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AUTO-ID CENTRE

WHITE PAPER

The Role of Product Identity in End-of-Life Decision Making

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ABSTRACT

The core output of the Auto-ID Center's developments is the availability of networked product identity. This white paper argues that product identity data is a key requirement in the development of efficient management of the product life cycle – with a specific focus on the so called "End-of-Life" phase. End-of-Life is of particular importance in both Europe and Japan at present where stringent legislations are being introduced to ensure maximally efficient reuse, reworking, recycling or disposal of products. Because product identity implies access to a unique information profile, we develop in this paper a product information model. We discuss the ways in which such a product information model can be used to enhance decision making at the end-of-life of a product. This paper represents the first in a series of white papers on this role of Auto-ID in Product Lifecycle Management (PLM).

WHITE PAPER

The Role of Product Identity in End-of-Life Decision Making

Biographies

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Ajith is currently reading for his PhD degree at Cambridge University. He has a first degree in Mechanical Engineering and has gained Master of Science qualifications from Birla Institute of Technology & Science, India (Industrial Management) and NC State University, USA (Industrial Engineering). Ajith also has experience in the textiles, machine tool and steel industries from India and has worked on projects with Nortel Networks and IBM in the USA. For his PhD, he is researching the impact of product-identity information on decision making associated with end-of-life and reverse logistics processes. In his free time, Ajith enjoys travelling and playing cricket.

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Duncan McFarlane is a Senior Lecturer in Manufacturing Engineering in the Cambridge University Engineering Department. He has been involved in the design and operation of manufacturing and control systems for over fifteen years. He completed a Bachelor of Engineering degree at Melbourne University in 1984, a PhD in the control system design at Cambridge in 1988, and worked industrially with BHP Australia in engineering and research positions between 1980 and 1994. Dr McFarlane joined the Department of Engineering at Cambridge in 1995 where his work is focused in the areas of response and agility strategies for manufacturing businesses, distributed (holonic) factory automation and control, and integration of manufacturing information systems. He is particularly interested in the interface between production automation systems and manufacturing business processes.

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Contents

1. INTRODUCTION

Businesses are getting increasingly competitive and companies are constantly on the lookout for tools and methods to help them concentrate, develop and build on their core competencies. In particular, shortening product lifecycles and increasing government regulations have forced organizations to take a second look at the way they manage their products throughout their lifecycle. The motives for better lifecycle management have been well documented in the academic literature [1,2,9,10,13, etc].
Three key issues are:

– Environmental considerations
– More effective reverse logistics[1]
– New marketing opportunities

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 minimize eco-burden. It had been predicted that 7.3 million tons of electronic waste will be produced in Europe in 2002 with growth rates of 3 to 5% [2]. In June 2000, DG XI of the European Commission issued a "Proposal for a Directive on Waste from Electrical and Electronic Equipment (WEEE) [3,4]" that makes the producers of electronic and electrical equipment responsible for take-back and recovery management of their products. The directive also specifies collection targets for local authorities as well as recovery and recycling targets for the producers to be met by the given deadlines. Such laws have been enacted in Japan [5,6] and are actively debated at the Federal and State levels in USA [7]. This has prompted many firms to become environmentally responsible and to change their operations in a more eco-friendly way. Guide et. al. [8] provides illustrations of how various companies have embraced recoverable manufacturing as a way to minimise waste disposal and ensure environmental sustainability.

In addition to the "eco-motive", efficient reverse logistics has a financial motive as well. Returns related costs for U.S. companies in 1997 was estimated to $35 billion (0.5% of U.S GDP) [9]. This reveals a scope for improvement and costs benefits associated with product returns/reverse logistics. There is also an added incentive of lower purchasing/inventory costs due to reuse of components from End-of-Life products [10]. Returned products may enter the production process again as input resources, either in the original form or as components and modules after disassembly. Many firms have recently reported increased profits by reselling returned products in secondary markets after refurbishment [8,11]. Guide et. al [8] claims that remanufacturing operations account for sales in excess of $53 billion per year in the US. More examples and illustrations of benefits reaped by companies from implementing reverse logistics programs can be found in Stock [12]. In addition, the shift from selling products to selling sets of services makes the reuse of recovered materials, parts, and products desirable.

Besides ecological and economic factors, customer awareness is creating opportunities for "green marketing" and new markets for returned goods [12]. This brings the attention here to the management of products at end-of-life (EOL), which concerns the processing of products after the initial user discards the product [13]. Due to increasing legislative pressures as well as the opportunity to use lifecycle management as a competitive advantage, organizations have started actively getting involved in a number of consortiums such as PROMISE (Product Embedded Information System for Service and End-Of-Life) [2], CARE (Comprehensive Approach for the Recycling and Eco-Efficiency of Electronics) [3], RevLog [4], etc. that collaborate with research institutions in order to develop tools and solutions for better product lifecycle management.

The focus of this research is to assert the role that the association of unique identity with a product can play in decision making associated with end-of-life management of products and to provide rationale for a product-oriented lifecycle information management system.

[1] Reverse Logistics is defined as "The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal. [9]"

[2] PROMISE Proposal (http://www.ims.org/projects/project_info/promise.html)

[3] CARE Electronics (http://www.care-electronics.net)

[4] RevLog, the European working group for reverse logistics (http://www.fbk.eur.nl/OZ/REVLOG/)

2. END-OF-LIFE MANAGEMENT OF PRODUCTS

End-of-Life management involves those options available to a product after its useful life. Thierry et. al. [14] illustrates five product recovery operations, aimed at recapturing value from EOL products as well as components:

– **Repair and reuse**, the purpose of which is to return used products in working order. The quality of the repaired products could be less than that of the new products.

