data collection, management, control and effective sharing of information among various stakeholders. The generic ELIMA system consists of three layers: database management system (DBMS), lifecycle information management, and external world (Figure 1). This three-tier architecture clearly depicts the storage, knowledge discovery and management of product life cycle data in an ELIMA system.

The DBMS layer in the ELIMA system consists of a data store with a suite of management components including data manipulation, security monitor, transaction management, concurrency control and database administration. This layer can be regarded as an ELIMA database system, which provides persistent storage and database management functions to house product life cycle data and information. Standards of data storage and management already exist.

The open source platform MySQL [12] has been qualified as a good approach to ensure high flexibility among other commercial counterparts like Enterprise Resource Planning (ERP) systems. This enables a relative high independency of hard- and software.

The ELIMA database system has the following main features:

(1) Supports creation of relational database
(2) Facilities housing of the data/information in various forms (charts, text, binary objects, etc.)
(3) Provides a standard way for data exchange (e.g. independent from programming language, DBMS and operating system)
(4) Supports both intuitive and structured query methods to retrieve the required data/information
(5) Based on client-server architecture
(6) Web-enabled for access by manufacturers, relevant stakeholders and actors via the Internet / Intranet

Storage of raw data in the database does not provide relevant information to the stakeholders and actors. As such, information engine and ELIMA manager in the lifecycle information management layer provide tools to manage and extract information from the product life cycle data in order to predict the remaining lifetime or the treatment of the obsolete products and components.

The ELIMA manager is at the core of the ELIMA system to administer the data/information flow between various internal modules and external actors. It also provides various functions such as report generating and event scheduling to support various

