

## **Balancing Technologies for Reverse Supply Chain with Modularity as Strategy for Competitiveness**

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**Topic:** D - Competing with innovation, solution providers

### **Purpose**

In this paper we review applications, case studies, models and techniques proposed for the design and optimization of reverse logistics systems according to the principle of modularity. Based on these studies we give an overview of scientific literature that describes and discusses cases of reverse production activities and modularity in practice. We examine high technology industries and their potential competitiveness implementing reversed supply chain. The main research question addressed in the paper is: How can modularity guide and determine the development of complex technology and subsequently contributing to enhancing the efficiency of the reverse supply chain (RSC)?

### **Theoretical foundation**

The issue of modularity plays a crucial role in the context of innovation and new product introduction (Ulrich, 1995). Recent research (Nunes et al. 2008; DeBrito, 2003) suggests that product modularity may help to improve the sustainability of manufacturing as defined by the number of products produced and consequently disposed of over time. An issue that has not received a great deal of attention to date is the impact of product modularity on RSC. In this paper modularity refers to a new product development strategy for complex technology where the integral architecture designs enhance knowledge sharing and interactive learning. With modular product architectures, firms may be able to customize their products to satisfy customers' particular needs and the environmental aspects (Mikkola and Gassmann, 2003; Baldwin and Clark, 1997). Life cycle thinking is the essence of life cycle design (Behrendt, et al., 1997). The concept of "product life cycle" is used with different meanings in and contexts but it usually does not take into consideration the phases of retirement and disposal (Hata et al., 2001).

### **Design/Methodology/Approach**

Based on the extensive literature review on modularity and RSC as well as to better clarify the life cycle design approaches, we introduce a conceptual framework. We then apply the framework to analyse complex products including those from Canon and Siemens's medical technology.

### **Findings**

We found that the research about RSC and its application. What is mostly agreed upon is to apply product modularity design and open architecture interfaces as part of the overall technique of integration, as this created new possibilities for changes, modification, and upgrade of a product of system, rather than disposing of a product or system only because it's becoming obsolete or at the end of its original design life.

### **Relevance/Contribution**

This work enables a starting analysis on the subject of modularity related to environmental aspects. Particularly relevant is the integration of environmental practices with the supplier's capability to seize on manufacturing and logistics efficiency of modular versus non-modular production systems.

### **Introduction**

Technology-intensive products are becoming more complex (O'Grady, 1999) and by developing the ability to produce a wide variety of products through assembling standardized modules, manufacturers can expect to significantly reduce uncertainty and complexity, cut product development time, and lower overall costs (Sanchez, 2000).

The term modularity is an approach for organizing complex products configuration and processes efficiently (Baldwin, 1997). Product modularity has traditionally been discussed in the context of enabling firms to handle increasing product variety and complexity, as a means of navigating the learning curve more quickly to achieve economies of scale in parts and materials. In an organizational context, modularity is supposed to allow firms to further specialize and thus differentiate themselves from competitors. The issue of modularity thus plays a crucial role in the context of innovation and new product introduction. Furthermore, recent research (Nunes et al. 2008) suggests that product modularity may help to improve the sustainability of manufacturing as defined by the number of products produced and consequently disposed of over time. An issue that has not received a great deal of attention to date is the impact of product modularity on the forward and green supply chains. In this paper modularity refers to a new product development for complex technology where the integral architecture designs enhance knowledge sharing and interactive learning. With integral product architectures, firms may be able to customise their product to satisfy each customer's particular needs and the environmental aspects.