– **Refurbishing**, the purpose of which is to bring the quality of used products up to a specified level by disassembly to the module level [5], inspection and replacement of broken modules. Refurbishing could also involve technology upgrading by replacing outdated modules or components with technologically superior ones.

– **Remanufacturing**, the purpose of which is to bring used products up to quality standards that are as rigorous as those for new products by complete disassembly down to the component level and extensive inspection and replacement of broken/outdated parts.

– **Cannibalisation**, the purpose of which is to recover a relatively small number of reusable parts and modules from the used products, to be used in any of the three operations mentioned above.

– **Recycling**, the purpose of which is to reuse materials from used products and parts by various separation processes and reusing them in the production of the original or other products.

In addition, parts and materials that could not be recovered by any of the above five operations will be **disposed** in accordance with safety and environmental regulations. An alternative for disposal is **energy recovery** by means of incineration, which has its own environmental impact. Environmental directives specify the maximum proportion of the product that can be land-filled. For example, the WEEE directive requires that 70% by weight of EOL electronic products should be recovered and at least 50% of the recovered WEEE should be reused or recycled [4]. Hence, the objective of any reverse logistics chain should be to minimise the proportion of products being disposed.

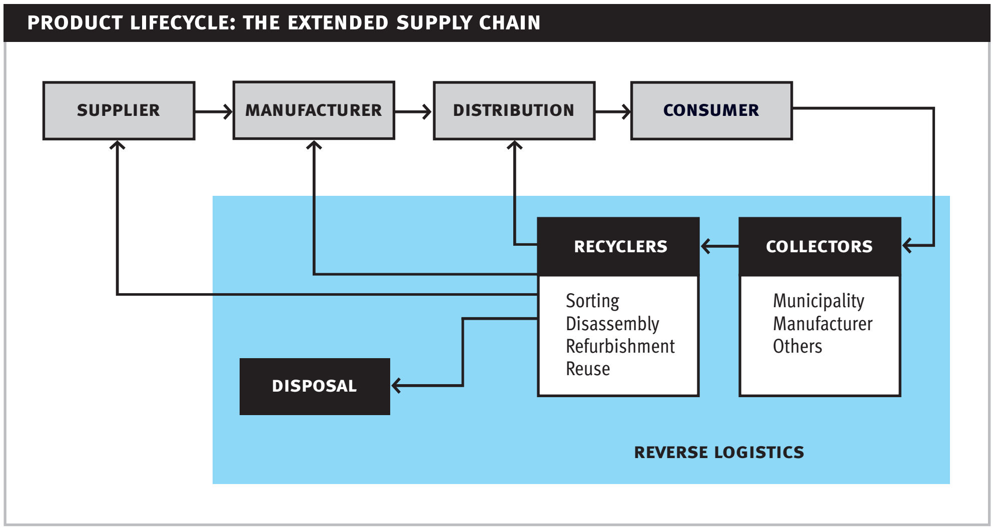
As discussed earlier, one of the motives for effective EOL management is to minimize the environmental impact of products, however without sacrificing function and quality. Design for Environment (DfE) is an optimisation process with the goal of minimising the detrimental impact of the product on the environment throughout its life cycle. As mentioned previously, a number of various alternatives are available to process products at their end of usage life. Rose et. al. [15] describes a good EOL strategy is to choose the alternative that causes minimum damage to the environment and maximises the reusability of the products and components.

Several researchers have illustrated how the EOL strategy depends on the characteristics of the product [13,16,17,18]. The key for effective DfE is planning of EOL strategies in early stages of design [18]. Designers can design products that can be easily disassembled, have longer life, have modular construction, require minimum disposal, etc. Tools such as End-of-Life Design Advisor [19] are available to help designers to select the best EOL strategy for a given product.

Once a product is designed according to a DfE policy and an appropriate EOL strategy has been selected, the next step is to ensure that sufficient information is made available to the different actors (e.g., logistics providers, recyclers) in the value chain so as to manage the product across the different stages of its lifecycle. Figure 1 shows the different stages of a product's life cycle.

[5] A module is defined as a group of individual components connected together physically and logically to perform a particular function (e.g.: power supply, gear box, etc.).

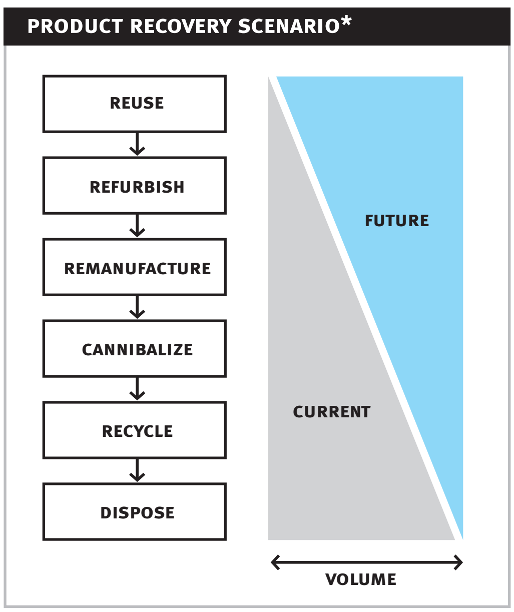
Figure 1



The hierarchy of product recovery options in order of preference for environmental sustainability is shown in Figure 2. The figure also shows the current and expected future scenarios of product recovery in terms of volume of product recovered [20].

