COMPARATIVE STUDY OF PRODUCT SERVICE SYSTEM BASED ON LIFE CYCLE ANALYSIS— INNOVATIVE LUNCH TAKEAWAY SERVICE SYSTEM DESIGN

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ABSTRACT

As a design strategy with great sustainable potential, product-service systems are widely used to discuss issues related to sustainable developpment. However, systems that are not properly designed will generate further serious irreversible consequences on the environment. It is therefore necessary to accurately assess and analyze the environmental impact of product-service system solutions. This paper expands the method of environmental life cycle analysis from the analysis of products to the analysis and evaluation of product-service systems, discusses life cycle differences between product-service systems and traditional product models, and demonstrates the application of life cycle analysis methods to systems. The process unit establishment method was applied in sustainable design curriculum, in which a sustainable takeaway lunch service system solution that was proposed in the course was tested. The process unit was described to provide a theoretical basis and support for future in-depth measurement and analysis.

1. THE SUSTAINABILITY OF PRODUCT-SERVICE SYSTEMS

The impact of design activities on the environment is enormous and far-reaching. Design and designers have been and remain a necessary component of modern business systems, and design has promoted consumption as well as a large amount of waste and garbage. Design seems to be both within and outside of the life cycle of products. Design is only an intermediate link in the industrial chain, but it is also the origin that determines whether products can be born. From a life cycle perspective, the product of design never leaves the environment, whether in the form of raw materials, finished products, or waste; it is instead transformed into different forms of matter.

Mont (2004) defines product-service systems (PSS) as products and services that support networks and infrastructure systems designed to compete to meet customers' needs and have less impact on the environment than traditional business models. The PSS field has continued to evolve, and environmental considerations are no longer the most influential aspect of the PSS research process.

From a macro perspective, product-service systems can promote the acceleration of economic development in emerging economies and low-income countries, skipping the stage of the personal consumption of products and leaping into the service economy stage based on consumer satisfaction and low resource consumption (UNEP, 2002). An idealized product-service system can also help companies improve their economic impact and competitiveness while reducing their environmental impacts.

Overall, the development of product-service systems has great potential; they can improve environmental impact while improving profits and achieve a win-win situation. Such systems have the potential to provide some of the necessary conditions to promote a shift in social and economic systems to resource-saving (lower resource consumption). However, it is important to emphasize that even with good design, some changes in product-service systems may have a negative impact (e.g., a rebound effect).

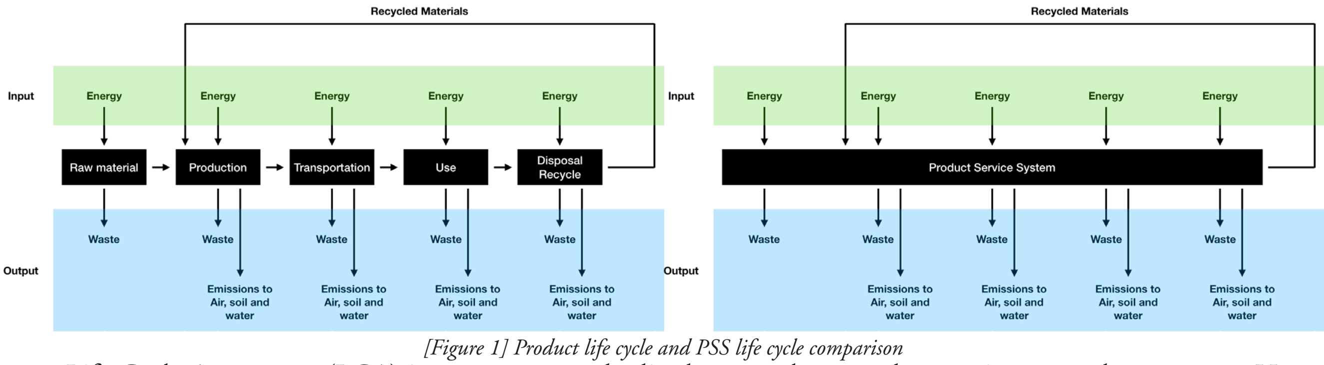
2. PRODUCT SERVICE SYSTEM LIFE CYCLE AND ASSESSMENT

The PSS strategy involves the transformation of business models from selling specific products to providing functional services through a mix of products and services in order to motivate resource efficiency and user satisfaction. Although PSS has the potential to reduce environmental impact, it is not at an absolute advantage over the traditional system.