While the concept of modular product architecture is not new, research only hesitantly began to analyse the impacts of modularity on a product's life - cycle costs as well as its effects on efficient reverse logistics operations. Mazahir et al., (2011) highlight the importance of the supply chain strategy for product design and reverse logistics. Huang et al . (2012) note that modularity can be seen as a strategy in mitigating a product's negative environmental impact and additionally it can reduce re cycling or remanufacturing costs. Reverse supply chain is concerned with the return flows of products or equipment back from the customer to the logistic networks for reuse, recovery or recycling for environmental, economic or costumer care reasons

### **Research Framework**

#### **Modular design in life cycle**

Electronic waste deals with that portion of the electronic products that have reached their end of life and must be properly disposed of or dumped. It is the handling and impacts of the portion of the end

of life electronic products that are not properly disposed of that form the basis for this paper. The handling of these products is a growing international problem that is not limited to one particular continent or just for developed countries. Companies are facing increasing demand concerning the environmental performance of their products. The market for companies dealing with high technology medical equipment is also growing rapidly.

The concept of “product life cycle” is used with different meanings in different contexts and include any possible support services for the product, but usually it’s not taking into consideration the phases of retirement and disposal. Life cycle thinking is the essence of life cycle design (Behrendt, et al., 1997). It must be considered, understood and accepted by a company before starting to elaborate life cycle design.

The processes of product life cycle consist of service related operations, such as maintenance and upgrade, and inverse processes such as collection and recycling. Thus, modular design is an important elemental technique in life cycle design for improving, maintainability, upgradability, reusability, and recyclability. Indeed, the reverse flow of product in the supply chain is a complex operation that evolves and changes throughout the product life cycle. There is an extensive literature that concerns modular and integral architecture, where different characteristics are identified. An integrated architecture usually has the following properties (Ulrich, 1995): the functional elements of the product are implemented using more than one block (interchangeable components that implement similar functions); a single block may implement many functional elements; the interactions among the blocks are defined and may be incidental to the primary function of the product. Modularization refers both to the tightness of coupling between components and the degree to which the ‘rules’ of the systems architecture enable mixing-and-matching of components (Schilling and Steensma, 2001). Mixing-and-matching of components creates product variety (Mikkola and Skjøtt-Larsen, 2004). Components and sub-assemblies, which are relatively modular in nature, are called modules. A product that incorporates integral architecture most of the time is designed for high performance. Decisions on how to decompose the product into blocks and how much modularity to be established are closely devised according to the markets strategies and the management of product development. The combination of complex technology choices and architecture design thus seems to lead to different strategies concerning reverse logistics. Reverse logistics is green by design as it manages returns to resell, refurbish, recondition, remanufacture, cannibalize for parts, or recycle products to minimize landfill waste.

Understanding modularity is fundamental to avoid eventual evolution in technology making machines obsolete. Moreover, modules would make equipment easier to disassemble increasing the chances of reuse of valuable components and a better final disposal of scrap.

However, modular design methods have been studied for ease of, mainly, manufacturing or assembling. Therefore, in the context of life cycle design, modular design should be able to examine other aspects than manufacturing and assembling.

Focusing on reverse logistics implications, modularity can become environmentally beneficial by expanding the useful life of products, since only components become obsolete and are discarded, instead of the entire product. Research on the impact of modularity on repair operations and the disassembly of end - of - life products can be found for instance in Tseng et al . (2008) and Huang et al . (2012). However, potential positive effects of modular products on the environment may be damped by an accelerated obsolescence of modules (see Ülku et al, 2012).

Generating sustainable product life cycles explains the importance of a holistic long-term planning and management approach to reaching a maximum product benefit over the entire life cycle.

As mentioned earlier, the paper attempts to focus on the green life cycle of product design. Redesign a design practice which incorporates the reuse of ‘still-living’ components salvaged from

‘deceased’ or discarded products could be a way forward for sustainable production. Such techniques have been noticeably part of consumer culture for at least the last few decades. This suggests that the recovery and reuse of key components is an economically viable green logistics strategy in a high-modularity case; in contrast, scrapping or recycling of materials is often the most viable strategy for integrated architectures. The design should identify components or modules, and each module should solve one part of the problem. The purpose of the modules should be well defined. Each module should include the structure and the control necessary to accomplish the purpose. Modules should communicate to each other using interfaces.

