Book Chapter

Environmental and Economic Contribution of Design Changes in Integrated Product Service Offerings

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Environmental and Economic Contribution of Design Changes in Integrated Product Service Offerings

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Abstract. Design changes performance significantly, as has been proven in the case of physical products. Quantitative research on a real offering in a market consisting of physical products and services is rarely reported. This paper aims to illustrate and discuss how design changes on a physical product or a service can improve the environmental and economic performance of an offering. The series of offerings compared in this paper are provided by a manufacturing company and are currently found in the marketplace. The in-depth study of this case shows the substantial contribution of design changes on performance, and reveals the high relevance of the interrelation between product and service on performance.

Keywords: LCA (Life Cycle Assessment), LCC (Life Cycle Cost), PSS (Product/Service System), IPSE (Integrated Product Service Engineering)

1 Introduction

More and more companies have abandoned traditional sales of products or service offerings in favour of Integrated Product Service Offering (IPSO), which is a term used in this paper to refer to PSS (Product/Service System) [1] with an emphasis on the importance of integration. However, they still often base their new offerings on their traditional products and services, without making any design changes (see e.g. Sakao & Lindahl [2]). Even though several researchers (e.g. [3-5]) have advocated that companies need to redesign their physical products in order to make their new offerings profitable and environmentally friendly, this is rarely realized. The reasons include that their current products and services were developed based on the old business logic, where spare parts and maintenance during the active use phase was considered to be very profitable. In the IPSO business logic, spare parts and maintenance are considered as costs and thus detrimental in terms of improving the economic performance of the offering. The subject of this paper how a provider's processes (mainly design) influence IPSO performance.

In general, different processes affect the performance of an IPSO, with the major processes being design, production, and use. Note that other processes by a provider

adfa, p. 1, 2011.

such as logistics, maintenance, and take-back are modelled here as service within an IPSO. In addition, production and use of service happen simultaneously, i.e. simultaneity or ubiquity of service [6], while that of a product occurs sequentially. The contribution of design on life cycle performance is perceived to be high. Specifically, the earlier stage of design is most influential. From the economic aspect, for instance, in the case of products, "the task clarification stage of product design accounts for only 10-15% but determines 50-70% of the total cost" is well-known [7, 8].

The influences of design, production, and use on economic and environmental aspects using real-life cases in industry have been reported, especially in the last decade. The influences of design are reported mainly from the automotive sector. For instance, Alonso *et al.* [9] and Schmidt [10] show the life cycle cost and the life cycle environmental impact of different materials and/or designs for a specific part of a car. Concerning production, the relationship between manufacturing process precision and environmental impact is quantified by extending the LCA methodology, and was reported to be positive in the case of an automotive drive train [11]. The use process' influence is also addressed. For instance, Avram *et al.* [12] proposed a method for adopting AHP (analytic hierarchy process) and applying it for sustainability assessment of different alternatives within the use phase, such as cutting parameters, to a case on machine tool systems. Fig. 1 depicts the processes and aspects of an IPSO system, as well provides some example references for the processes.

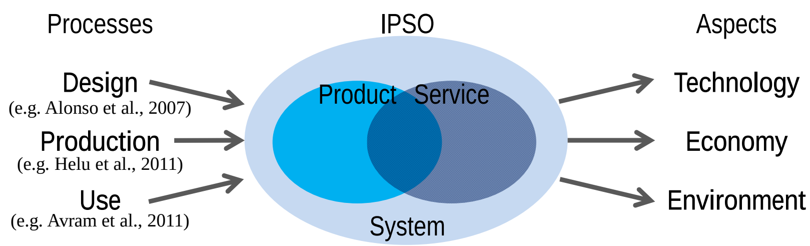

Fig. 1. Processes influencing an IPSO and major aspects for evaluation.

As briefly reviewed above, existing literature based on real-life cases in industry focuses on physical products. One of the few papers reporting the different economic and environmental performances, depending on if it is an IPSO or product sales, is Sundin *et al.* [13]. There is clearly a lack of knowledge on how design of an IPSO, especially its service component, influences the economic and environmental aspects.

2 Objective

The objective of this paper is to, based on an in-depth case study in a manufacturing company providing an IPSO, illustrate and discuss how design changes on a physical product or a service can improve the environmental and economic performance of an offering. In contrast to Sundin *et al.* [13], this paper addresses a series of design changes longitudinally in order to better illustrate the design activities of IPSOs in industry.