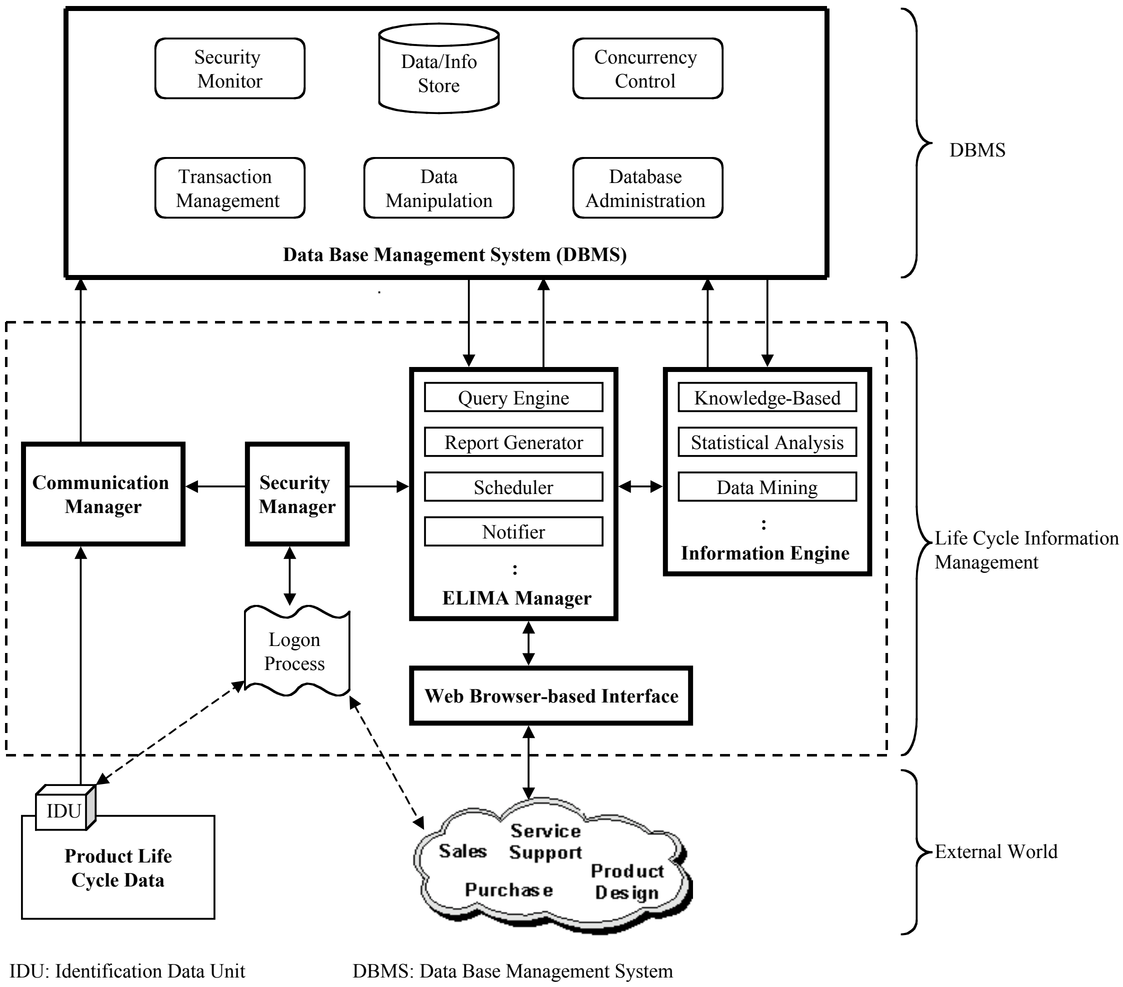

Figure 1: ELIMA Reference Architecture

ELIMA activities. The ELIMA manager comprises the following components:

a) Query engine. An application component that facilitates information retrieval from DBMS.
b) Report generator: An application component designed to present the requested information in a structured form. XML standard should be used to separate the data content and presentation so that the same data set can be presented in various forms such as chart, table, etc.
c) Scheduler. An application component responsible for scheduling the regular mandatory operations.
d) Notifier. An application component responsible to notify the appropriate user(s).

6. DATA USE FOR RELIABILITY/LIFE TIME PREDICTION

6.1. Failure Modelling

Failure modelling is a key to reliability engineering. Validated failure rate models are essential to the development of prediction techniques, allocation procedures, design and analysis ethodologies, test, demonstration- and control procedures, etc.

Failure models based on physical or chemical reactions will not give the time for a component to fail. Rather the time a given percentage of the parts will fail or the probability that a given part will fail in a specified time.

There are three main basic reliability concepts [13]:

Mean-Time-To-Failure (MTTF)
MTTF is the expected value of time to failure and is derived from basic statistical theory.

Mean Life (□)
The mean life refers to the total population of items being considered. For example, given an initial population of n items, if all are operated until they fail; the mean life is merely the arithmetic mean time to failure of the total population.

Mean-Time-Between-Failure (MTBF)
This concept appears quite frequently in reliability literature; it applies to repairable items in which failed elements are replaced upon failure.

Individual parts will fail according to their individual strengths, which will vary from part to part and are practically unknown. Similarly, the time to repair a failure will also vary depending on many unknown factors.

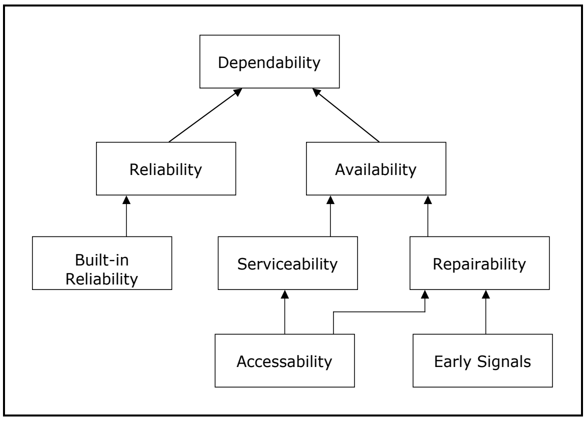

Figure 2: Characteristic of Dependability

Inputs to failure rate models are operational field data, test data, engineering judgement and physical failure information. These inputs are used by the reliability engineer to construct and validate statistical failure rate models and to estimate their parameters.

6.2. Reliability Prediction

A hierarchy of reliability prediction techniques has been developed to accommodate the different reliability study and analysis requirements and the availability of detailed data as the system design progresses [14]. These techniques can be roughly classified in four categories, depending on the type of data or information availability for the analysis. The categories are [15]:

(1) Similar Item Analysis
Each item under consideration is compared with similar items of known reliability by estimating the probable level of achievable reliability, and then combined for higher level analysis.