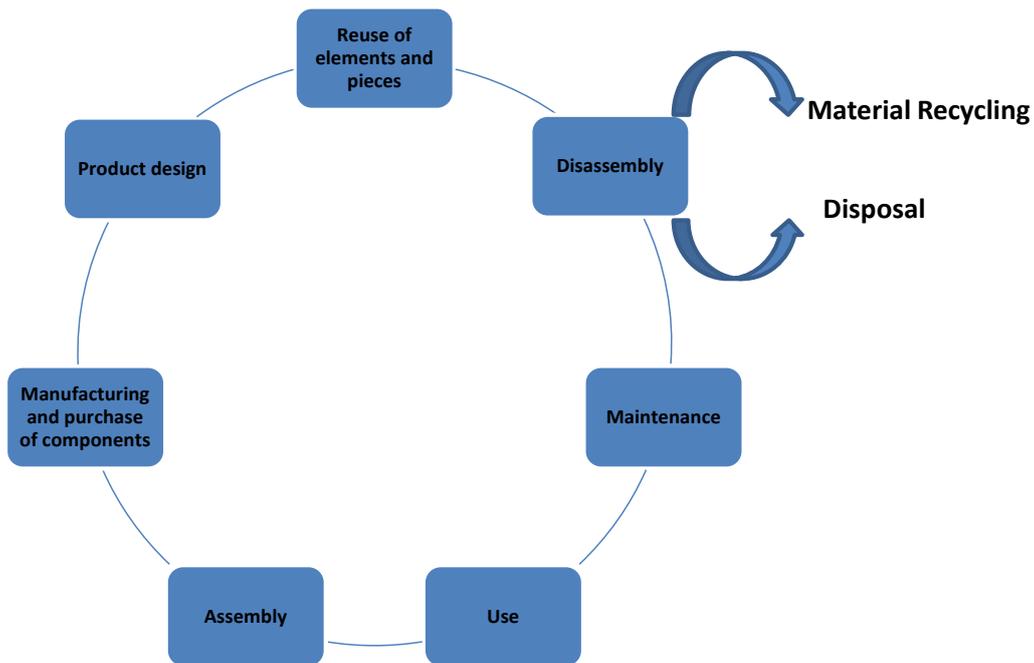


Figure 1: Diagram of lifecycle design

The high lifecycle design modularity can be beneficial from all viewpoints of interest. That should imply that manufacturers, recyclers, and maintenance personnel will tend to view a product’s structure in similar ways. The aim of this paper is to develop a frame that the designer can use in configuration design in order to determine a design that meets its function, service, and post-life goals. It is important to investigate specific characteristics as material recycling, service and post-life. The intent is to have material compatibility, service frequency and the intended destinations for each component.

### Reverse Supply Chain

Rogers and Tibben-Lembke (1999) provided a definition of reverse logistics 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.”

The focus in reverse logistics is the cost and availability of landfill space, rather than conducting specific studies on the organizations environmental impacts (Tage Skjøtte-Larsen, 2007). De Brito et al. (2002) distinguish several types of recovery activities: product recovery, where the products may be recycled or sent to the second market. Component recovery is products dismantled and part can be remanufactured into the same kind of product. Material recovery recuperated and recycled into the raw material and the last one is energy recovery (incineration).

Tage Skjøtte-Larsen et al., 2007 book use the term 'reverse supply chain' instead of 'reverse logistics' to emphasize that the management of returned products cannot be limited to a single entity in the supply chain, but must encompass the entire chain. Guide and van Wassenhove (2002: 25), state that the reverse supply chain as "... the series of activities required to retrieve a used product from a customer and either dispose of it or reuse it ... becoming an essential part of business."

According to Fleischmann et al. (1997), and Guide et al. (2000) the condition of used products may vary widely, the tasks of materials planning, capacity planning, scheduling, and inventory management are complex and difficult to manage. Managing this high amount of variability is expensive for the firm since decoupling the system requires higher investments in materials, equipment, and labour.