Figure 2:

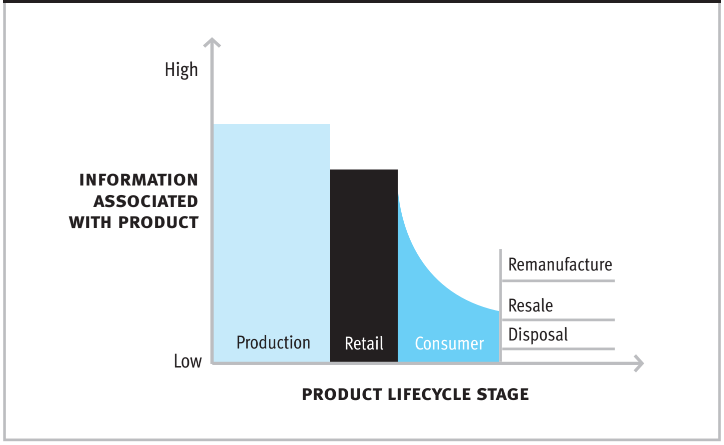
* Current and Future (adapted from [20])



However, a fundamental obstacle to achieving more acceptable product recovery levels is that information associated with the product is often irrecoverably lost after the point of sale [21]. The progressive loss of product information as it moves through its lifecycle is illustrated in Figure 3. Hence, when the product reaches its end-of-life, little information is available to the recyclers regarding its identity, constituent components or its current state. Rogers and Tibben-Lembke [9] found in a survey that lack of information systems infrastructure was one of the largest barriers reverse logistics executives face. Moreover, the huge variety of products and the complexities involved in the EOL management of these products makes it a difficult task to collect a wide range of information.

Figure 3

SCHEMATIC PLOT OF PRODUCT INFORMATION CONTENT LOSS [21]



With environmental directives taking effect, in the next few years manufacturers expect a big rise in the number of returned products. This, as well as high personnel costs compared to the relatively low potential of value recovery, makes strictly manual product recovery such as manual sorting, disassembly etc. as is done today, non-profitable in the long run [22].

Although there is a myriad of commercial software tools [23,24,25,26] to manage various stages of product lifecycle from design to distribution to customer service, little has been done towards EOL management or reverse logistics [27]. Current Product Lifecycle Management (PLM) systems are designed to support design, manufacturing and distribution of products only up until the point of delivery to the customer (e.g., My SAP PLM [23], EDS PLM Solutions [24], etc.)

To summarise, for reasons such as lack of infrastructure, excessive costs, and lack of necessary information, products today are not recovered at the end of life in an efficient and environmentally friendly manner. With the development of suitable infrastructure, it is hoped that the situation can be reversed (as per Figure 2) with maximum emphasis on reuse and the minimum possible disposal.

In the next section we begin to establish an information model to support a product over its entire lifecycle as a means of improving the availability of product information at end-of-life.

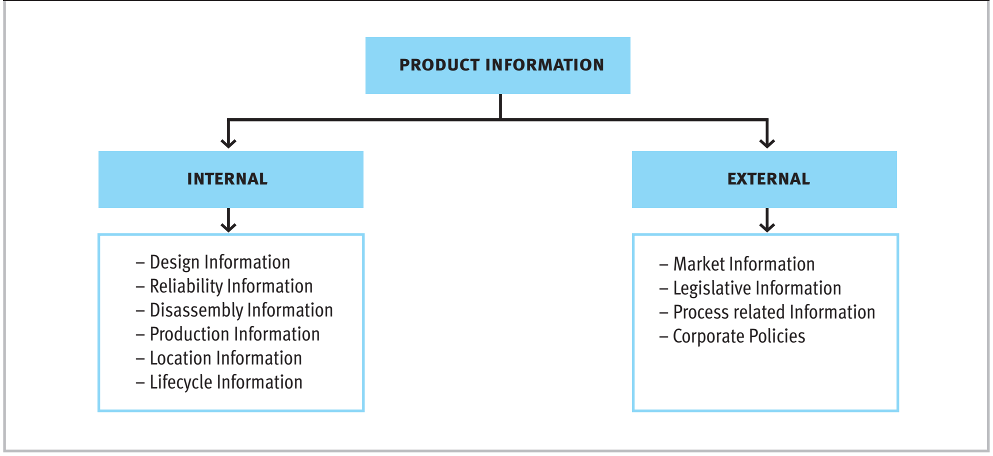
3. INFORMATION REQUIREMENTS FOR END-OF-LIFE DECISION MAKING

In order to build a model for lifecycle information systems, it is essential to first determine the information requirements for decision making at end-of-life. The aim of this section is to illustrate the role of product information in end-of-life product recovery decision processes and to provide a basis for determining the possible characteristics of a lifecycle information management system.

The product information required for end-of-life decision making can be classified into (a) Internal information, and (b) External information [28,33,41]. The composition of each of these categories is shown in Figure 4, and we define and describe each category in detail on the next page.

Figure 4

INFORMATION REQUIREMENTS FOR EOL DECISION MAKING



3.1. Internal Information and its Impact on EOL Decisions

Internal information includes information required to maintain the identity of a product throughout its lifecycle. The different components that provide this information will now be explained along with its impact on end-of-life decisions.

Design information

Design information primarily comprises of information regarding the physical structure of the product, i.e. information on the location, size, shape and weight of components and modules within the product. Such information is usually obtained from CAD drawings developed during the design of the product. This information is crucial during disassembly for identifying, locating and recovering reusable components. The weight and volume of the product has consequences for collection, handling and storage. This often determines the economic viability of various recovery methods.

Information regarding material composition of the components is essential for determining their recovery value. Providing this information will enable recyclers to make better informed decisions on the best option to recover the product. Armed with this information, for example, a recycler would be able to determine that the recovery value of a particular component outweighs the cost of disposal. Information regarding material composition will also result in identifying potentially hazardous materials used and determining their proper disposal method.

Reliability Information

Reliability information pertains to the parameters describing the expected life of the components. Length of lifecycle or the life of the product is a critical factor influencing EOL decision-making [20]. Availability of reliability information of components will help in determining their reusability and residual value with a higher accuracy. This information could be provided in terms of commonly used reliability parameters such as MTBF, MTTR [6] etc.