The paper discusses the contribution of changes on a contract of IPSO business based on our earlier investigation, in an integrated manner, with the changes on a physical product. The value of this paper lies in its argumentation on the importance of design changes on the IPSO context, i.e. those on a physical product and a contract, based on real cases in the manufacturing industry.

3 Method

Literature studies, interviews and questionnaires were the methods used for gathering data about the case. Strong trust between the authors and participating companies, built over many years, has enabled unique access to data that are considered to be business secrets in many companies. These data have been carefully managed and agglomerated so that the final results do not reveal sensitive secrets, yet maintain the sufficient sources for scientific argumentation.

Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) methodologies have been used to illustrate the quantitative changes in environmental and economic performance, the two of which are briefly described below.

3.1 Life Cycle Assessment

LCA is a method used to assess a product's life cycle's total environmental impact, from an overall perspective, associated with all the stages of its life, from cradle-to-grave. These stages span from raw material extraction to manufacturing processes and use in waste management, including all transport and energy consumption. Life cycle analysis can be done in all human activities and products such as food, packaging, electronics, fuels, transportation, etc.

3.2 Life Cycle Cost

LCC is a cost model that reflects the total cost of an investment, product or system. All costs associated with all the stages of its life, from cradle-to-grave, are summarized, i.e. from raw material extraction, through manufacturing processes and use in waste management, including all transport and all energy consumption. It is a method used for instance in the analysis of overall costs and comparative studies in procurement, product development and maintenance planning.

4 The Case – Core Plugs for Paper Mills

Polyplank AB has developed a process to transform plastic waste and wood fibres into a cheap, recyclable and moisture-resistant composite material used in different system solutions, one of which is the core plugs used by paper mills [13, 14]. Paper mills use core plugs, on which the paper is rolled up; thus, the core plugs follow the roll out to the customer. Below is a description of how Polyplank’s core plug IPSO concept has been developed over time, and how the development has influenced - and has been influenced by - the core plug design.

4.1 Background

Polyplank’s core plugs have, in several cases, come to replace previously used core plugs that were made of a formaldehyde material. Fig. 2 shows an example of how they can look. Formaldehyde-based glues are used extensively in the woodworking industries, e.g. in the glues that bond particle board together. Formaldehyde core plugs are normally made of moulded wood chips that are glued together with formaldehyde-based glues. Core plugs made of formaldehyde material have several drawbacks that caused both paper mills and their customers various problems.

Fig. 2. A traditional core plug made of formaldehyde material.

One problem was that they often gave rise to splinters that destroyed the paper so that it could not be used. This caused a financial loss for the paper mill and especially their customers. Furthermore, since these plugs were designed for single use, it caused the paper mill's customers extra work and costs for waste disposal. All this implied that the paper mill was interested in finding a new, more suitable plug that could solve the problems above.

4.2 The Orginal Polyplank Core Plug Design

By coincidence, Polyplank obtained information about the paper mill’s need. The paper mill company had already started to consider a core plug made of virgin plastic, and had also come up with a design for the plugs. Together with a competitor that made core plugs based on virgin plastics, Polyplank started to deliver and sell core plugs in a traditional way, i.e. for single use, as shown in Fig. 3.

From a traditional sales perspective, the core plugs were nearly perfect. As a single-use designed product predefined by the customer, it required a lot of material and was dependent on the geometry, which was complicated to produce. Sharp edges and corners implied extra requirements on the tool for the injection moulding, and also for the time in the tool. At the same time, the production complexity implied that the company could charge a premium for the production. Furthermore, the selected geometry also implied a relatively high weight, which also meant high use of Polyplank's material. This was also good from a traditional sales perspective, especially since the company could refer to the initial customer's specification. The paper mill's customer, however, still had difficulty disposing of the used core plugs.

Fig. 3. The orginal Polyplank core plug design.

4.3 The Take-Back System of Destroyed Core Plugs – The Starting of an IPSO

One of the major benefits of Polyplank's self-developed material is that it is easy to reuse in new core plugs or other Polyplank offerings. This also implied that Polyplank had an idea from their beginning to be able to take back and reuse the material in their old products. This goal has also had an impact on how they have designed their products or systems; in other words, it should be easy to take back the Polyplank material. It was, therefore, not unusual when Polyplank proposed to their customers that they could start to take back their core plugs and as well as those made of virgin plastic. Those made of virgin plastic became a raw material when producing the Polyplank material.