Guide and Van Wassenhove et al., (2004) since not all the RSC are identical, they list five key components to the reverse supply chain:

- *Product Acquisition.* The used product must be retrieved.
- *Reverse Logistics.* Once collected, used products are transported to some sort of facility for inspection, sorting, and disposition.
- *Inspection and Disposition.* The returned products are tested, sorted, and graded. Diagnostic tests may be performed to determine a disposal action that recovers the most value from the returned product. If a product is new it may be returned to the forward supply chain. Others may be eligible for some form or reconditioning while others may be sold for scrap or recycling.
- *Reconditioning.* Some products may be reconditioned or completely remanufactured. Most people have seen products labeled factory reconditioned which implies it is used but like new and may have a warranty. Some products may have parts that can be extracted for reuse or as spare parts. Others go for salvage or recycling.
- *Distribution and sales.* Reconditioned or remanufactured products may be sold in secondary markets where customers are unwilling to purchase a new product. In other instances the firm may need to create a new market if demand is not currently present. Of course, there are distribution needs in getting the product to the secondary market.

Reverse supply chains deserve as much attention at the corporate level as forward supply chains and should be managed as business processes that can create value for the company.

### **Product Recovery Options**

The literature provides and extensive interpretation of sustainable design, from Eco design to the design for sustainability (Bhamara, T. and Lofthouse, V., 2007).

There are 8 types of recovery/disposal options. Direct reuse/resale, repair, refurbishing, remanufacturing, cannibalization, recycling, incineration, and landfilling. Each of the product recovery options involves collection of used products and components, reprocessing and redistribution. The main difference between the options is in reprocessing.

Repair, refurbishing, and remanufacturing upgrades the product. What they differ in is the degree of upgrading. The figure below represents each of the recovery options that we will discuss afterwards.

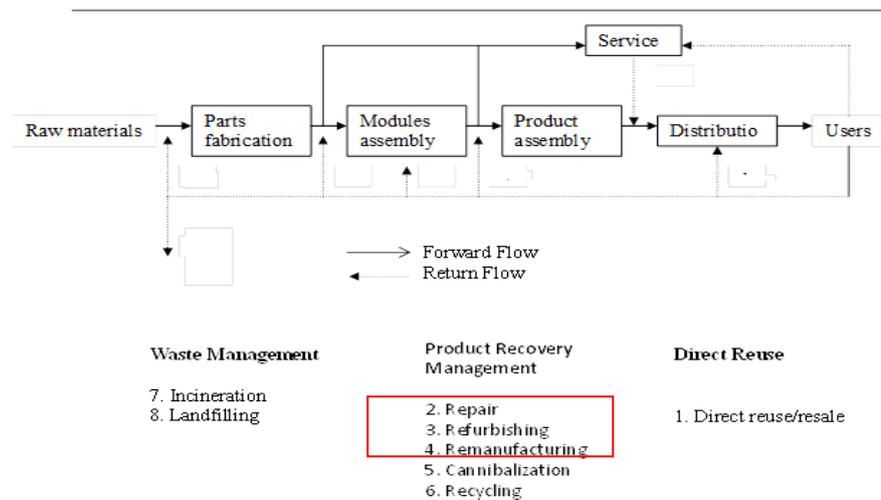


Figure 2: Integrated Supply Chain (Thierry et al., 1995)

**Repair:** The aim is to return the used products to working order. Quality of the repaired products is more likely less than the original. It requires limited disassembly and remanufacturing. This operation can be performed anywhere. Durable product manufacturers (e.g., IBM, DEC, and Philips)

**Refurbishing:** The aim is to bring used product to a specified quality level. Quality is less rigorous compared to the new products. It consists of fixing the improper modules and replacing them with working or technological ones. Military aircraft are examples of refurbished products.

