Taxonomy of Product–Service System Perturbation

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Perturbations have a negative influence on the operation of the business system, which may weaken business performance. Product–service system (PSS) perturbations could be classified into six categories, namely, behavioral, social, environmental, competence, resource, and organizational perturbations. The proposed terminology and taxonomy appear to be effective, which could enable researchers to understand the scope of PSS perturbations on a conceptual level. This finding is also expected to provide useful knowledge and information for researchers who are interested in vulnerability analysis and the robust design of PSS.

product service system | perturbation | taxonomy

1. Introduction

In recent decades, the manufacturing industry in developed countries has faced the challenges of higher costs and competitive markets. It appears that traditional manufacturing companies cannot keep the business mode they used to own. Thus, servitization is considered a direction to mitigate this predicament, which could improve value and competitiveness by providing additional services (Martinez et al. 2010; Kryvinska et al. 2014). In this context, the product–service system (PSS) has attracted tremendous attention since it could sustainably integrate products and services. According to Mont (2002), PSS is a marketable set of products and services capable of jointly fulfilling a user's needs. Furthermore, it was also pointed out that this system could benefit itself by sharing the ownership of products with customers (Tukker 2004), which has shown great potential in reducing environmental impact and improving competitiveness (Haase et al. 2017).

Despite the promising potential, the problems caused by PSS perturbations are worrying. In PSS, a perturbation is any endogenous or exogenous event that modifies the stated PSS operational conditions (Estrada and Romero 2016). The existence of perturbations could lead to an unwanted change in the PSS. Compared with PSS failure, which focuses on the undesired function of a single actor and item (Kimita et al. 2018), the concept of perturbation focuses on all kinds of events that could lead to the unwanted performance of all components of the PSS, namely service actors, products, tasks, and the whole system. Perturbation does not focus solely on the issue of failure and disruption; it is the integration of the deterioration of performance, the disruption of tasks, and the collapse of the system (Wang et al. 2022).

In the field of robust product design, perturbation is a similar concept to the noise factor. A noise factor is an uncontrollable and sensitive event that can seriously affect the performance of artifacts (Taguchi 1986). Thus,

considering this feature, noise could be considered a type of perturbation with high sensitivity and uncontrollability. The most common categories of noise factors are internal, external, and unit-to-unit noise factors (Taguchi 1986). Given that noise factors are expensive and difficult to control, researchers usually recommend reducing the sensitivity of products toward noise instead of mitigating its influence (Park 1996; Arvidsson and Gremyr 2008). However, for a real business, it has been found that companies usually do not prepare a database about this type of event. Instead, they just collect the loss of events (Creveling et al. 2002). It would be a complex task for researchers to propose a robust design if they cannot understand the cause, effect, and features of a perturbation. A clear understanding of perturbation and noise-related manufacturing is considered a promising solution. For the service industry, the major concern related to perturbation is the disruption of process and deviation in service quality brought by accidental events. The huge loss is caused due to the wrong response of staff and the poor design of the process. Most customers have been found to reject purchasing a service again and show lower satisfaction if they experience a service failure and service recovery (Smith and Bolton 1998). Thus, how to enable the service process or service actors to respond to an accidental event is regarded as a critical mission toward robust service (Weiss and Goldberg 2019).

For perturbation in PSS, several pieces of evidence show that PSS is not a robust system that cannot fight against the influence of perturbations. Multiple PSS providers suffered a huge loss during unexpected accidents, which could be called perturbations. For example, COVID-19 is a typical unforeseen event that has caused considerable economic and social loss to PSS providers. In New York, the shared bike system experienced a sharp reduction in average trips (Padmanabhan et al. 2021). It was also reported that the number of bookings and occupancy rates for Airbnb was significantly reduced in the US during COVID-19 compared to previous years (Boros et al. 2020). The income of Airbnb also experienced a sharp reduction during COVID-19 (Chen et al. 2020). Furthermore, given that PSS is a direction for manufacturing firms who are struggling to survive in the competitive market, some PSS firms are not just organized but also transformed from manufacturing enterprises. Therefore, the unwanted change in performance could happen in a pretty early period of PSS operation due to the inability of the PSS firm. According to de Jesus Pacheco et al. (2019a) and Michalik et al. (2019), many small- and medium-sized manufacturing firms struggle to transform themselves into PSS providers due to the lack of financial resources and management experience. Furthermore, the findings in multiple kinds of literature show that the features of PSS might form unique PSS perturbations. For traditional manufacturers, the theory of ‘service paradox’ proposes that manufacturing firms may have no experience to manage the risk of becoming a service provider. There is a potential resistance and misunderstanding toward PSS novelty from internal staff, which leads to inadequate efficiency and poor service quality (Brax 2005). The special orientation about ownership is also a troublesome issue. Inagaki et al. (2022) propose that it is highly possible for an early barrier to be related to the features of PSS, especially the special orientation about sharing the ownership of the products. They propose that this would lead to a lack of a sense of responsibility and cultural support, which then cause financial loss and mismanagement. For user-oriented and result-oriented PSS, providers have exposed the inability to control the adverse behavior of customers when there is poor legal support or moral guidance. For example, in the PSS of the shared bike, the destructive behavior of customers is always regarded as an annoying perturbation by PSS providers, leading to