At the same time, because the problems that PSS faces and aims to solve are often wicked problems, their solutions cannot typically be optimized and improved. Once implemented, such solutions will have irreversible effects, so a sufficient number of decision makers and designers must be involved in the development process. At the beginning of the design, this will allow the development of a more comprehensive understanding of the advantages and disadvantages of PSS solutions and the quantification of their impacts on the environment. On the other hand, since the types of PSS are complex and varied, the systems they face and try to optimize are equally complex. Therefore, the environmental impact of PSS must be assessed and the circumstances under which PSS leads to environmental improvements must be determined to support PSS design and related decision-making during implementation or when optimizing existing PSS.

Life Cycle Assessment (LCA) is one of the most effective methods for the environmental assessment of systems that include goods, services, or a combination of both. However, the current LCA guidelines focus on evaluating tangible products and lack special attention to more complex systems, such as product-service systems.

As shown in Figure 1, life cycle analysis can measure the energy input and output of each link and process in the life cycle of the target product to evaluate the environmental impact of the entire process. This process helps decision-makers adjust and optimize the target system. However, when faced with a product-service system, the entire process becomes a "black box" system that is difficult to define due to its complex boundaries, intricate material flow, and information flow.



[Figure 1] Product life cycle and PSS life cycle comparison

Life Cycle Assessment (LCA) is a mature, standardized approach to product environmental assessment. However, using LCA in a PSS environment is challenging. Current LCA guidelines are product-centric in nature and do not clearly state the characteristics of PSS. According to the LCA standard of ISO 14040:2006, a "product" can be defined as any good or service (ISO, 2006a). Therefore, the steps involved in LCA are considered to be the same regardless of whether the function is implemented by delivering a physical product or an intangible service. This definition implicitly makes the method applicable to PSS.

Kjaer et al. found that the main challenges of applying LCA in three PSS (2016) were:

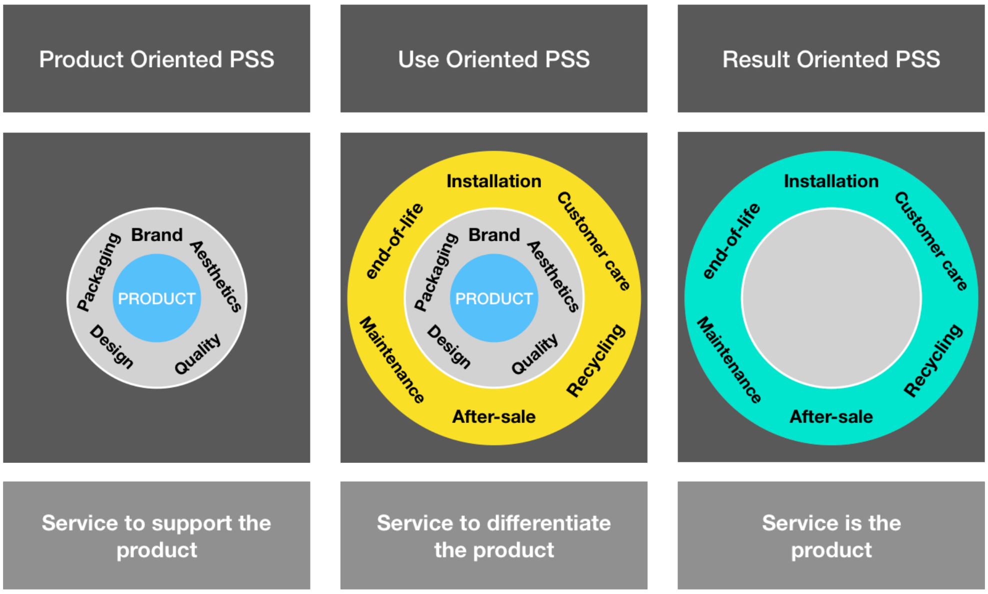
1) Identifying and defining the reference system: How does one identify and describe the relevant reference system of the PSS for comparison? Three ranges of PSS evaluation are defined: (1) PSS optimization (in which the reference system is an existing PSS); (2) PSS comparison (in which the reference system is one or more predefined comparable alternatives, usually traditional business models); and (3) PSS consequences (in which the reference system is defined as the baseline case without PSS).