**Remanufacturing:** The aim is to bring the products to the quality level of new products, that is, to make them “as new”. Used products are completely disassembled to the parts level. All parts are extensively tested. Worn-out or outdated parts are replaced with the new ones. Repairable parts are extensively tested. Approved parts are subassembled to the module level, and approved modules are subassembled to product. (BMW has been manufacturing for a number of years.)

**Cannibalization:** In the past three options, identity of used product was preserved. In this case, only a small amount of used products, which are recoverable, is taken out of the old product and reused. This is sometimes called as selective disassembly. Those parts are used in, repairing, refurbishing and remanufacturing activities. Quality of cannibalized parts depends on the process in which they will be used. Aurora, a US Company, is engaged in cannibalizing the integrated circuits.

**Recycling:** As opposed to the previous activities, in recycling neither product nor part identity is preserved. The aim is to reuse the materials from used products. Quality required depends on the process in which the recycled material will be used. (75% percent of the metals from discarded parts are recycled in European countries, such as Germany, U.K.)

Sustainability is considered to be more of a direction that a destination that we will actually reach.

There is an early belief that materials specification decisions can have a considerable influence on the environmental performance of the products they create. Though this is true to a certain extent, the degree of flexibility in material selection depends on the nature of the products being designed and the industry they are being designed for. Designers of medical or pharmaceutical devices, for example, are then limited to using specific grades within a given polymer type due to the regulatory requirements of the industry. Similarly designers, who focus on the redevelopment of core products for large manufacturers such as Electrolux, are limited on the types of materials they can specify.

## Research Methodology

### Complications and Framework of the study

In research about RSC and its application, what is mostly agreed on is possibility to introduce modularization and open architecture interfaces as part of the overall technique of integration, created new possibilities for changes, modification, and upgrade of a product of system, rather than disposing of a product or system only because it's becoming obsolete or at the end of its original design life.

Research and Development (R&D) plays a critical role in the innovation process. It's essentially an investment in technology and future capabilities which is transformed into new products, processes, and services. In industry and technology sectors R&D is a crucial component of innovation and a key factor in developing new competitive advantages.

The need for design knowledge reuse in product development is driven by the design challenge: to (re)produce the right product in the minimum amount of time with minimum costs. Design reuse, must be design in a way to facilitate the reuse of materials or components. During the technical process for "re-use" different steps have to be considered: disassembly, diagnostic, cleaning, replenishment and product assembly.

Electrical and electronic waste is a growing problem as volumes are increasing fast. Rapid product innovation and replacement, and in order to support the market for "reuse"/"reassembly", companies have follow guideline in specific aspects as a legal aspects, technical aspects and economical, ecological and social aspects. Legal aspects are correlated to the EU directive on waste electrical and electronic equipment (WEEE) which aims to minimise WEEE by putting organizational and financial responsibility on producers and distributors for collection, treatment, recycling and recovery of WEEE. Therefore all stakeholders need to be well-informed about their WEEE responsibilities and options.

Establishing of WEEE and RoHS (Restriction of Hazardous Substances Directive) legislations have pressurised manufacturers into adopting sustainable product design principles, for example designing for disassembly (DfD). Designing for disassembly (DfD) isn't just about meeting legal requirements. Reducing waste in the manufacturing and recovery processes using DfD techniques can significantly reduce production costs and allow for greater technical efficiency. Modular design principles within DfD techniques allow for greater flexibility during product development, shorter development timescales and reduced development costs. Implementing DfD into a design specification allows the product and its components to be better suited for re-use or recycling when it has reached its end of life, thus reducing the scale of resources required creating new products. A process by which a product and its parts can be easily: reused, re-manufactured, refurbished or recycled

As mentioned earlier, disassembly is a very labour intensive process. In addition, an automated disassembly line may not be feasible to cater to different kinds of product infrastructures and design for remanufacturing (ref: S.L. Soh, S.K. Ong, A.Y.C. Nee).