broken bikes and low customer satisfaction. PSS providers are at a loss about how to maintain these bicycles and guide customers to use them carefully (Jia et al. 2018).

Based on the above information, PSS researchers and designers were exposed as having poor preparation for perturbation mitigation due to a lack of knowledge related to perturbation identification and management. The substantial loss was caused before they proposed appropriate mitigation. For PSS design, it is important to make a checklist or database about risky events that are related to perturbation. Low completeness of related tasks leads to low performance in PSS maturity (Muto et al. 2015). A knowledge-based design is proposed as a solution to improve the quality of PSS (Akasaka et al. 2012). There is a need to utilize knowledge of perturbation to achieve a robust PSS design. Frustratingly, the useful information that researchers could find in the field of PSS is often partial or not enough. Researchers seem to be reluctant to use the term 'perturbation'; this phenomenon was already shown when researchers were reviewing studies related to the vulnerability of PSS (Wang et al. 2022). Instead, the terms 'barrier' (Besch 2005; Kuo et al. 2010; Moro et al. 2020; Inagaki et al. 2022), 'service paradox' (Oliva and Kallenberg 2003; Brax 2005; Dmitrijeva et al. 2022), and 'operational risk' (Reim et al. 2016) have become popular recently. For the description of events that have a risk of bringing unwanted change, there is still no research integrating the findings of the various aspects of other research. It is still unclear whether all the events involved in the above concepts would also lead to unwanted changes in the operating performance of a PSS. Furthermore, so far, current research in the field of PSS has not provided a clear explanation of the scope of PSS perturbations. Despite the definition provided by Estrada and Romero (2016), a single definition cannot enable designers and managers to understand perturbation in a complex business environment. Designers and managers have been proven to require further knowledge to overcome challenges during the operation stage (Sjödin et al. 2017). In the real business world, perturbation can originate from various aspects, which require further details about the categories of the various perturbations (Wang et al. 2022). Thus, a detailed taxonomy of PSS perturbation is the critical theoretical basis for understanding the vulnerability of PSS and achieving robustness in PSS. For the above reasons, there is a strong requirement to provide effective and comprehensive knowledge about PSS perturbation through a taxonomy.

2. Behavioral Perturbation

The item of behavioral perturbation refers to events related to a customer's adverse behavior, which could destroy products or reduce a product's life. During the influence period of this type of perturbation, the maintenance efficiency and product availability seriously deteriorate.

The problem of customer adverse behavior is a typical PSS perturbation, which has been focused on in the research of Reim et al. (2018) and mentioned by Reim et al. (2016), Sakao et al. (2013), and Moro et al. (2020). Compared with the traditional manufacturing industry, PSS companies often need to provide customers with a longer period of business, such as maintenance and leasing rather than simply selling products (Reim et al. 2018). Therefore, customers have more possibilities and time to damage products, and companies must consume a lot of resources for maintenance and remanufacturing. According to Reim et al. (2016, 2018), adverse customer behaviors can be observed from three perspectives, namely, careless behavior, opportunistic behavior, and reverse

selection. Careless behavior refers to damage to products caused by customers when they do not pay enough attention during operation. Opportunistic behavior and reverse selection refer to intentional destruction or behavior. For PSS, especially user-oriented and result-oriented PSSs, there is no available regulation that could punish customers if they lead to a breakdown of products. It seems that PSS providers can only expect that a high-level morality in customers could prevent such types of events. This general condition promotes the motivation of immoral behavior, including intentional destruction and earning money through a renting contract. It has been reported that some customers even tend to use vulnerable machines to obtain compensation (Reim et al. 2016).

