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A modification of P-diagram for the robust design of product service system

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Abstract

For product-service system (PSS), it is critically important whether PSS could fulfil the requirement of customers. However, in the real business environment, multiple perturbations or noises might happen to weaken the experience of customer. The robustness has become a serious issue for the success of PSS. More seriously, to date, there is no existing robust design method for researchers to prevent the above conditions. Therefore, it is essential to provide a conceptual diagram model to enable researchers and designers to identify key factors for robust PSS design. This paper demonstrates a modification of the P-diagram, which is the most famous diagram of robust design. The modification is aimed at supporting the robust design of PSS in a conceptual level based on the fulfilment of customers' requirements during perturbations. To verify the effectiveness, a case study is used to show the feasibility of this diagram.

Keywords: Product service system; robust product service system; perturbation; noise factor; P-diagram; Taguchi method.

1. Introduction

For recent decades, product-service system (PSS), which is an integration of products and services, has received tremendous attention. It is proposed that PSS has great potentials in the aspects of improving value, saving material, and increasing the satisfaction of customer, which shows a high-level sustainability and business value [1]. However, PSS is a complex system, which consists of products, services, supporting network and infrastructure [2]. The existence of multiple components and the complex stakeholder network decides it is difficult for designers to design robust components against the attack caused by internal and external accidents. For example, due to the accidental attack of Covid-19, shared bikes system experienced a sharp reduction in the aspect of average trip [3].

To date, there has been some effort for mitigating the above conditions. There are some existing failure evaluation and analysis method for PSS design [4]. For sharing system, a pilot study has been conducted to fulfilling the gap between supply and demand [5]. The robustness of solution has been given a high-level importance. Further consideration about uncertain events and risk management is required [6]. Reim et al have suggested a risk management for PSS operation. However, they also argue that the special value orientation about sharing lead to a need for risk related to owning a product, thus there is no perfect solution to balance out the risk and value [7]. The current studies are focusing more on the stage of redesign and evaluation, there is a lack of design method that could make PSS be insensitive to risky events in the stage of design. Further on, there is also a lack of theoretical support for researchers who have interest to realize the robust design in the field of PSS.

In order to support researchers and designers to understand how to achieve robust in product service system, this paper adopts the most famous conceptual model of robust design, namely Parameter diagram (P-diagram). P-diagram is an effective model to present the four critical factors to achieve robustness, namely signal factors, control factors, noise factors and response factors. To clarify the scope of the above four factors in PSS, authors have proposed a modified P-diagram based existing literatures relating to PSS design.

The remainder of this paper is structured as follow. Section 2 gives explanation about the definitions of key concepts of this paper. Section 3 provides research method. Section 4 is going to build a P-diagram for PSS design. Section 5 uses a case study of Airbnb to illustrate how to build a P-diagram for a real business case. Section 6 gives one conclusion and discusses the future works

2. Research background

2.1. Feature of PSS

It is proposed that PSS could be classified into three major types: Product-oriented, use-oriented and result-oriented PSS. Product-oriented PSS refers to the mode of providing additional services on the basis of product selling. For example, consulting and maintenance. Use-oriented PSS refers to making profits by renting out products. For example, shared bicycles. Result-oriented PSS refers to sharing the right to use the equipment and selling the production results of the equipment. For example, a printing system. Moreover, the concept of sustainability is also considered as being related to PSS. The focus of PSS is the usage, not the ownership of product, which could enable manufacturer to manufact fewer products. Researchers believe that tremendous amount of material and resource could be saved in this way [5,6]. PSS is also regarded as a system that consist of products, services, supporting networks and infrastructure.

2.2. P-diagram

P-diagram is a conceptual method to represent essential factors required for robust design, which is widely used in the field of the manufacturing industry [7]. This diagram was firstly proposed by the most famous researcher of robust design, Taguchi. The proposed diagram was based on the core concept of robust design that 'Robust Design Methodology means systematic efforts to achieve insensitivity to noise factors. These efforts are based on an awareness of variation and are applicable in all stages of product design' [8]. The classic P-diagram (see figure.1) includes four factors, namely signal factor, control factor, noise factor and response factor. According to Taguchi, the definition of the above four factors are introduced in table 1 [9].
However, the complexity of noise lies not only in its severity and uncontrollability, but also in its difficulty to be recognized. There has been considerable discussion on how to recognize noise. It is found that companies usually do not prepare a database for the cause of the failure. Instead, they just collect the loss of events [10]. Therefore, it is hard for designers to collect enough and effective information about noise from public database or companies' database. Designers' own experience and group discussion with multiple experts are considered to be options.