The paper mill agreed and used reverse logistics to handle the take-back, something that became immediately successful. The paper mill and their customers had less costs for waste. From Polyplank's perspective, this was of course a win as stated above, since after a chopping process it could reuse incoming scrapped core plugs as direct raw material for new ones.

4.4 The Reuse System for Core Plugs

Those within Polyplank continued to think of how they could improve their offerings. They realized that a lot of the core plugs that came back were like new and could be reused by the paper mill company. However, in order to secure the quality, they had to be inspected and washed. Only the worn-out or destroyed core plugs should be sent back for material recycling. Therefore, they proposed to the paper mill that they should launch a take-back and refurbishment system within their own operations, i.e. reuse of core plugs from their customers. From a traditional business perspective, this made no sense for Polyplank, but the company had a longer and broader perspective. The paper mill set up a take-back system, including cleaning, as seen in Fig. 4, and from the beginning this was a success for both their customers and themselves.

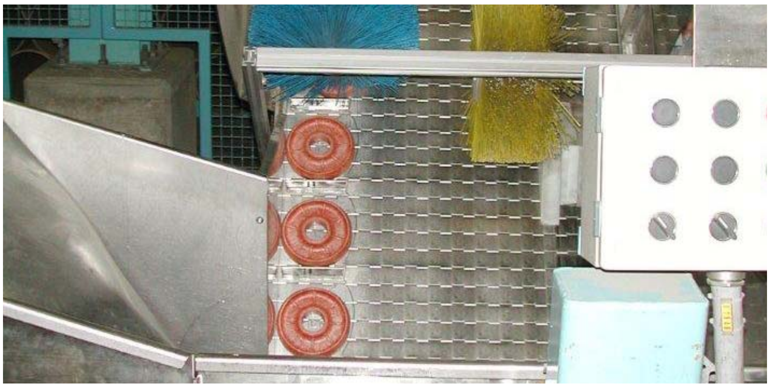

Fig. 4. Cleaning of used core plugs at the paper mill company.

At the same time, it started to become obvious that the core plugs' original geometry with sharp edges and corners, often the starting points for cracks (see Fig. 5), had several cons. Even though broken new core plugs didn't cause major damage to the paper, e.g. that caused by splinters, they still resulted in an economic loss since the core plugs could not be reused, but instead had to be sent back for material reuse. After introducing the tack-back system, it also became obvious that the complex geometry also made it tricky for the paper mill to clean the plugs before reuse. This, however, this was not a cost that affected Polyplank.

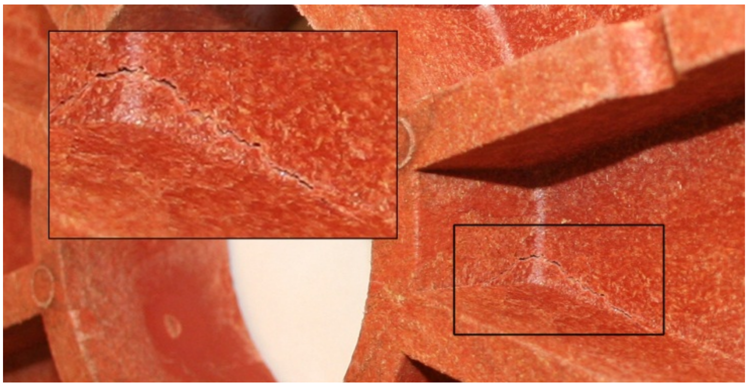

Fig. 5. Magnification of cracks on a core plug.

4.5 The New Polyplank Core Plug Design

Even though Polyplank creates their products and IPSOs based on recycled material, they prefer to use as little material as possible in their offerings. Cutting down the material use has been a core value for Polyplank since the beginning; they want to develop, from a life cycle perspective, resource-efficient and effective products.

In line with this, internally Polyplank also had thoughts of how they could modify the original core plug design into a design that not only solved the above described cons with the existing core design, but also reduced their cost for providing the offering.

Even though they could reuse their material, their idea was to develop a core plug that required less material, was easier to produce, was easier to transport and clean and, not least, more durable. The latter was important in order to make the plug more competitive, and also allow more reuse between the paper mill and their customers. The key was to use less material in the product. By using less material in each core plug, less material had to be chopped and processed in Polypank's factory, i.e. heated up etc. in the moulding machine and transported to the customer. In addition, the paper mill's transportation costs could be reduced.