3. Resource Perturbation

The item of resource perturbation refers to any events related to a lack of financial resources, human resources, or material and natural resources, which weaken the performance of a PSS. A lack of resources could lead to difficulty for PSS firms to manufacture products and operate the system, which causes a further negative influence on the efficiency of the system.

The lack of financial resources is usually given high-level importance for the stable operation of PSS. For user-oriented PSS, these PSSs often require a large initial investment (Moro et al. 2018; de Jesus Pacheco et al. 2019a) and might have a high cost (Moro et al. 2020). This makes PSS firms have a strong requirement for stable cash flow to stay operational. A long-term lack of financial resources would lead to the bankruptcy of PSS firms. A lack of personnel has also been cited as a risk factor by multiple kinds of research (Moro et al. 2018; Vezzoli et al. 2015; Kuo et al. 2010). There is also a lack of infrastructure to support the operation of PSS (Vezzoli et al. 2015; Inagaki et al. 2022). Compared with manufacturing firms, the daily operation of PSS requires more staff to support the provided service and products (Kamal et al. 2020; Baines et al. 2020). A lack of experienced service actors would lead to poor service quality and low efficiency. The number of available resources is considered a critical factor for PSS offerings and operations, which can lead to the condition that no material is available for machine production (Reim et al. 2016; Benedettini et al. 2015; Baines et al. 2020). Furthermore, the lack of infrastructure has also been mentioned (Oliva and Kallenberg 2003; Kamal et al. 2020). For some manufacturing firms, a major barrier to servitization is the lack of infrastructure related to IT and services (Oliva and Kallenberg 2003; Inagaki et al. 2022).

4. Competence Perturbation

The item of competence perturbation refers to perturbations caused by a lack of a specific competence in the PSS to conduct its duty in any aspect, including design, accounting, finance, monitoring, and management. This type of perturbation involves two kinds of events:

- Accidental events: When an accident happens, the competence of the service provider plays an important role in mitigating the loss and restoring the operation.

- Known barriers: This type of event is known as a barrier since the design and implementation stage by PSS providers. However, due to a lack of specific competence, the loss is still caused.

Based on the result of the literature research, technical competence is considered an important issue, especially when related to monitoring and IT (Kamal et al. 2020; Martinez et al. 2017). A lack of monitoring techniques is believed to result in product malfunction, which reduces the availability of products and the efficiency of the maintenance system (Reim et al. 2016; Sakao et al. 2013). There is also some focus on other types of competence, including a lack of experience in service design and offerings (Baines et al. 2009; Benedettini et al. 2015; Moro et al. 2020), lack of control and management material (Kuo et al. 2010), difficulty in accounting (Coreynen et al. 2017; Moro et al. 2018; Inagaki et al. 2022), and difficulty in performing logistics and reverse logistics (Besch 2005; Kuo et al. 2010). It has been shown that competence in assessing risk and cost deserves more attention, especially for result-oriented PSS. To ensure that sharing the machine could provide more profits for the firm, the choice of material and energy for saving waste plays a crucial role in the long-term benefit of the machine (Coreynen et al. 2017). There is also a lack of training related to specific skills including communication and IT skills (Kuo et al. 2010; Martinez et al. 2017; Kamal et al. 2020).

5. Organizational Perturbation

Organizational perturbation mainly refers to any events that originate from the organizational structure that hinder the operation and development of the system and collaboration among different stakeholders. The low efficiency and profitability of firms is a usual unwanted change caused by this perturbation.

The prominent sub-perturbation under this group is the low engagement of stakeholders. Multiple works propose that PSS providers might face difficulty in operation due to a lack of support from senior management (Kuo et al. 2010; Martinez et al. 2017; Baines et al. 2020; Kamal et al. 2020). The sudden loss of senior support due to personal reasons has also been recorded as an accidental disaster for manufacturing firms to develop themselves into PSS providers (Baines et al. 2020). Moro et al. (2020) and Besch (2005) illustrated that a PSS's cost and efficiency are influenced by the engagement of supply chain and logistics operators. Moro et al. (2018) proposed that a low-level engagement from the implementation team is a major barrier to a shared bike system being implemented and operated.