The reverse supply chain represents all operations related to reuse of products, components and their materials. Recently, environmental issues including energy usage and implications of products have attracted attention. Thus, designing product modular architectures that consider not only the interactions across components but also component end-of-life options (i.e., reuse, recycle, and disposal) have become important. In the paper, we illustrate the literature and we compare results of two modularity methods for their RSC implications.

Following are the case studies based on the situation of multinational engineering and electronics conglomerate that had been involved in product recovery management for a numbers of years.

These cases illustrate a strategic production and operations management issues in reverse supply chain.

### **Case Study: Canon**

<http://www.canon.com/v-square/movie.html?id=e017>

#### **R2 certificate**

Canon is a company that currently operates on a global scale and has headquarters in the America, Middle East, African, Japan, Asia and Oceania. Their main European Headquarters include Canon Europa NV in the Netherlands and Canon Europe Ltd in London (website). We observed the same approach in other industries. For examples, Canon's products are not only used around the home and the office. They are also used in medical, optical and broadcast products to help with x-rays, scanners, filming and broadcast lenses.

In the last few years, Canon is motivated to link its cost engineering framework to reducing environmental impact. They introduced a new Design for the Environment (DfE) method in 2009 and are pursuing environmental designs that take into account entire product lifecycles. To help build a recycling-oriented society, Canon focuses on the development of energy- and resource-efficient products characterized by reduced size and weight, as well as easy-to-recycle product designs.

Canon also conduct environmental response evaluation through Product Environment Assessments carried out at three stages in the commercialization process; namely, product planning, prototyping, and quality control. To manage environmental responses throughout the supply chain they gather data about their suppliers through an internal system calls "Supplier Environmental Evaluation System". That provides data for planning, development and design, prototype creation, quality assurance, manufacturing, and sales. Moreover, this system makes it possible to share environmental data about products, materials and packaging materials within the Canon staff/group. Canon's compliance with regulations such as the WEEE Directive, the RoHS Directive and REACH, as well as their response to eco-labelling worldwide.

### **Case Study: Siemens Recycling Program**

Siemens' technical expertise, comprehensive portfolio and long-standing experience are helping to pioneer a sustainable future across the globe. The topic areas that exemplify Siemens' success in providing state-of-the-art solutions are in fields as IT, industry, finance, healthcare and energy.

In order to adopt specific strategies, their levels of modularization differ in order to provide the personalization of the customer's needs, maintenance and updating. Siemens equips each product with product information in order to make its ecological advantage visible. Used medical equipment is a valuable asset that has to be preserved by saving resources and improving their environmental performance such as reverse logistics.

In Siemens, modular design helps to accommodate the product to customer requirements without the need to keep track of a large variety of purchased components. In power electronics performance change is often made by selecting and changing components. Only a few components (although the most expensive ones) need to be specially designed to cater for each customer's order. Modular platform may permit an easy replacement of some components during the equipment's use life-cycle because of the product simplification through the modules. The retail unit might be used

as a collecting and maintenance points. However, it depends on the company's customer relationship management.

For example, when it comes to product life cycles, Siemens Healthcare Sector is concerned with protecting the environment and using resources efficiently. To that end, a multi-step take-back concept has been developed. Used devices, such as X-ray machines, will be remanufactured into "refurbished systems." Individual components will be reused or used as replacement parts, and valuable materials, such as the heavy metal molybdenum that is recovered from X-ray emitters, will be reused.

Design-to-recycling, as Siemens call it is another promising approach. This involves designing products in such a way as to maximize ease of disassembly and separation of materials. In this setup, non-recyclable materials are removed before old components are reprocessed. For example, the aluminum frames of Siemens subway trains are held together by easily removed hexagonal bolts. The trains also contain a large amount of recycled metals, and their insulating boards are installed only between the shell and the paneling. The cork tiles for reducing impact noise in floors are covered with aluminum foil and rubber. These material layers can simply be stripped off when the trains are disassembled.