Together with the paper mill they started up a redesign project in order to design a more system-optimal core plug. In collaboration with a consultancy company and a university, they began to re-design the current core plug. The company performed advanced Finite Element Method analysis to find a design that could improve the core plugs' durability while also making the core plugs easier to wash, produce and transport. The result was a core plug that was 35% more durable, and at the same time 30% lighter, as shown in Fig. 6. The higher durability implied more loops between the paper mill and their customers, and the reduced weight meant less transportation and production costs, since less material needs to be managed in the production process, for example in the injection moulding used for producing the core plug.

Fig. 6. The new Polyplank core plug design.

The core plug IPSO is now more than 10 years old, and has resulted in Polyplank taking market shares from competitors as well as a close collaboration between Polyplank and the paper mill company. Normally, the core plugs go back and forth several times between the paper mill and their customers before the plugs return to Polyplank.

5 Changes in Environmental and Economic Performance

As described above, the core plug and the system in which it is used has been changed several times over the years; the question is the effect this has had on the offering's environmental and economic performance. In order to investigate and illustrate this, LCA and LCC analysis have been used. All calculations are based on data provided by Polyplank.

Based on how the core plug and its system have changed over time, nine different alternatives have been calculated to illustrate the performance effect of the changes. Table 1 presents the different alternatives.

Table 1. The different alternatives used for the calculations.

ID	Product	Product reuse?	Material recycle?
1	Virgin plastic core plug	No	No
2	Polyplank core plug with original design	No	No
3	Polyplank core plug with new design	No	No
4	Polyplank core plug with original design	5 times	No
5	Polyplank core plug with new design	5 times	No
6	Polyplank core plug with original design	No	5 times
7	Polyplank core plug with new design	No	5 times
8	Polyplank core plug with original design	5 times	5 times
9	Polyplank core plug with new design	5 times	5 times

Discussed below are some of the most important effects of changes performed. Note that all of the results below are related to the entire life cycle. Also important to note is that the compared LCA result only relates to global warming (CO_2 eqv); other environmental categories, such as savings regarding natural resource etc., are not included.

5.1 Effects of the Introduction of Polyplank's Core Plugs

Since it is not possible to make a comparison with core plugs made of formaldehyde, the starting point and reference used is core plugs made of virgin plastics that are used one time before being scrapped.

Not surprisingly, the introduction of the Polyplank core plug resulted in a substantial environmental performance improvement, 31% for the old design and 57% for the new design. This was the case despite that they would be sold in a traditional way and only used one time before being scrapped. The economic performance improvement was even higher at 36% and 62%, respectively.

5.1 Effects of the Take-Back System of Destroyed Core Plugs

When comparing the effect of the take-back system of destroyed core plugs with the single-use system of core plugs made of Polyplank material, the relative environmental / economic improvement effect is high, 57% vs. 51%. When comparing the improvement between the old core plug design used once and the new core plug (reused for material 5 times), the effect is 70% vs. 66%.

5.2 Effects of the Reuse System for Core Plugs

Compared with the newly-designed core plugs, used only once, core plugs used five times have a significantly improved environmental and economic effect, approximately 71% and 73%, respectively. If the core plug could be reused even more times, this would further increase the improvement effect. However, the percentage improvement effect decreases for each time the product can be reused, since the relative cost for reuse in comparison with the production cost increases.

5.3 The Total Effect of the Polyplank Core Plug Offering

Fig. 7 shows the environmental and economic improvement effect of Polyplank's Core Plug Offering in comparison with different alternatives. In the figure below, the most interesting is Alternative 9, since it is most like the offering that Polyplank provides. The exact number of reuse and material recycling instances, however, differs slightly from the real case.

Nevertheless, in comparison to the original core plugs sold for single use, their offering's environmental and economic performances have improved, 9% vs. 13%. If compared with the core plug made of virgin plastic, the figures are 6% and 8%, respectively. At the same time, the offering's performance also improved, something which was not anticipated.

6 Discussion

As shown in the previous section, all of the design changes on either the product or the service (such as product reuse and material recycling) in the case were found to improve the environmental and economic performance compared with Alternatives 1 or 2. Note that Alternative 2 represents the traditional product sales business with the original design at the IPSO provider. This means that this provider could design a product or a service that contributes to both the economy and the environment: i.e., Alternative 3 (new design of product) or Alternative 8 (new design of service) as a reference to Alternative 2. However, it is important to note that Alternative 3 and Alternative 8 are both unrealistic. Considering each service, Alternative 3 has excessive quality regarding the product, while Alternative 8 may have insufficient quality regarding the product. On the other hand, Alternative 9 (new design of both product and service) makes sense because the implemented product quality is required by the provided service. In fact, the new product design was carried out based on the service (as shown in Section 4.5). This case shows how design of service and design of product influence each other on a real offering in industry, and serves as evidence of the need for the integrated design of product and service.