Furthermore, the low transparency and exchange of information between partners have also been proposed as organizational problems that could deteriorate the efficiency of a system (Moro et al. 2018). Some firms tend to separate the departments of services and sales; this is regarded as a cause of internal tension, which further reduces efficiency (Dmitrijeva et al. 2022). The inappropriate structure is illustrated as a major source of operational risk, which could weaken the performance of the system (Reim et al. 2016). In the case of shared furniture in North Europe, Besch (2005) found that a decentralized structure is more suitable for PSS when the shipment fee is high. Conversely, a centralized structure can lead to a dramatic increase in the cost of logistics, leading to poorer economic performance. Furthermore, internal organizational conflicts between sales and service areas are believed to be risky in the operation phase. Furthermore, a lack of appropriate organizational strategy

has also been given importance. PSS firms have been shown to require organizational readiness, namely, robust processes and products (Baines et al. 2020). For the different stages of servitization, a sustainable and reliable strategy is important for winning the market (Oliva and Kallenberg 2003; Baines et al. 2020).

6. Environmental Perturbation

Environmental perturbation is used to refer to any event that leads to a change in the legal and economic environment of a PSS that then changes the prerequisites of the contract. This change is usually unwanted, which could make the firm fail to fulfill the commitment and even disrupt the operation of the system.

In discussions about environmental perturbation, the topic mentioned most of the time is legal environmental problems. Legal support, especially related to laws that support the dissemination of shared use, is considered a key policy for operating a PSS (Hannon et al. 2015; Vezzoli et al. 2015; Moro et al. 2020). For many PSS firms, there is a high expectation for government actions to propose an educational strategy that can guide customers to become familiar with this novel renting business mode (Kuo et al. 2010). Furthermore, a policy that encourages customers to buy products is also regarded as a major barrier that hinders the promotion of user-oriented PSS, which reduces the demand for PSS.

Furthermore, despite the limited discussion, the unwanted change in the economic environment, namely, the competitive market and fluctuation of prices of materials, is also worth attention. A lack of profitability and a restricted market is proposed as a major barrier that hinders the economic performance of PSS. The competitors' imitative actors are considered major threats for PSS firms to survive (Baines et al. 2009; Coreynen et al. 2017). In terms of external economic environments, economic downturn and industry recession, which lead to a disrupted market, are considered major causes of the breakdown of PSS firms (Benedettini et al. 2015; Moro et al. 2020).

7. Social Perturbation

The term social perturbation describes any adverse attitude toward PSS on a social level that can weaken the acceptance, trust, and satisfaction toward this novel system. These kinds of events do not have a direct and physical influence on the products. Instead, they show their threat on a social and psychological level.

Generally, adverse social attitudes toward PSS can be classified into three major types, namely, resistance to change, a lack of acceptance toward the design of products and services, and a lack of awareness related to PSS.

Compared with the other two types, resistance to change is given higher importance according to discussions in the majority of the reviewed research. This resistance is believed to be related to the operational challenge inside PSSs, which can disrupt the operation and weaken the service performance. Internal rejection of PSS novelty is a critical problem, which requires some staff to learn how to provide services and understand the value proposition of PSS (Oliva and Kallenberg 2003; Baines et al. 2009; Kuo et al. 2010; Moro et al. 2018; de Jesus Pacheco et al. 2019a; Kamal et al. 2020; Dmitrijeva et al. 2022). There is strong resistance from manufacturing staff to learning

knowledge about services. This perturbation happens in the initial period of operation and implementation, as internal personnel do not have enough knowledge and understanding in this stage. For example, for PSS firms to implement this system in a new context, resistance to established local habits has been proposed as a prominent challenge (Moro et al. 2020). For customers, there is also a problem with resistance toward consumption without possession (Moro et al. 2018), and they have also been found to be sensitive to being monitored by PSS providers when they are renting or using a product (Vezzoli et al. 2015). The above resistance issues could lead to lower efficiency and low interest in PSS, which further reduces the demand of customers.

The lack of acceptance for the design of products and services is considered a prominent type of perturbation on the performance of demand and satisfaction. Some are reluctant to change their habits about purchasing products (Coreynen et al. 2017). According to the finding of the case study of a shared furniture business in North Europe, customers were found to be sensitive to the price of products and services. Furthermore, for the design of products that are used for sharing, the element of fashion is given a high-level focus. Customers present a preference for fashionable and new products, which means that there is a high probability for them to reject using shared furniture or reject continuing a contract after finishing one (Besch 2005). Consumers also show a strong desire to have technologically up-to-date products (Moro et al. 2018).

Furthermore, for the issue of awareness related to PSS, customers are considered a major stakeholder that holds this attitude. It has been shown that users have a hard time perceiving the economic advantage of PSS. In addition, low awareness of environmental impacts reduces the value of PSS for potential customers. Furthermore, since service is intangible, it is difficult for customers to grasp the intangible value of the additional services of PSS (Moro et al. 2020).

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