2) Defining the unit process: How does one determine functional equivalence when defining the unit process (UP)? If the relevant sub-functions are not included, an imbalance in functional results and quality will occur. In addition, differences in the perceived value of users may result in a rebound effect.

3) Setting system boundaries: How does one ensure sufficient integrity of system boundaries (including products and services in the back-end system) to avoid truncation errors and thus ignore potential important contribution processes?

Kjaer also pointed out that using LCA to evaluate the environmental performance of PSS can be challenging. While the method framework in LCA is considered to be the same for products and services, the PSS concept is more concerned with differences between tangible products (such as machines) and intangible services and activities (such as maintenance) because their integration is value-added and creates a "system" (Baines et al., 2007). In this sense, PSS is not just a set of product and service inputs; it is also the result of design strategies based on new value systems and innovative market opportunities (Manzini and Vezzoli, 2003). In their multi-level design model, Joore and Brezet (2014) used PSS as a link between product technology systems and social technology systems, demonstrating PSS's position to transform social needs into novel solutions.

To clarify the relationship between products and services in this model, we combine the three core design strategies proposed by Tukker (2004) – pure product design, product-service system design, and service design – in conjunction with Thoben's (2001) and C. Favi's (2012) concept of extended products and two service-oriented scenarios: the product+service and product2service models. Product-oriented PSS is a service that supports a product, while use-oriented PSS is a service that differentiates a product, and in result-oriented PSS, the service is the product.



[Figure 2] Product-service system model

We can consider that in the product-oriented phase, the service is only used to support the product. In the LCA, the rules of cut-off can be used because in a conventional product-oriented system, the service usually appears as infrastructure or manpower consumption. This is negligible in LCA. In the other two types of systems, however, intangible services and tangible products have undergone fundamental changes in their relationship.

In a product-oriented PSS consisting of traditional washing machine sales and the related after-sales services, the corresponding life cycle generally refers to the life cycle of the washing machine itself, and the related incidental services are not considered therein. However, life cycle analysis in a usage-oriented PSS such as a shared laundry room considers the energy consumption of the washing machine itself and the energy consumption (electric energy and water consumption) generated by the single-use service, as well as the number of times the service occurs and the maintenance of the machine. In a results-oriented PSS such as the provision of cleaning services, the service itself can be regarded as a "product," and its life cycle includes the energy consumption of the related material products as well as the "intangible service" that can comprehensively consume energy (such as the traffic, electricity, and water consumption involved in the service itself) and the number of services. This is shown in Table 1 below.

[Table 1] Life cycle consideration for three PSSs

Type	Life cycle consideration			
Product-oriented PSS	Product life cycle			
Use-oriented PSS	Product life cycle	Energy consumption per use	Service frequency	Maintenance
Result-oriented PSS	Product life cycle	Comprehensive energy consumption (transportation, water, electric, etc.)		Service frequency

According to the three main challenges proposed by Kjaer, PSS may be considered a "black box" system in LCA due to the uncertainty of its process unit, which is necessary for the establishment of an effective basis for a complete life cycle model. All data collection and analysis for LCA is based on such process units. We will use the sustainable product-service system developed by students at Tsinghua University as a case study to establish a process unit for description.

3. CASE STUDY

3.1. Background

This project relies on the sustainable design curriculum of the Academy of Fine Arts of Tsinghua University, in which research and practice are conducted on the theme of "sales-based sustainable service systems" from the perspectives of lunch box garbage, healthy eating, and sustainable lifestyles. The life cycle analysis checklist method is applied in the design of product-service systems for sustainability assessment.