### Case study: Phoneblocks

Phoneblock is an innovative product, consisting of a tablet attached to a base and separate modules, allowing each module to be changed individually.

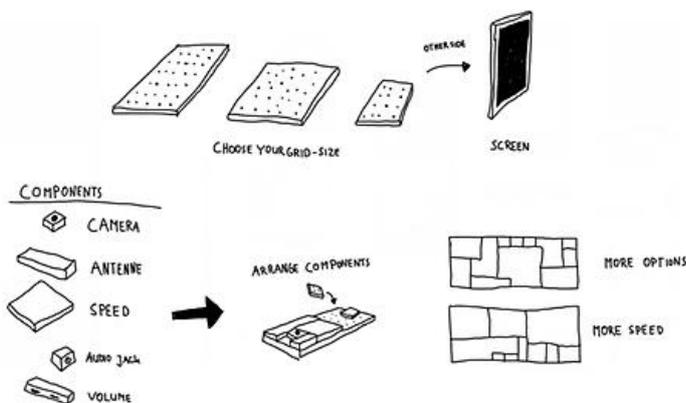
The founders of Phoneblocks, define it as an open source, the production of the modules is open to everyone.

The customers they will be able to faulty, broken or out-dated components as well as temporary rearrange the hardware of the phone to meet their specific needs.

The overall concept of Phoneblocks is based on a distinctive modular product architecture that shapes the product design, basically, an open hardware platform with modular components.

Phoneblocks follows a more contemporary supply chain to either dispose of them or reuse them. There are many reasons why a customer would like to return an entire phone or single module (blocks). First of all, the customers might want to upgrade certain parts of the phone, or exchange parts that are damages. Moreover, customers might just want to sell used modules that they not need anymore.

Phoneblocks recycling Program offers free and environmentally friendly dispose of devices. As



organisation, they try to all the tasks which are really crucial in the management of reverse supply chain. The process of acquisition is structure with a central return centre which is responsible for retrieving and used products, as quality, quantity and timing of product-return in order to create a profitable supply. Transportation the retrieved goods to the central return centre for inspection happens either directly via postal return from the customer or through

the distribution that connects the retailers to the return centre, Reverse Logistics process. The last free tasks, as Inspections takes place at the central return centre. The Reconditioning of used products for reselling and remanufacturing happens at the supplier's factories. And finally, the distribution and sale will occur at the shop again.

### **Case study: Fairphone**

Mobile phones are one of the most popular electric products all over the world. They often have a relatively short life cycle and hence waste from that device is rapidly increasing.

Every year, around 1.8 billion mobile phones are produced and sold. Only an estimated 0.3 billion are recycled each year. The highest reuse & recycling percentage for phones in developed countries is only around 35%. In many developing countries, scrap recycling isn't facilitated (Closing the Loop Foundation, 2012- 2<sup>nd</sup> October 2014).

Fairphone started in 2010 as a project to raise awareness about conflict minerals in electronics and the wars that they fuel and fund in the Democratic Republic of Congo. In 2013, they established their own independent social enterprise to design and produce a first smartphone and take the next crucial steps in uncovering the story behind the sourcing, production, distribution and recycling of electronics.

### **Interpretation and Conclusion**

This paper investigates design for remanufacture in terms of both detailed new product design and the environmental performance in which modularization and reversed production may operate.

The life cycle of the product can be managed through the modularization since it permits components to be produced separately and used interchangeably in different product configurations without compromising system integrity. The adoption of environmental approaches enables considerations beyond purchase price to be made. It also considers costs and environmental impacts over the lifetime of a product or service (manufacturing, packaging, transport, energy consumption, maintenance and disposal).

The concept of "product life cycle" is used with different meanings in different contexts and include any possible support services for the product, but usually it's not taking into consideration the phases of retirement and disposal.

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