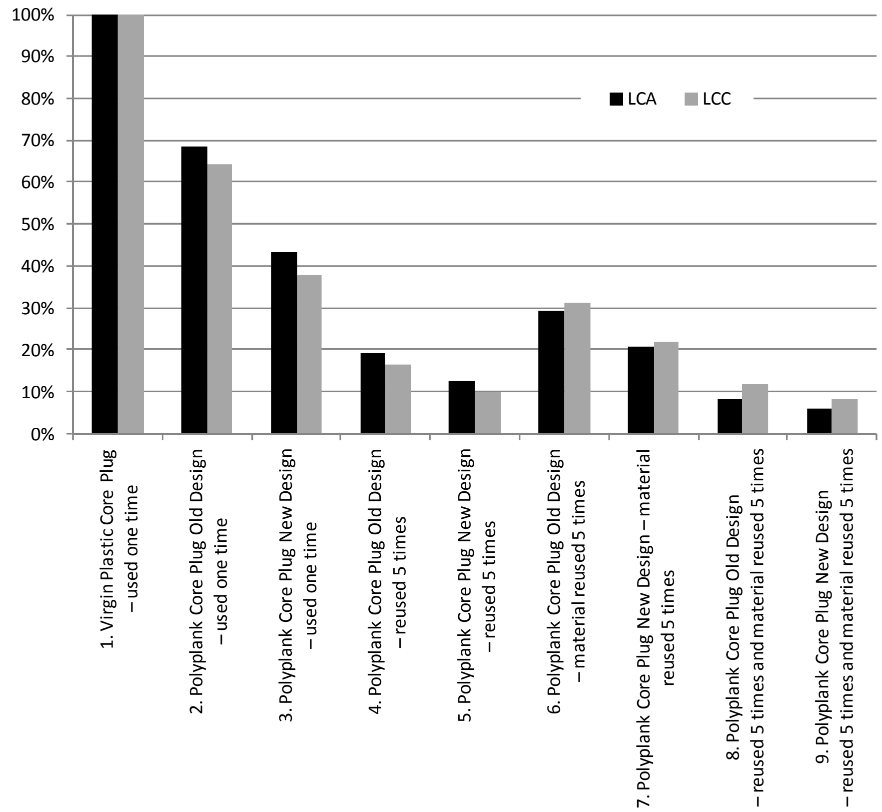

Fig. 7. Relative comparison of the environmental and economic effect of different alternatives.

The degrees of contribution by design changes on performance given different alternatives were found to be up to approximately a factor of 10 (with Alternative 1 as a reference) in this case. This case did not show the contribution of production and use of this IPSO on performance. Such quantitative comparison between the contribution by design, production, and use would be an interesting topic for future work.

Correlation between environmental and economic improvement was found to be positive in most of the comparisons of different alternatives in this case. Although this cannot be generalized, earlier research [13] also shows that some other cases have a similar trend. It would be interesting to identify the key factors influencing this trend, and this will be part of our future research.

Another interesting research avenue is determining the factors that enabled Polyplank to design this series of IPSOs. Apparently, successes in designing IPSOs with better performance on the environment and the economy like Polyplank are not so common. One can ask what kinds of factors are keys to this success – product characteristics, company characteristics, or something else.

Unfortunately, since it has not been possible to obtain any data for the formaldehyde core plug, this is not included in the comparison. It would have been interesting to calculate the environmental and economic performance change related to the losses of paper and extra work at the customer caused by the formaldehyde core plugs.

7 Conclusion

This paper presented one of the first in-depth and quantitative studies of an IPSO's effects on the environment and the economy. It focused on design changes rather than changes of production or use. The case showed substantial improvement (reduction of approximately 80 to 90% in terms of both LCA and LCC) by the provider's design changes of a product or a service on environmental and the economic performance. Most importantly, the high relevance of the interrelation between the product and the service on the performance was shown.

This case can be used as a reference to illustrate the effects of design changes of IPSOs on the environment and the economy, as well as to argue for the importance of the integration of product and service design. It should be mentioned that this is thanks to the in-depth study. In addition, the relatively simple structure of the physical product can be argued to support the ease of understanding the comparison among different alternatives. Our future work includes conducting similar case studies with different types of offerings to obtain more insight within this area, and investigating key factors for success such as in the presented case.

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