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Single product, multi-lifetime components: challenges for product-service system development

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Abstract: The rapid turnover in consumer electronics, fuelled by increased global consumption, has resulted in negative environmental and social consequences. Consumer electronics are typically disposed of into UK landfills; exported to developing countries; incinerated; retained in households in a redundant state; or otherwise 'lost' with very few being recycled. As a result, the high value metals they contain are not effectively recovered and new raw materials must be extracted to produce more goods.

To assist in a transition from the current throw-away society towards a circular economy, the Closed Loop Emotionally Valuable E-waste Recovery (CLEVER) project is developing a novel Product-Service System (PSS). In the proposed PSS, component parts with 'low-emotional value', but requiring regular technical upgrade (such as circuit boards, chips and other electronic components) will be owned by manufacturers and leased to customers, and potentially 'high-emotional value' components (such as the outer casing) will be owned and valued by the customer so that they become products that are kept for longer periods of time. This research conceptualizes a consumer electronic device as comprising a 'skin' - the outer casing, or the part that the user interacts with directly; a 'skeleton' - the critical support components inside the device; and 'organs' - the high-tech electronics that deliver the product's core functionality. Each of these has different longevity requirements and value-chain lifetimes, engendering different levels of stakeholder interaction.

This paper contributes to academic debate by exploring the feasibility of creating a PSS which addresses conflicting issues for different components within the same device with different optimal lifetimes and end-of-life fates.

Introduction

Continuous replacement of consumer electronics and disposal into UK landfills, or to developing countries, results in negative environmental and social consequences (Widmer, Oswald-Krapf, Sinha-Khetriwal, Schnellmann, & Böni, 2005). Nearly six million small household appliances are discarded each year (Cooper & Mayers, 2000) with only 5% of them being recycled (Axion Recycling Ltd., 2006). Production of these appliances requires the consumption of approximately 125 TJ of energy per annum and over 90% of discarded products are land filled, incinerated, or otherwise 'lost' (Darby & Obara, 2005). Europe consumes 25-30% of all the metals produced globally, but is only responsible for 3% of global metal production. As a result, Europe and the UK are becoming increasingly dependent on imports of raw materials, creating concerns about 'critical resource security' (e.g. House of Commons Science and Technology Committee, 2011). On the demand-side, over 50% of householders are dissatisfied with the lifetime of small household appliances and think that they should last longer than at present (Mayers, 2001). Yet, while strategies to extend product lifespans are myriad, they are widely under-utilized within the consumer electronics market, which relies on obsolescence to drive continued sales (Cooper, 2004). Methods employed to reduce resource use of individuals
in the Global North are typically based on voluntaristic and/or information-driven campaigns, thus failing to achieve significant behaviour change.

However, although designing products with increased physical durability may seem the answer, this does not necessarily lead to longer life spans if the ‘value’ (both technological and emotional) of the product has deteriorated over time.

A Product-Service System (PSS) is a function oriented business model incorporating both service and ownership, offering a viable method for reducing material consumption:

“shifting the business focus from designing (and selling) physical products only, to designing (and selling) a system of products and services which are jointly capable of fulfilling specific client demands” (Manzini & Vezzoli, 2003, p. 851).

Whilst the PSS literature highlights the importance of the citizen, current approaches to the circular economy are typically industry and design-led, focusing on developing technological solutions. Therefore, any proposed PSS would need to acknowledge citizens’ needs and preferences to ensure acceptance and to overcome existing barriers to the adoption of PSS’s.

Closed loop emotionally valuable e-waste recovery
Consumer electronic devices tend to be discarded rapidly and are not effectively recovered, as is the case with mobile phones we use as a case study throughout this paper. Thus ‘leakage’ of significant quantities of metals from the manufacturing chain occurs and e-waste accrues (UNEP, 2011). The challenge is to encourage owners to return devices and then to recover valuable metals, so assisting the UK move towards a circular economy (European Commission, 2011).

Product-Service System – creating value
CLEVER combines a PSS model with design for emotional durability, which is design that creates an emotional attachment between the product and user to increase longevity and postpone product replacement (Chapman, 2010). As such, the project is developing a system in which components with ‘low-emotional value’ that require regular upgrade (the electronic components), will be owned by manufacturers and leased to customers.

Returning these components for regular upgrades will satisfy consumer demand for the

Figure 1. The ‘skin’, the ‘skeleton’, and the ‘organs’.
latest hardware, whilst enabling manufacturers to retain the components that have been designed for efficient metal recovery. Potentially, *high-emotional value* components (such as the outer casing) will be owned and valued by the customer so that the product itself is kept for a longer period of time. Within CLEVER we conceptualise the outer casing, or the part that the user interacts with directly, as the *‘skin’*. The critical support components inside the device are the *‘skeleton’*; and the high-tech electronics that deliver the function as *‘organs’*, as seen in Figure 1. In doing so, we propose a novel closed-loop system in which a single product can contain multiple components with varying lifetimes and value propositions.