[6] MTBF – Mean Time Between Failures; MTTR – Mean Time To Repair

Disassembly information

Disassembly, being the precursor to any product recovery operation, has been identified in the literature as the most important activity in EOL management [29,30, and references therein]. Almost every recovery option involves some amount of disassembly. For various reasons such as irreversible joints, degradation during use, changes to the structure brought about by maintenance or upgrade etc, the disassembly process is often not the exact reverse of assembly process. Hence, in addition to design and reliability information, disassembly information possibly in the form of instructions should be made available at EOL. As end-of-life management gathers importance in the industry, increasing number of products are designed for disassembly. In these cases, disassembly instructions can often be provided at the design stage itself.

Another decision to be made at EOL is the level of disassembly to be performed. In the simple case, the level of disassembly depends on the cost of disassembly, cost of disposal and value of disassembled components. Dini et. al [31] shows that other factors remaining constant, as disposal costs increases, increasing level of disassembly needs to be performed for profitable product recovery. This necessitates the generation of an optimal disassembly sequence for the product, that terminates when the maximum possible value has been recovered from the product. Since this depends on various factors such as the condition of components, their residual life and value at EOL, it is necessary to generate the disassembly sequence dynamically during the disassembly process itself.

The availability of disassembly instructions, coupled with other related information such as design, reliability, production and lifecycle information (described below) will enable automation of the product disassembly process, thereby increasing cost efficiency and lead to a possible reduction of components disposed.

Production Information

During production, the product would have undergone various processes such as forging, painting etc which might change the fundamental properties of materials used or which necessitates special requirements for disassembly. For e.g., a part coated with a hazardous chemical might need to undergo special treatment before it can be handled for disassembly. Hence it is important that the recoverer must have some degree of knowledge about all the processes and materials that were used in the manufacture of the products.

Due to the unseen complexities arising during the manufacture of the product, it is often required that modifications to the design be brought to efficiently build the product. This has ramifications further down the lifecycle of the product. For instance, the design of a product might have had a screw joint that had to be changed to a welded joint during production. This requires the disassembly process to be changed as a welded joint cannot be separated in a non-destructive manner.

Hence, design information associated with the product needs to be updated with the relevant changes made during its production. This will help in decreasing the uncertainty associated with the structure and composition of the product at its end-of-life, and hence reduces unforeseen changes during disassembly processing.

Location information

The quantity of product at various stages of the lifecycle coupled with information regarding the expected life of the product (reliability information) helps to predict the time when it will reach its end-of-life and thus help in the planning of recovery resources.

The installed base of product is an aggregate of quantity and geographic distribution, i.e., it is a measure of geographic concentration of the product. The profile of the installed base has implications for the collection system design and for collection costs.

Location information provides the specific location and the quantity of the products available as they move across the supply chain throughout its lifecycle. Retailers and users are the main providers of this type of information. A case study with a company that provides reusable pallets [32] conducted showed how location information could be used for formulating strategies to minimise pallet damages and losses, and for planning collection logistics efficiently.

Lifecycle Information
This includes information related to the use of the product over its entire life. Lifecycle information is typically collected over all the stages of the product's lifecycle from distribution to end-of-life.

Klausner and Grimm [33] establish that information on product properties and the history of product use are essential for higher levels of product recovery. This is due to the fact that operating conditions and maintenance has a huge bearing on the structural composition of the product and quality of the components at its end-of-life. Quality, in the context of product recovery is defined as the functionality, reliability, and remaining lifetime of the product [34]. Due to strict quality requirements for reuse and refurbishment, the reusability of components and modules depends on their quality at the time when the product is returned. Only with that, their residual lifetime can be calculated.

Another issue is that of component replacement during usage phase. A recently replaced component will have a longer residual life than those that were originally part of the product. Hence, maintenance and replacement history will lead to greater chance of parts and modules reuse and reduce the cost of lost opportunity due to the disposal of potentially reusable parts and modules.

The importance of collecting lifecycle history data was further verified by a case study [32], where information on product usage, breakage and losses along the supply chain supported pricing strategies as well as provided key input to improving performance measures.

In the next section, we describe a different set of information required for EOL decision making classified as "external information".

3.2. External Information and its Impact on EOL Decisions

External information includes those types of information that is not directly associated with the product, but those that impose constraints on the recovery options available. The different components that constitute this category of information will now be explained along with its impact on end-of-life decisions.

Legislative information
Different countries and governments impose different legal requirements for waste management and recycling. Environmental directives specify the maximum proportion of the product that can be land-filled (refer to section 2). In addition, these directives specify certain guidelines for disposing hazardous materials found commonly in many products (e.g., batteries, medical equipment, etc.).

As these rules and regulations change continuously, effective EOL decisions depend on the ability of the information system to keep track of the most recent legal requirements. The availability of this information leads to product recovery processes that are compliant to government legislation and hence minimise the negative impact on the environment.

Market information
Market information intends to provide knowledge regarding demand and price of refurbished components and modules that constitute the end-of-life product. Since this determines the economic viability of product recovery operations, they are essential for deciding the optimum disassembly level and EOL strategy of products.

For instance, knowledge regarding market demand and price for a particular component will help the recycler to decide whether it is economical to disassemble the end-of-life product and retrieve that particular component for reuse, or to recycle it for material recovery.

Process information
Process information pertains to the knowledge regarding the recovery process itself, for e.g., resource availability, schedules, etc. This information enables matching of resources available with the recycler to the processing requirements of the product.

Corporate Policies
Legal requirements and environmental responsibility may prompt manufacturers and other actors in the supply chain (including users) to impose recycling and product recovery policies for products. These policies may change between the time of product inception and production and the time when the product reaches its end of life. By providing updated information regarding corporate policies will ensure that products are recovered as per the standards and policies of all parties involved.