3.2. Needs analysis

Consumers in many cities in China use digital takeaway platforms to order food daily. In addition to a delicious meal, takeaway delivery leaves consumers with plastic bags, plastic lunch boxes, and tableware. This practice has obvious environmental implications. In the first half of 2018, China's two major takeaway platforms (Meituan and Hungry) distributed an average of 33.9 million takeaway meals a day, and takeaway composition usually included at least one set of tableware and two meals. This means that on average, 60 million plastic lunch boxes are born in China every day.

The waste created by plastic lunch boxes is usually mixed with other types of domestic garbage and sent to landfills or incineration plants. Without proper professional treatment, this waste will undoubtedly cause severe pollution to the soil, water, and air near municipal waste treatment plants.

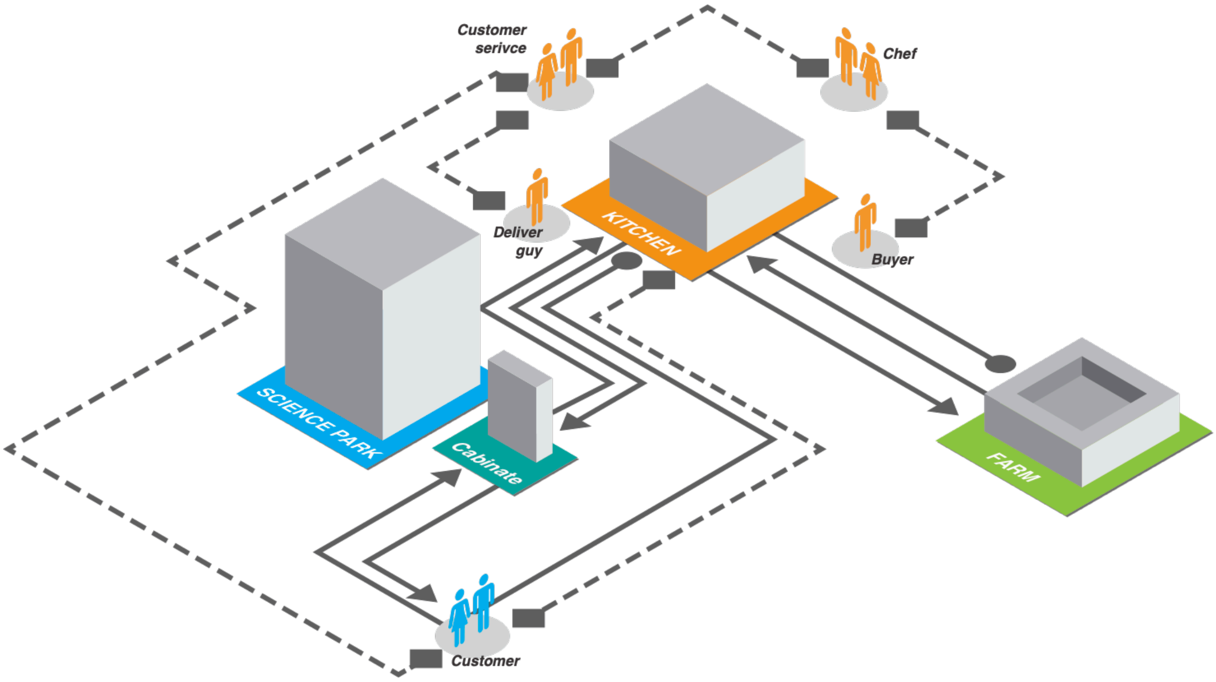
Through interviews and investigations, we found that although most white-collar workers are willing to bring meals to work, the companies they work for often do not have food-heating equipment, and when they return home from work, they often have no time to prepare ingredients and cook. This leads them to order food. In addition, white-collar workers tend to pay more attention to their own health, and although takeaway platforms provide choices such as health- and fitness-focused meals, they are expensive and the ingredients and processing methods they use are not satisfactory.

[Figure 3] Field study on typical takeaway meals

3.3. System Design

The design scheme in this project adds a new dining option for lunch, which encourages users to use reusable lunch boxes and customize their lunches through a localized dining platform. Multiple stakeholders such as catering companies, health and medical institutions (such as gyms), consumers, and farmers are included in the consideration.