In order to convert this novel idea into a feasible solution, CLEVER is taking a user centred design approach (Rogers, Sharp, & Preece, 2007). A *‘top down’* business origami workshop involving CLEVER investigators and researchers (Hanington & Martin, 2012) has been carried out to provide a designer-centric perspective. This will be combined with the outputs from a *‘bottom up’* co-design workshop with users to provide a citizen-centric perspective, as illustrated in Figure 2. From this a tangible PSS will be proposed that could potentially extend product life through the creation of emotional value, and that will differentiate ownership and service. Both the products and the service components of the proposed PSS will be prototyped and evaluated through focus group interviews (Bruseberg & McDonagh-Philp, 2002; Buchenau & Suri, 2000) before finally being evaluated in a *‘real world’* context (such as in a *‘pop up’* store concept format), to determine whether such a system could feasibly extend product lifetime (Maguire, 2001; McClelland & Suri, 2005). To achieve this, CLEVER will work closely with stakeholders throughout the electronic device supply chain from materials manufacturers, through electronics manufacturers and retailers, to the end user: individuals who purchase, use and (currently) frequently discard their devices, or relegate these to hibernation, rather than committing them to the recycling loop.

The first stage of the PSS design process, the internal top down workshop, has been completed and the output is presented below in Figure 3. To summarise, its key features are as follows.

- The user purchases the service contract and associated phone from a distribution platform. Several platforms were discussed during the workshop, including, but not limited to: e-commerce and online shopping; traditional bricks-and-mortar

![Figure 2. The PSS design process.](image-url)
retail and dedicated upgrade centres; local franchises (based within, for example, a local coffee shop); independent community upgrade shops; and vending machines.

- When the user requires or desires an internal upgrade (which could be due to one factor, or a combination of reasons for obsolescence; absolute, functional, technological, societal etc. (Cooper, 2004; Packard, 1967; van Nes & Cramer, 2006)), the user returns the phone to the distribution platform and the phone is serviced (with internal hardware and software upgrades and exterior treatments as requested). The phone is returned to the user with the new internal components; the user retains the valued external skin of the phone. The reclaimed components from the individual platforms are consolidated for sorting.

- After consolidation, organ and skeleton components and sub-assemblies are either recovered for reassembly and reuse, or sent for material recovery and metal refining. Mixed metal recycling streams can input into the metal refining process here, maximising the use of external resources to negate any process losses.

- Raw materials from the materials recovery and metal refining processes are remanufactured into new organ and skeleton components. In the short term it is likely that manufacturing would occur in established world-wide manufacturing hubs for consumer electronic devices.

- Recovered and new components and sub-assemblies are assembled (as hardware upgrades, or as new phone assemblies with new skins) and circulated to the distribution platforms in order for the circular process to be repeated.

Figure 3. Output of the ‘top down’ workshop.
This model is simplified in that it assumes that recovered metals must be used in the same application, i.e. phones, but, in fact, recovery of valuable, but dispersed or dissolved metals is a developing business in itself and is likely to remain so as there are benefits to combining recovery feed streams.

In order to encourage greater emotional attachment to the skin, new materials which 'age gracefully' are being developed and consumer responses to these materials explored. To recover component parts (organs) quickly and efficiently for metals recovery, new skeleton materials amenable to degradation by enzymes, and thus release of 'organs', are being developed. These aspects of the CLEVER project, which support the PSS implementation, are discussed in the following section.

**Multi-lifetime components**

Emotionally durable design utilizes the strong relationships that can exist between people and their possessions to create longer lasting products, thus postponing product replacement (Chapman, 2010). 'Heirloom materials', which increase in emotional and aesthetic value with age, have been proposed conceptually by product designers, but have not yet been engineered, and limited work has been carried out on correlating consumer response to physical characteristics of materials (Karana & Hekkert, 2010). The desire to retain the external 'skin' of an electronic device creates an incentive to return the product for upgrade, rather than purchasing a new device, allowing the manufacturer to recover the skeleton and organs, vital within the context of our PSS.

In response to this challenge, CLEVER is developing and prototyping its own materials with heirloom characteristics, manifest with visual complexity and variability of surface texture, and appropriate response to wear and ageing. Design requirements for heirloom materials for consumer electronics are being developed through an investigative process of understanding the physical properties of natural materials, that, in certain contexts, increase in emotional value with age (e.g. wood or leather). These requirements are informed by the testing of materials towards an understanding of emotional responses elicited by such materials, combined with conventional material requirements, such as strength, stiffness, weight and cost. New materials based on these design requirements will be prototyped and assessed for creation and sustenance of emotional attachment.

In addition to the development of new materials, it is recognised that the decoupling of the longevity of skins and internal components provides opportunities for the use of materials with appropriate lifetimes, which in turn helps facilitate end of life recycling and recovery of valuable elements contained in the organs. Chiodo and Jones’ work on active disassembly using smart materials (2012) aimed to rapidly separate the skin and skeleton, and here we complement this approach by developing new materials that ease the separation of skeleton and organs.

