Improved Life Cycle Management by Product Communication

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Abstract. Many manufacturing companies have limited insight into the complete life cycle of their products. Insight that is necessary to manage the environmental impacts associated with the company's operation. One possible solution to this challenge is to apply emerging sensor technology for communicating with products. Despite the current trend of digitalization and use of sensors in the manufacturing industry, there is little attention given to how product communication may improve environmental sustainability.

We propose a framework on how product communication can facilitate improved life cycle management, by contributing with needed information for improved value chain insight, design for environment and end-of-life management.

Keywords: Sensor application · End-of-life management · Design for environment · Value chain insight

1 Introduction

Environmental awareness is growing throughout the society and the pressure on manufacturing companies to operate in an environmental sustainable way is increasing. In order to address the environmental impacts associated with a product, a life cycle perspective is required. Both to ensure that all impacts are addressed, and to prevent problem shifting of environmental issues. Life cycle management (LCM) is one framework for assuring that the life cycle perspective is kept throughout all company activities.

Having control of, and insight into, the entire value chain is becoming an important part of running a business. However, for many manufacturing companies that are not distributing their products themselves, knowledge of the complete life cycle of the

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products is limited. In particular, insights into users and end-of-life stages are particularly restricted. On the other hand, technologies that enable information tracking or product communication throughout the product life cycle are increasing. Digitalization, sensors and internet of things (IoT) are overall trends in manufacturing. They are anticipated to result in better products, zero defect manufacturing processes, more integrated value chains etc. However, less attention is given to how these trends may improve environmental sustainability for the manufacturing industry. Based on the challenge of lack of necessary information from the product life cycle to manage the environmental sustainability issues, and the possibilities with new emerging sensor technology, a conceptual framework is developed. By communicating with products (through integrated sensor technology) manufacturers upstream in the value chain can gain valuable information from the use-phase as well as end-of-life of their products that can be useful for improving environmental sustainability.

This paper presents theoretical background and considerations on how LCM can be improved by increased knowledge on the products life cycle, enabled by sensor technology. By exploring LCM of reusable or reconfigurable products, this paper addresses the potential of applying sensors to improve the environmental performance of the companies and provide basis for improved LCM. This paper first discusses relevant literature, before introducing potential applications. Thereafter we propose and discuss three areas of LCM where product communication can contribute with valuable information.

2 Literature Review

2.1 Life Cycle Management

During the past decades, international agreements and initiatives have been calling for a broader more holistic perspective on sustainability than that of a factory's or an organization's physical boundaries. Moving towards more sustainable manufacturing there is a need of framework that integrates life cycle thinking and the different instruments available to address the environmental consequences of an organization's operation. LCM is not a specific tool, but an extensive framework with a toolbox for governing environmental aspects. LCM is aiming to widen the traditional management scope beyond the organization's boundaries by managing the impacts associated with the entire life cycle of a product or product portfolio [1]. Therefore, LCM requires contributions from across the entire organization and external stakeholders. The different departments in an organization contribute to LCM in performing their operations by using sustainability tools and frameworks. Product development can contribute by performing design for sustainability, production and distribution, sales and marketing and purchasing by performing their tasks with a clear sustainable objective, and additionally an environmental department contributes by coordination and capacity building [1]. Balkau and Sonnemann [2] identifies a broad range of instruments for practicing LCM in an organization. They all require insight into the life cycles of the products and processes, value chain analyses, environmental management systems (EMS) as a framework for LCM, product stewardship or extended producer liability and design for environment in particular. In this paper we will, inspired by Balkau and Sonnemann [2], focus on the parts of LCM that is assumed to have a potential for improving LCM through the utilization of data from product communication: value chain insight, design for environment and end-of-life management.

2.2 Environmental Improvement by Product Communication

Sensors are currently used for many purposes, in particular in logistics and transportation for tracking and tracing products. A sensor detects a value or a change in a value, like pressure, temperature, vibration and converts it into a signal [3]. There is a wide range of functionality of sensors, and they come in a wide range of sizes, with or without an external power source, from simple RFID to advanced internet of things (IoT) solutions. For this paper, the broad range of sensors and communication technology available for producers or users to communication one-way or two-way with products is labeled *product communication*.

The amount of literature available on the use of sensors for improvement of environmental sustainability impacts appears to be limited. Most of the studies that are published focus on the use of RFID for improving environmental performance. Sensors and RFID may give access to information that can be used to achieve more efficient energy use, reduction of CO_2 emissions, improved waste control and improved recycling rates [4], reduced transport due to improved inventory management [5] and reduced traffic congestion due to faster and automated driver security inspection [6]. Integrated sensors may be used for monitoring, detection and prediction of product failures, as well as estimating the remaining life of product components [7]. This may provide a basis for improving environmental sustainability by changing existing end-of-life processes. For WEEE (Waste of Electrical and Electronic Equipment) recycling effectivity may be raised by improved product information and product identification from RFID technology [8]. Finally RFID tags can be used for improving recycling, including recycling of the RFID tag itself [9]. Digitalization and integration of manufacturing, referred to as Industry 4.0 also provides opportunities for improving resource efficiency and continuous energy management [10], holistic resource efficiency, facilitation of cradle-to-cradle thinking and sustainable process design [11].