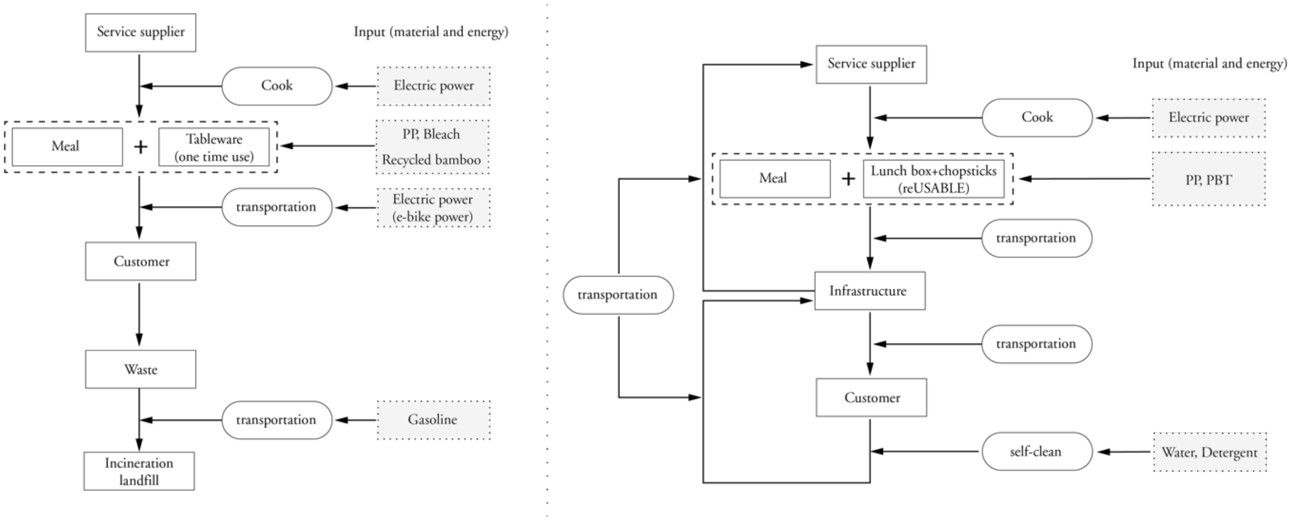
The customized, reusable lunch box allows users to feel a sense of belonging during meals and reduces the use of disposable lunch boxes. Second, the user and the service provider interact through the use of customized lunch boxes in the process of ordering meals and feedback, which will increase trust in the service as well as transparency. Cooperation with local farms may also be increased with this system. The future kitchen in the science park will become a community interface, and the large degree of freedom and flexible service model can easily be copied and provide interaction with different nodes of the system.



[Figure 4] Service system map of new takeaway food system

3.4. Unit Process

In LCA, any production or consumption activity can be described as a unit process. A unit process consists of the underlying stream (input, output), the intermediate stream (input, output), and the product/by-product or service. Combining the current takeaway system and the product-service system design in the conceptual solution, we defined the unit processes of the two services, as shown in Figure 5.



[Figure 5] functional unit of current takeaway food system (left) and concept design (right)

In our research, we found that in the existing takeaway service, electric heating is primarily used for cooking. Tableware is usually made of PP-based lunch boxes and recycled bamboo chopsticks. Food transportation is based on lithium-ion battery electric vehicles, and garbage-transfer vehicles are mainly gasoline-driven. In the new solution, the input of the unit process mainly includes power consumption from cooking, reusable lunch boxes, and the water and detergent required for users to clean their lunch boxes.

4. CONCLUSION

In this paper, environmental life cycle analysis is extended from the analysis of products to the analysis and evaluation of product-service systems, demonstrating its evaluation power. The process unit was developed in a sustainable design curriculum, in which students' solutions were tested.

In the future, tools such as Gabi and Sima Pro will be used to further help students establish a comprehensive "system thinking" perspective. This may guide students to understand life cycles, apply life-cycle thinking to solve practical problems, and consider the impact of decisions at each stage of the life cycle in a quantitative and qualitative manner.

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