Having described the various components that constitute product information, in the next section we summarise the role of product information in EOL decisions making.

3.3. Summarising the Role of Product Information in EOL Decision Making

Table 1 provides a summary of product information requirements and their impact on end-of-life decisions. It is seen here that availability of product identity information appears to have a positive impact on EOL decision making, leading to more effective EOL management as measured by increasing levels of product reuse and minimal impact on environment due to reduced levels of product disposal.

In addition, factors external to the product impose constraints to the product recovery processes. Making information about these factors available enables the system to ensure that efficient EOL decisions are made that conform to the requirements and constraints imposed by these external factors.

Table 1: Product Information and its impact on EOL decisions

TYPE	CATEGORY	DESCRIPTION	IMPACT ON EOL DECISIONS
Internal Information	Design	– Physical Structure. E.g., size, shape, weight etc. – Material Composition	– Lead to easier identification, location & recovery of components. – Help in calculating recovery value of components. – Lead to better-informed decisions on best option available to recover the product.
	Reliability	– Expected life of components (e.g., MTTR, MTBF, useful life, etc.)	– Provides critical input for calculating residual life and value of parts and modules.
	Disassembly	– Disassembly instructions – Disassembly process plan	– Efficient allocation of disassembly resources (e.g., planning and scheduling of operations). – Provides crucial input to determine the optimal disassembly level. – Lead to determining the best disassembly sequence. – Lead to higher recovery levels and lower disposal of reusable components. – Enable automation of disassembly processes, resulting in higher cost efficiency of operations.

Continuation of Table 1

TYPE	CATEGORY	DESCRIPTION	IMPACT ON EOL DECISIONS
Internal Information	Production Information	– Design changes required due to production complexity – Material and structural changes brought by production operations	– Reduces uncertainty associated with structure and composition of product. – Reduces unforeseen changes during disassembly processing.
	Location Information	– Installed base, i.e., geographical concentration of the product	– Lead to better planning of resources. – Lead to efficient collection planning.
	Lifecycle Information	– Operating conditions – Maintenance data – Parts replacement information	– Lead to better assessment of residual value of products, modules and parts. – More accurate information regarding the structure and composition of the product at end-of-life.
External Information	Legislative Information	– Recycling laws and legislation – Product disposal limits – Product recovery guidelines	– Results in ensuring that product recovery is handled according to rules and regulations imposed by the government.
	Market Information	– Demand and price of refurbished products and components	– Leads to maximisation of cost efficiency of product recovery processes.
	Process Information	– Resource availability, schedules, etc.	– Enables efficient management of resources.
	Corporate Policies	– Corporate recycling and product recovery policies	– Ensures product recovery management in a way that conforms to the standards and policies imposed by supply chain partners.

The next section is devoted to determining the possible requirements for a lifecycle information system that will ensure the availability of all necessary product information identified in the above discussions.

3.4. Characteristics of Lifecycle Information Systems

Having identified the information requirements for EOL decision making, we now establish a possible set of characteristics of a lifecycle information system that would provide appropriate decision support for EOL management.

A product-oriented approach is proposed as a means to model lifecycle information management systems. A product-oriented approach is where information is maintained at unique item level and is updated as the product moves across the various stages of its lifecycle. This will enable decision support that handles the unique requirements of every single product.

One of the factors that forces such an approach is that manufacturers today are increasingly embracing the concept of mass customization [35,36], where each product is manufactured uniquely to suit the requirements of individual customers. Hence, it is unlikely for instance, that a product sold to customer A be exactly similar to another product, sold under the same label, to customer B. Moreover, the fact that each product is subjected to a different set of conditions throughout their lifecycle makes it evident that product information will be unique to every single product.

In addition, factors external to the product, such as regulations, policies, market demand, and processing requirements imposes a different set of rules and constraints for each and every product. Thus, recovery processes depends extensively on the characteristics of each product and the components that constitute the product. The recovery processes and associated support systems are hence required to adapt flexibly to the varying requirements imposed by each different product.

This flexibility required by the recovery processes can be enabled by a lifecycle information system that has the following possible characteristics:

1. Ability to uniquely identify and track products at the item level throughout the supply chain.
2. Ability to provide relevant identity information associated with the product as well as external information as required by EOL processes.
3. Ability to provide information to determine the "current state" of the product.
4. Ability to update product information as it changes throughout the product's lifecycle.
5. Ability to communicate all related information across all partners of the supply chain as required.
6. Ability to provide instructions that enable the system to automatically route products through the product recovery processes.
7. Ability to provide decision support at various stages of the product recovery process.

It is our contention that a "product-oriented" information system is well suited to meeting these needs. However, before beginning to model a lifecycle information system in this way, it will be useful to review existing lifecycle information systems developed by the reverse logistics research community. In the next section we present a brief overview of some of these systems and discuss their characteristics and shortcomings.

4. Existing Lifecycle Information Systems

This section reviews existing product lifecycle information systems designed to support EOL decision making. These systems can be divided into two categories:

– Design/disassembly data sharing systems
– Lifecycle information monitoring systems

Each of these addresses specific aspects of product information, and we summarise their contributions next, and examine their shortcomings.

4.1. Design/Disassembly Data Sharing Systems

Design/disassembly data sharing systems are designed to allow manufacturers to share design and disassembly related information with the recyclers. We now have a look at some of these systems.

Toyama [37] proposes the model of "Inverse Manufacturing Product Recycling Information System (IMPRIS)", a prototype of a recycling information retrieval system that allows manufacturing companies and recycling companies to publish and access information via internet to promote product recycling.

Hesselbach et. al. [2] describes the “recycling passport”, which is a comprehensive information source for product recovery activities. The recycling passport provides information about the design of the product including materials and mass weight of substances, information about accessibility and about hazardous substances and their separation. It focuses on product identification and describes the procedure to disassemble the product, all supported by illustrations.