Table 1. The definitions of key factors in P-diagram

The type of factor	Definition
Signal factor	A variable that could change the value of the functional characteristic to achieve the required value
Control factor	The factor that could be handled to improve the performance or mitigate the perturbation
Noise factor	The factor that cannot be handled and lead to weakened performance
Response factor	The output of the diagram, which is the actual performance of the combination of control and noise factors

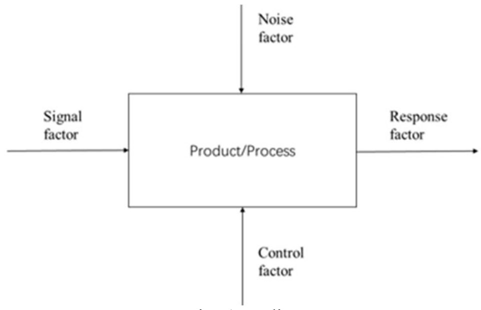


Fig. 1. P-diagram

2.3. Research gaps to be filled

For utilizing P-diagram in PSS design, there are several gaps that have not been filled. Firstly, in term of the signal factor and response factor, which are the input and output of design, there are multiple choices and indicators due to the existence of various stakeholders. There is a strong requirement for selecting the most critical factor as the signal factor and use an indicator to assess the performance of response factor. Secondly, for control factors, there is no discussion about the control factors in PSS design. Even if the control factors are understood as design elements, so far, there is no consensus in the PSS design field. Thirdly, for noise factors, in the field of PSS, to date, no researcher has discussed the concept of noise. The limited discussion only exists in the concept of PSS perturbation, which has large similarities with noise factor. Therefore, how to distinguish between noise and perturbation, and how to recognize the noise in PSS is extremely critical.

3. Proposal

3.1. Introduction

To solve the problems proposed in the section 2.3, this paper modifies the framework of P-diagram so that researchers and designers could identify the required factors to design a robust PSS. As introduced by section 2.2, P-diagram is a conceptual model that can represent the essential factors for robust design. Thus, in term of signal and response factors, it is essential to identify the requirement of PSS through literature review. For control factors, authors have divided PSS design into basic elements through a service model [11]. In term of noise factors, this paper provides a standard to identify PSS noise from PSS perturbations.

3.2. Signal and response factors for PSS

For PSS design, the signal factor and response factor could be understood as the requirement for the system and the fulfilment of the requirement. However, in the domain of functional requirement, the multiple components of PSS cause designers must consider both the requirement of customer towards products and services [12]. Further on, in the domain of stakeholder requirement, the existence of multiple stakeholders (customer, provider and manager) also leads to various requirements based on different interests. Based on the above consideration, there are three issues related to signal factors and response factors of PSS: 1) Customer requirement for service. 2) Customer requirement for product. 3) Stakeholder requirement for product service system. For response factors, the indicator of satisfaction is selected to assess this factor.

3.3. Control factors for PSS

According to section 2.2, control factors are design elements that could enable designer to make the performance of response factors close to signal factors. Therefore, in this study, we adopt the classification of the components of Hara et al. [11], which is an effective classification to divide functional requirement into basic elements. The function is divided into function of service activities and function of physical products. Three components are proposed to achieve the above functions, namely hardware, humanware and software (see figure 2). The introduction of the above terms is showed as below. Humanware is any human component of the service system such as staff and customers Hardware is any physical and non-human component of the service system as a product, equipment, or facility. Software is any component such as policies, norms, rules, procedures and practices that define the way in which the system components interact.