3 Industrial Application of framework

The objective of the overall research project is to guide manufacturing companies towards improved sustainability performance by applying LCM. The framework is developed with complex, high-tech reusable or reconfigurable products for either business or consumer markets in mind. Products with a medium to long lifetime, consisting of multi-materials and that must fulfill high quality and safety demands. The companies operate on worldwide markets, adding complexity to the products' life cycles because of the different types of markets, users groups and end-of-life options available.

4 Framework and Discussions

We propose a framework on how sensors can be used to facilitate LCM for such manufacturing companies. **Fig. 1** shows the data that is potentially available from sensor technology, both data collected from the life cycle of the products (straight lines), and information sent from the producer to other actors in the life cycle (dotted lines). From a manufacturer's perspective, interesting data can be collected from communicating with the products throughout its lifetime. A producer can collect data from the end user on user patterns, from the distributor on maintenance, repair and reuse intervals, from the end-of-life handler on why and how the product reaches end-of-life, and challenges with end-of-life handling. Finally, the producer can potentially gain information from products that are subjected to unregulated disposal.

A producer can also communicate with the product and / or the users throughout the lifetime by sending information to end user on safe use and safe disposal, to the distributor on safe maintenance and repair and information on reuse of parts and to end-of-life handlers on information on the content of the product and recommendations for disposal. This information gathering and exchange influences environmental sustainability of the product by providing value chain insights, basis for design for environment and proper end-of-life management, which are all central part of LCM.

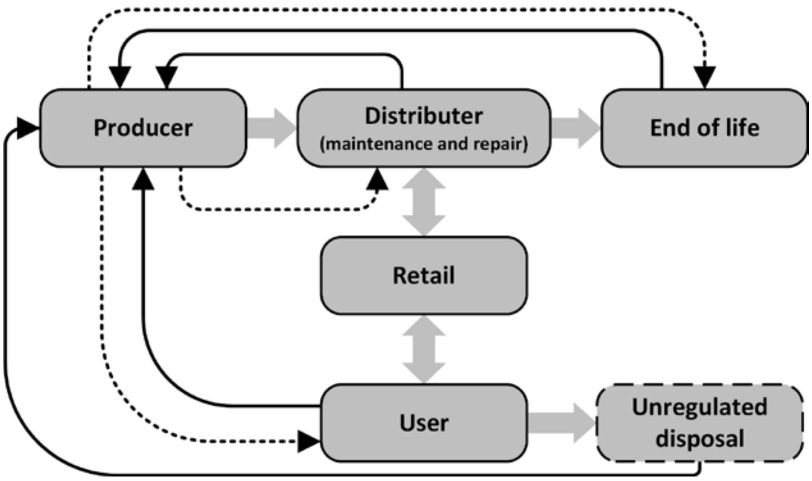

Fig. 1. Data collection from the products life cycle by product communication.

4.1 Value Chain Insight

The focus on environmental issues is increasing and the manufacturing companies are experiencing pressure for managing these issues. It might be requested by governments through laws and regulations or more indirectly by stakeholders such as customers or NGOs. Some companies choose to manage their environmental impact through following a standardized environmental management system (such as ISO14001 or EMAS). Addressing environmental issues is a complex task, and the reporting associated with the EMS may be work-intensive and challenging. Many companies are experiencing a lack of insight and knowledge to carry out the reporting in a responsible way.

Life Cycle Assessment (LCA) is one of many tools used for reporting and environmental sustainability planning by companies. However, it is a complex tool and challenges with data availability and data quality often occur [12]. Improving data availability and quality, by utilizing sensor data, may simplify and lighten the work efforts put into this type of analysis and reporting.

Lack of data with sufficient quality for use and end-of-life of products is often a problem in LCA, and affects the applicability of the obtained results [13, 14]. Improved data will not only make LCA more robust, but also improve its role as a decision making tool integrated in a LCM system. By tracking products and gaining insight into user patterns, service and maintenance patterns and part replacement history, data improvement may be feasible, and provide more robust LCA results.

Besides environmental reporting that is required by regulation, manufacturers frequently receive inquiries from customers to document environmental footprint of the products. Increased knowledge on environmental issues for their products is therefore necessary. There may also be strategical benefits in increased environmental knowledge on the products, as more and more consumers are concerned with environmental issues. It will be a competitive advantage if they can promote their products as the greener choice.

4.2 Design for Environment

In general, up to 80% of environmental and social cost factors of a product are determined in design and product development phases [15, 16]. For reusable and reconfigurable products with long lifetimes; design of new versions as well as replacement parts, and maintenance services of products in use are crucial for minimizing the environmental footprint. Point of departure for design is often an overview of the product's entire value chain and insights into the various users' needs, user patterns and situation.