Soga et. al. [38] illustrates a “Products Lifecycle Management System (PLMS)” developed at Hitachi Corporation that uses Radio Frequency Identification (RFID) technology to store and retrieve information regarding product on an individual basis.

Rosemann et. al [39] describes an integrated Recycling Data Management System (ReDaMa) that holds product data during the entire lifecycle of products from the engineering design, over production and use, up to the end of life. The central module of the software system permits the generation and visualisation of an abstract product model, which consists of recycling and dismantling relevant data concerning component and connection properties as well as of information about the structure of the product. This information is used to determine the best disassembly sequence for the product by taking into account the efforts of disassembly processes by the simulation of dismantling.

In general, it is seen that these systems have the following characteristics in common:

- Manufacturers share product level (not unique item level) design data with the recyclers.
- They provide disassembly instructions to recyclers as set down at the design stage of the product.
- Recyclers and other authorised supply chain partners are able to access this information through the Internet.

4.2. Lifecycle Information Monitoring Systems

Lifecycle information monitoring systems are designed to monitor and record performance parameters during the usage phase and make this information available to the recyclers when the product reaches its end-of-life. We now provide a brief summary of some of these systems.

Klausner and Grimm [33] describe the idea of “Information System for Product Recovery (ISPR)”, where product data strongly correlated to the degradation of components during the usage phase of the product is recorded in an electronic device called “Electronic Data Log (EDL)” embedded in the product. In addition to the dynamic data captured during the usage phase, the system also holds static data, which describes the design of the product and also disassembly-related information in an external database. The EDL contains a product identification, which would provide a link between the product and the static data on the product stored in the external database. The data recorded during the usage phase are retrieved and analysed by the ISPR along with the static data for to provide input for disassembly planning when the product is returned at its end-of-life.

Simon et. al. [40] describes a life cycle data acquisition (LCDA) system where performance parameters and error conditions of products are continuously monitored, timed and recorded during operation and during servicing and make the recorded data accessible to the recyclers at the time of product recovery. Scheidt and Zong [41] describes a system where a data storage unit called the “identification unit” is attached to all modules of interest in a product. Important life history data is monitored and collected along with product design information in the identification unit and this data is made available during recycling through a standardised interface called the “green port”.

In general, these systems display the following characteristics which are relevant to lifecycle data monitoring systems:

- Enable unique identification of products at item level.
- Provide design and disassembly information as set down at the design stage of the lifecycle.
- Monitor and records important performance parameters of components throughout the lifecycle and stores this information within the product.
- Recyclers are provided access to the dynamic information stored with the product and also linked to the 'static information' stored by the manufacturers through the Internet.

4.3. Shortcomings of Existing Systems

We now discuss the shortcomings of these systems by comparison with the requirements for a lifecycle information system as identified in section 3.4.

The design and disassembly data sharing systems described in section 4.1 are designed with the sole purpose of providing design and disassembly information to the recyclers. Table 2 provides a brief summary of the characteristics of existing lifecycle information systems. By comparing with the requirements of lifecycle information systems illustrated in section 3.4, it is clear that at the present none are capable of providing accurate information about the state and structure of the product at its end-of-life because they fail to incorporate changes brought throughout the product's lifecycle and associated external information required for making decisions at end-of-life.

The lifecycle data monitoring systems in section 4.2 classify information into (a) static classes, which includes design and disassembly information, and (b) dynamic classes, which includes performance parameters that affect EOL decisions. The major drawback of such an approach is that it fails to capture the dynamic nature of the so-called 'static' information. For example, it is unable to incorporate changes inflicted by the production process on the design of the product. In addition, they fail to integrate necessary external information (legislation, corporate policies, etc.) that is required for making effective product recovery decisions. This results in the inability of these systems to provide accurate information regarding the status of the product at end-of-life, thereby failing to provide sufficient support for EOL decision making.

Table 2:

* Only a part of lifecycle history and current state information is provided by monitoring performance parameters.

CHARACTERISTICS OF EXISTING LIFECYCLE INFORMATION SYSTEMS

Existing Solutions	Unique Product ID	Product Identity Info	External Info	'Current State' Info	Lifecycle history	Communicaton with supply chain partners	Process Instructions	Decision Support
IMPRIS[37]		✓				✓	✓	
Recycling Passport[2]		✓				✓	✓	
PLMS[38]	✓	✓	✓			✓	✓	✓
ReDaMa[39]	✓	✓				✓	✓	✓
ISPR[33]	✓	✓	✓	✓*	✓*	✓	✓	✓
LCDA[40]	✓	✓		✓*	✓*	✓		
Green Port[41]	✓	✓		✓*	✓*	✓		

Hence, we note that at present, there is no one single information system that comprehensively covers all the requirements of an ideal lifecycle information management system. Noting these shortcomings, in the next section we begin to outline a new model for lifecycle information management systems.

5. TOWARDS AUTO-ID BASED LIFECYCLE INFORMATION MANAGEMENT SYSTEMS

This section proposes a product-oriented information model for lifecycle information management systems which is enabled by the product identification technologies developed by the Auto-ID Center [7]. The Center is an industry-sponsored global research organization working to create standards and technology solutions needed to establish a new network for tracking items across the supply chain. We begin this section by providing a very brief overview of the technologies developed by the Auto-ID Center. The reader is referred to Sarma [42] for a detailed insight on these technologies.

7 AUTO-ID CENTER (http://www.autoidcenter.org)

5.1. Auto-ID Technology

The Auto-ID Center essentially aims at improving the bridge between information networks and material flows to form a seamless, synchronous network functioning as a product data repository. In order to achieve this, the center is developing:

A Unique product identity described by an EPC™ (Electronic Product Code™)

The EPC™ is currently a 96-bit numerical code embedded on memory chips – “smart tags” that are attached to individual products and physical objects. Auto-ID technology thus makes dynamic data collection possible, where product identification is build into a product, giving it a unique footprint. (See Figure 5).