(2) Part Count Analysis
Item reliability is estimated as a function of the number of parts and interconnections included. Items are combined for higher level analysis.

(3) Stress Analysis
The item failure rate is determined as a function of all the individual part failure rates as influenced by operational stress levels and derating characteristics for each part.

(4) Physics-of-Failure Analysis
Using detailed fabrication and materials data, each item or part reliability is determined using failure mechanisms and probability density functions to find the time to failure for each part. The physics-of-failure (PoF) approach is most applicable to the wearout period of an electronic product's life cycle and is not appropriated for predicting the reliability during the majority of its useful life.

The reliability specification must cover all aspects of the use environment to which the item will be exposed and which can influence the probability of failure. The specification should establish in standard terminology the "use" conditions under which the item must provide the required performances.

Time is the most relevant dynamic value for predicting the lifetime. Temperature is known to vary the rates of many physical and chemical reactions. Because the failure mechanisms of many electronic products are basically physical/chemical processes, temperature is often used as acceleration stress in life testing. Humidity is a factor that will alter the electric conductivity between integrated circuits and if combined with high temperatures it might cause corrosion and other damages to the ICs. The failure mechanism affected by humidity includes corrosion of metallisation, electrolytic conduction between electrically biased metallisation paths, and charge separation on the surface of metal oxide semiconductor (MOS) structures.

Mechanical shocks are important because they could cause some rupture of soldering or contact disconnection in the electronic/electric device or also break some sensible parts in several electronic equipment (like coils and/or antennas) as well as the support parts of the PCB, like screw bases, etc. Lots of devices are really sensitive to inappropriate power.

Voltage in conjunction with temperature is an agent of many surface degradation processes. Current increasing is a direct indicator of occurred failures in a device. Failures induced by vibration in combination with other environmental parameters may be due to flaws that vary from gross drilled-hole misalignment, cold solder joint, and chemical contaminants to crystalline imperfections. High electric fields increase the mobility of any contaminating ions that may be present.

The information engine of the ELIMA life cycle information management consists of a collection of data analysis tools and data mining techniques to facilitate information processing, leading to exposure of hidden information, unexpected patterns and relationships within the data set. The methodologies incorporated include:

(1) *Knowledge-based analysis*

A qualitative analysis and an interpretation of nature to capture the rules, expertise, know-how, procedures, polices and rules. This analysis is normally used in troubleshooting and maintenance. In addition, decision tree, fuzzy logic could be used in the induction of knowledge.

(2) *Statistical analysis*

A traditional and useful data analysis tool used to support decision-making and value prediction. The main analytical tools include simple analysis, correlation, linear regression and on-linear regression.

(3) *Data mining*

A process of discovering meaningful new correlations, patterns and trends by mining large amount of data stored in the ELIMA database.

The ELIMA system including dynamical data is able to provide the required data for reliability prediction using standardized methods for data analysis.

7. OUTLOOK

The ELIMA system is a powerful approach to provide all environmental product related information, to track the product and ensure the information flow between the stakeholders during the lifetime. It combines static and dynamic data representing the environmental performance of the product. Depending on the product application and the purpose of the ELIMA system not all elements need to be implemented. For example providing a set of static data including material declaration and disassembly information would fulfill the WEEE requirements.

Especially the goal of the ELIMA system to support the reporting of environmental performance has the highest potential and need for standardisation, because these data will be externally used. The focus of standardisation should be on the data content. The approach of EICTA Environmental Supply Chain Management (ESCM) task force seems to be a good starting point to standardise the material declaration. Others have to be discussed with standardisation committees like ECMA or TCO.

Using dynamical data measurement methods and parameter should be standardized depending on the product application in order to answer reliability questions. Quality criteria should be used to classify the product depending on their remaining lifetime. The standardisation of such ELIMA systems has to ensure a soft- and hardware independency. Especially for electronic products this approach allows to share the function of product specific components and software modules, which are already included without any additional resources consumption.

8. ACKNOWLEDGEMENT

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