For manufacturers of products distributed through and serviced by other business actors, information exchange in the value chain is often limited. The value chains can be complex and include a large number of actors. A medium to long lifetime of the products add to the complexity and might further reduce access to information. The manufacturers typically receive information through inquiries from distributors on reoccurring problems with the product. Nevertheless, manufacturers often have limited insight into the cause of failures, declining product quality, accidents or misuse. Sensor data might provide insights into user patterns and situations that cause product failure, rather than a customer's narratives of what happens.

The manufacturers might have limited information on successful and safe user situations. In particular, restricted insight into how various users are handling the products in ways that affects safety issues and might prolong or shorten the products' lifetimes. For example, information on how roughly or careful the products are handled during transport and maintenance can provide a more accurate specification of impact loads. Product communication and co-creation with customers and distributors can result in products that are easier to maintain, new replacement parts and services, and solutions for reconfiguration, in all prolonging the lifetime of the products.

One important point of departure for design for environment is the end user. Understanding of the users are often achieved through interviews, observations or co-designing [17]; thus qualitative methods involving a limited number of users. Sensors might provide relevant information from a larger number of users and when direct contact with users is difficult. In particular for products distributed to wide geographical markets and there are large cultural differences between various user groups.

To develop more disruptive sustainable solutions, insights into user practices and behavior are necessary [18]. In design research, the aim of design for sustainable behaviour is to create products in such a manner that they are supporting greener choices and greener user behaviour related to products. A simple example is water kettles where the user can choose to stop the heating at 80, 90 or 100 degrees Celsius. Analysis of sensor aggregated data can potentially provide useful information on user habits and use-patterns that are more or less environmental efficient, supplementing understanding achieved through qualitative approaches. Finally, if a two-way product communication is developed, such a smart product might allow for instant feedback to the users on unsafe use of the product and support more sustainable user patterns and nudge the right end-of-life handling.

4.3 End-of-life Management

A part of moving towards an environmental sustainable society is reducing the emissions of greenhouse gases. A large share of the emissions is caused by production of goods and services. An escalation in the depletion of virgin resources is seen due to increased customer demands for new products. This is a threat to the environment for several reasons. Mining and extraction of virgin materials are often associated with several environmental consequences, increased CO_2 emissions, toxicity for humans, ecosystems on land and water and other emissions to air to name some. Besides the problems already mentioned, a decrease in availability for several virgin metals leads to a need for an improvement of take-back systems for products after service life. It is crucial to reduce the draw of primary resources, and keeping materials and resources in the loop, i.e. a shift towards a circular economy. Information on what happens with each product after its main purpose is fulfilled is essential for achieving this.

What kind of end of life treatment a product should be subjected to depends on the original design of product, but also several factors influenced by its use, maintenance frequency, replacements and other external conditions. Sensor technology may fulfil the mentioned needs for information. One important issue is deciding when a product reaches its end-of-life; either a distributor or a user find that the product is not functioning in a satisfying way, visual appearances is unsatisfactory, or after a certain amount of time, according to regional specific regulations. In addition, some users might dispose their products outside the regulated recycling plan.

The increase in the use of multi-materials in products also provides challenges for recycling and end-of-life. One way to simplify and improve end-of-life systems is to make decisions based on acquired product information from monitoring devices (sensors) embedded in the products. Tracking of products may give information on products that can enable correct waste handling, ensure proper handling of products with safety issues, simplify and facilitate sorting and recycling. This may provide basis for a larger degree of take back of materials and easier sorting, which is a huge step towards closing the material loops.

For the manufacturing companies information provided by attaching sensors may be used for designing a framework for regional specific end-of-life recommendations that may be communicated to the distributor and end-of-life handlers. Today, an increased complexity of products is often seen, with more and new materials and material combinations. Tracking gives the possibility for integrating this type of information in the product, and making it available for the end-of-life handlers. Information provided may simplify decisions on whether a product should be repaired or disposed. This information may prevent fully functioning products from being discarded due to strict regional regulations, owed to safety issues.

Finally, other environmental sustainable relevant information is how many products that reach end-of-life or is lost in the use stage due to unregulated disposal.

4.4 Potential Disadvantages with Sensors

The attachment of sensor technology to a product leads to more material, energy and resource use. The increased use of raw materials for producing the sensor, and a possible energy need for operating it, add to the overall environmental footprint of the product. The addition of a sensor can potentially complicate the final disposal of the product, by introducing more materials, complex structures and possibly detachment issues. For this reason, the addition of a sensor to improve environmental performance should be weighed against the material challenges the recycling of the product (and sensor) introduces [9].

Communicating with a product after factory gate is complicated due to data retention, security and customer privacy. Therefore, the ethical dimension of product surveillance must be carefully considered before implementing sensor technology.

5 Concluding Remark

The main contribution from this work is the link between LCM and product communication. We have shown that there are several environmental benefits associated with communication with products throughout the use and end-of-life. The areas where data collection can contribute to improve LCM are value chain insight, design for environment and end-of-life management. By communicating with the product throughout its lifetime, data that is collected can be used for improved reporting and simplified use of assessment tools such as LCA, design of products, parts and services based on actual user patterns, more robust decision making for environmental sustainable design and product development, and finally, a more responsible end-of-life management.

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