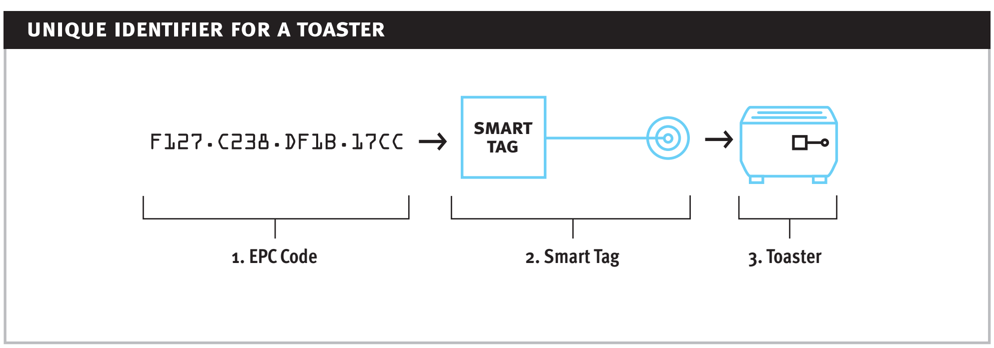


Figure 5:

1. EPC™ Code
Unique 96-bit identifier

2. Smart Tag
Made with microchip w/antenna – transmitting EPC™ Code

3. Toaster
Typical object becomes unique because of EPC™ and “smart tag.”

Each smart tag is scanned by a radio frequency ‘reader’, which transmits the product’s embedded identity code to the Internet, where the real product information is kept. Depending on product characteristics and associated lifecycle information requirements, the tags itself may not retain any information other than the EPC™. This minimizes cost while not compromising on functionality. Nevertheless, where required, ‘active tags’ that are able to store information can be used to capture dynamic lifecycle history information.

A Name Server that directs queries to information linked to an EPC™

The EPC™ acts as a pointer to a specific location on the Internet where product data is stored – it is analogous to a web address. An Object Naming Service routes queries to information about an object that carries an EPC™ code. The ONS is based in part on the Internet's existing Domain Naming Service (DNS), which routes 'addresses' to appropriate web sites.

A Mark-Up Language to describe Product features

Physical mark-up language (PML) is a new standard language for describing the Form, Fit and Function of Goods and Services to the Internet in the same way that Extensible Mark-Up Language (XML) is a language to describe data fields for Internet sites. The advantage of having a standard language to represent product information is that it can be used by all the actors of the value chain irrespective of the information systems and databases in place.

Auto-ID technology will allow the Internet to extend to everyday objects, providing connectivity between product and information. The 96-bit numerical code has the capability of accounting for over 268 million manufacturers, each with over one million individual products.

The Auto-ID project promotes the concept of distributed data storage allowing access to information from any point in the supply chain, regardless of the system used. This allows product information to be stored by various users in the product's lifecycle in their networks, but allow access to the information to authorized users (refer to Figure 6). This also provides the added flexibility of storing information in the smart tag itself, which could be uploaded to the network at a suitable time.

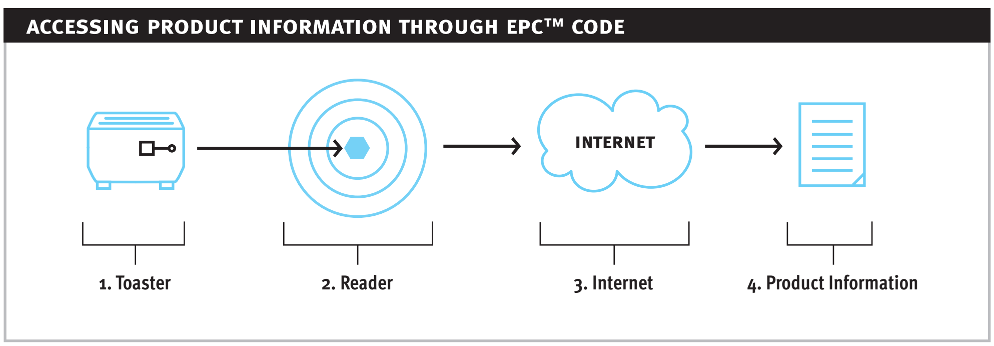
Figure 6:

1. Toaster
Transmits EPC™ Code from embedded smart tag

2. Reader
Could be found in sorting conveyors, disassembly table, etc.
Transmits EPC™ to the Internet.

3. Internet
Retrieves product information associated with the EPC™ Code.

4. Product Information
Product information retrieved in a standardised format.



This model for product identity extraction and linking it to related product information leads naturally to a product information model as developed in the next section.

5.2. Auto-ID Enabled Product Information Model

In this section we outline a product information model based on the capabilities provided by Auto-ID technologies. The model, which is developed along the requirements of EOL information systems as identified in section 3.4 is presented conceptually in Figure 7 and will now be described.

Requirement: Ability to uniquely identify and track products at the item level throughout the supply chain.

Approach: Electronic Product Code. The core of this model is derived from the ability of the system to uniquely identify every product by providing it with a unique ID, which is called Electronic Product Code (EPC™). It is envisaged that this code be encapsulated within the product using a 'smart tag', that can be read by radio frequency readers installed at various locations along the product's lifecycle. This also provides the ability to track the product as it moves through the supply chain and determine its location.

Requirement: Ability to provide relevant identity information associated with the product.

Approach: Product Specification Data. Data describing the physical form, properties, and other data pertaining to the product (for e.g., design & reliability information) will be stored in a database on the network and linked with the product through the product ID. The details regarding location of data storage and how this link would be implemented does not fall under the scope of this paper, but will be discussed in future papers.