The most important characteristic of these materials is that they will be stable and robust while in use, but can be triggered to decompose when the device is to be taken apart for recycling. Here we must differentiate between ‘triggered disassembly’ referred to above, which uses shape memory materials to allow rapid separation of skin elements from skeleton/organ assemblies and ‘triggered decomposition’, which breaks down the skeleton releasing organs. This will facilitate the recovery of the valuable metal containing electronic organs, so that these can be efficiently recycled and retained in the closed loop of electronics manufacture. Towards this objective the CLEVER project team are developing biopolymer composite materials, based on cellulose in the first instance, for skeleton elements such as printed circuit boards and flexible printed circuits, which are robust in use, but amenable to intentional degradation at the end of life, either enzymatically, or by disintegration or dissolution in solvents such as ionic liquids. This degradation will release metallic components, providing opportunities for recycling. Metals for recovery will be prioritized by value, scarcity and ease of integration of the technology into recycling processes. Electronic components, metal solders and contacts will be recovered by physical screening or flotation separation from the enzyme broth, or by a combination of these techniques and electro-winning from ionic liquid solution, post skeleton decomposition.
Feasibility and effectiveness

In the development of any new product or service, it is vital to robustly demonstrate that the new system delivers real benefits across a broad set of indicators including environmental, social, cultural and economic impact and sustainability. Here, the CLEVER project employs an environmental life cycle approach and facets of Social Life Cycle Assessment (SLCA) to underpin on-going research and to ensure that the proposed PSS, and multi-lifetime components contained within, are both feasible and effective.

The life cycle approach, essentially a streamlined LCA, assesses the potential impacts most relevant to resource efficiency throughout a product’s life from raw material acquisition through production, use and disposal. CLEVER employs this approach here as a technique for assessing the environmental aspects and potential impacts associated with new designs, materials and processes for the skin, skeleton and organs of electronic goods. Of interest are products to which consumers are likely to develop an emotional attachment; the production of the functional components of devices and the practical recycling of these; materials processing and recycling; and the mining and production of metals used in component manufacture. Following a benchmarking of existing product and service components, an adaptable model of the new product-service system will be developed and the results iteratively fed back to inform the PSS, materials and recovery process design. Thus, the approach serves to inform all aspects of the CLEVER project, guiding the development of, and providing input to, the stage-gate approach that will be used to establish whether or not new materials, product-service systems and materials recovery processes are an improvement on current practice.

In addition to understanding and evaluating the environmental aspect of the proposed PSS, the CLEVER project is also exploring the potential impacts of the proposed PSS upon society. Of late, a variety of methods and tools under the auspices of Social Life Cycle Assessment (SLCA) have been developed. While these tools are useful primarily on existing products and services, facets of SLCA are key to CLEVER, such as the observation that ‘the social (and socio-economic) impacts to be covered in an assessment and the way this should be done should be case and context specific’ (UNEP, 2009, p. 32). In light of this – and due to the limits of applying SLCA to a theoretical PSS - CLEVER will explore the reactions of a range of key actors to the PSS through, for example, qualitative interviews with key stakeholders and focus group with potential users, to gauge responses to the new PSS.

Conclusions

A common criticism aimed squarely at PSS literature is that the bulk of it is hypothetical. That is to say, despite the steady rise in the sustainable product-service systems corpus, there is a distinct lack of tangible and physical case studies that go beyond theoretical explorations. As articulated within this paper, CLEVER seeks to, and is in the process of, going beyond these acknowledged limitations towards an implemented ‘real world’ solution. This project programme therefore is designed specifically to identify the tangible impacts of the PSS, including social impacts (behaviour change), environmental impacts (closing the recycling loop), manufacturing impacts (novel materials, which enable the aforementioned impacts), and economic impacts (the business case for the novel PSS and the retention of valuable metals in the manufacturing cycle).

We propose that multi-lifetime components within a single product can increase product longevity and facilitate the recovery of valuable metals within a system model. Within this PSS, components with ‘low-emotional value’ but requiring regular upgrade (the ‘skeleton’ and the ‘organs’) are owned by manufacturers and leased to the customer, and ‘high-emotional value’ components (the ‘skin’) are owned by the customer. Thus, by differentiating between ownership and service we can create longer lasting products with components that have more appropriate lifetimes, commensurate with their function and value, thereby helping to move the UK away from the ‘throw away’ society it has become. A work in progress, the CLEVER project is currently in the process of developing the PSS that will encompass these proposed characteristics and attributes, whilst in parallel developing the materials and technologies that will support its realisation. Through a combination of workshops, laboratory testing and prototypes informed by public and industry stakeholder engagement, we will rapidly move beyond the theoretical, which underpinned with robust and stage-gated streamlined environmental life cycle
approaches, and social life cycle assessment, will enable the selection of the ‘best’ solution for overall life cycle, thereby ensuring that the PSS proposed is both feasible and has long term benefits.

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