Requirement: Ability to provide information to determine the "current state" of the product.

Approach: Other Sensory Data. Providing the product the ability to interact with its surrounding, by means of appropriate sensors will enable the system to monitor parameters that will provide necessary information to determine the current state of the product. This will enable the system to record any changes to the structure of the product, for e.g., changes due to complexities in production (refer to section 3.1) and update such information its information database.

Requirement: Ability to update product information as it changes throughout the product's lifecycle.

Approach: Product History. Product history data, as envisaged in this product information model is collection of all the snapshots recorded during its lifecycle, stored in a form that is retrievable for later use. This will include useful lifecycle information such as maintenance and usage data as well as parts replacements and upgrades.

Requirement: Ability to provide instructions that enable the system to automatically route products through the product recovery processes

Approach: Product Instructions. A rule represents an action taken on the basis of a logical condition and a recipe a structured sequence of rules for the completion of an operation. McFarlane et. al [43] associates the idea of a recipe with products and contrasts it to the "machine instruction" representing the sequence of steps carried out on a specific machine or resource. The uses of recipe information in the supply chain – and in fact the entire product life cycle – are numerous, ranging from supporting outsourced production, to distribution instructions for perishable products, to directing maintenance procedures, to providing recovery instructions at end-of-life. In the context of an Auto-ID product information model, rules and recipes form part of the 'active' information set that a tagged product may be connected to, in addition to product specification and history data.

Requirement: Ability to provide decision support at various stages of the product recovery process.

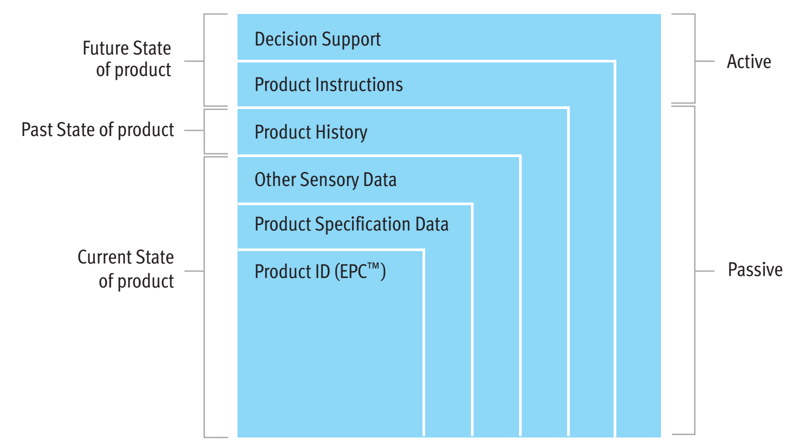
Approach: Decision Support. In addition to the information associated with the product, the information system may also include decision support software such as an intelligent agent [8] acting on its behalf. The reader is referred to McFarlane [44] for details on the role of software agents in Auto-ID based process control. These agents will bring to the system the capability to gather and analyze necessary information, rules and constraints, and to make effective EOL decisions regarding the destiny of the product represented

[8] A software agent is defined as "a distinct software process, which can reason independently, and can react to change induced upon it by other agents and its environment, and is able to cooperate with other agents. [44]"

by it. For example, when a product reaches the recycler for end-of-life product recovery, the decision making software agent associated with it will be able to gather information about the condition of the product, lifecycle history, disassembly data, etc from the product database, link it with the constraints imposed by external factors and generate an optimal disassembly sequence for the product.

Figure 7

AUTO-ID ENABLED PRODUCT INFORMATION MODEL



The model described here is only a conceptual one and clearly further investigation is needed to determine its practicality. However, it can be seen that this model enables a comprehensive representation of the current and past states of the product, as well as provide capability to also influence the future state of the product. The former can be seen as a near term strategy in which the product lifecycle information model provides information (passively) to the end-of-life decision processes. The latter, implies a product capable of being linked to information which influences decisions made about its reuse, rework, disassembly etc, and hence contributing to a highly automated product recovery process. Such an automated process will have the advantages of being cost efficient compared to manual processes and also would eliminate the cost due to lost opportunity and ineffective product recovery arising from wrongful disposal of reusable parts and modules.

Since product information according to this model is held uniquely at the item level and is continuously updated throughout its lifecycle (including the EOL phase), this information would provide crucial feedback to manufacturers and other supply chain users for analysing and improving the lifecycle performance of the products. For instance, manufacturers would be able to determine the components that are most reusable and have maximum market value at EOL or components that are most likely to break down during its usage. This information could be used to improve the design of the product for increasing its lifecycle performance.

We have noted earlier (refer to section 3.4) that information requirements for EOL management of a particular product depend on the product's characteristics. It is therefore logical that a product lifecycle information system built around the product information model of section 5.2 would provide a natural fit to today's EOL requirements. The flexibility resulting from taking a product-oriented approach instead of a process oriented approach to modelling enables the information system to adapt according to the changing requirements imposed by different products.

6. CONCLUSION

Lack of information infrastructure, excessive cost due to manual product recovery operations, and unavailability of product information were cited as the major obstacles for effective end-of-life management of products. It is argued in this paper that a product-oriented information model provides a logical way for presenting the information required for EOL decision making. Such a model based on the capabilities offered by Auto-ID technologies has been proposed. The benefits of a product-oriented information model can be summarised as follows:

– This model provides the access to product information at unique item level that is required for many EOL decisions.

– The model provides increased flexibility for an information system to be able to adapt according to the changing requirements imposed by different products.

– The ability of such a model to automate product recovery processes should result in increased cost-efficiency as well as a reduction in environmental damage due to disposal.

– This model can enable manufacturers and other supply chain partners to obtain feedback on the lifecycle performance of products, thus providing crucial input for better product and process designs.

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