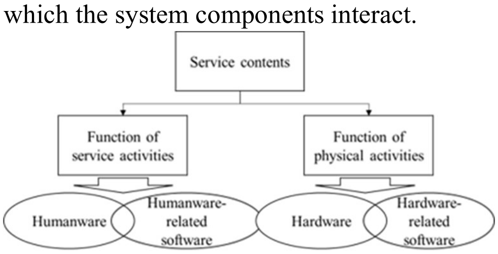


Fig. 2. The components for modelling service (modified from Hara et al., 2009)

3.4. Noise factors for PSS

3.4.1. The difference between PSS noise and PSS perturbation

To date, there is no definition or discussion about noise factor in PSS due to the lack of consideration about robustness and robust design. Given that, this paper chooses to get support from the concept of PSS perturbation, which is defined as any endogenous or exogenous event that modifies the stated PSS operational conditions [13]. According to the definition of noise factor that it is variables that could not be controlled by designers and this type of factor will leave product/process an undesired performance, noise is one type of perturbation. The major difference is that perturbation concept does not discuss about whether it is impossible to solve this perturbation with an acceptable cost. There is a strong requirement to consider the term of 'uncontrollability', which is the degree of difficulty for designers and operators to mitigate the influence of a perturbation.

3.4.2. The selection of PSS noise factors

To enable P-diagram to effectively assist PSS design, researchers and designers must effectively recognize noise factors. However, as introduced in section 3.4.1, the evaluation of perturbation usually involves two factors: severity and possibility, while noise needs to consider three factors: severity, possibility and uncontrollability at the same time. This means that the direct identification of noise factors is very complex. Therefore, the authors suggest that designers should screen out the noise factors in the PSS perturbations rather than directly identify the noise. In addition, some perturbations have high severity and low uncontrollability, which means that if designers turn a blind eye to them, PSS will become extremely vulnerable. Therefore, this study proposes that the following two factors should be considered to identify noise factors:

1) Noise factors: uncontrollable factors that have a serious negative impact on PSS.

2) Solvable perturbation: a type of controllable perturbation that can be resolved at an acceptable cost by PSS firms.

For distinguishing solvable perturbation from various perturbations, designers are required to assess the controllability. For PSS design, the controllability of one factor is decided by the involved resource, specific solutions, or the level of freedom to change the decisions by PSS firms.

3.5. P-diagram for PSS design

Based on the knowledge and discussion above, a P-diagram for PSS is provided in figure 4. The aim of this diagram is to illustrate the positive factors (control factors) and negative factors (noise and solvable perturbations) for enabling signal factors perform a desired performance (response factor). There are three steps to build a P-diagram.

Step one: identify the requirements of customers and other stakeholders in the part of signal factor. Set the fulfilment of the above requirements as response factor. Designers are required to set an indicator like satisfaction.

Step two: identify the types of the required function (physical activities/ service activities) and select suitable design elements for each function in the part of control factors.

Step three: identify the critical noise factors and solvable perturbations based on the dimensions of severity and uncontrollability. Provide mitigation for the solvable perturbations.

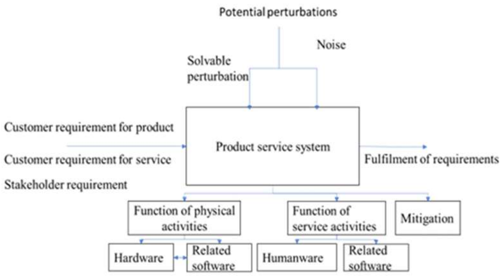


Fig. 3. P-diagram for PSS design

4. Case study

To show the effectiveness of this modified diagram, in this case study, authors select Airbnb, a successful use-oriented PSS as a case study. To show the process of presenting the essential factors for robust design (section 3.5), authors present the signal factors, control factors based on the information of the official website of Airbnb [14]. To understand and present the noise factors, we use a cause effect analysis to analyse them. After that, an assessment is applied to screen out noise and solvable perturbations.

4.1. Step one: Signal factors, response factors and indicators

According to the information of official website, the signal factors, which is the requirement of customer, could be divided into three types: 1) renting a residence; 2) providing comfortable environment; 3) experiencing landlord's life. The response factor is set as the fulfilment of the above requirements. The indicator of customer satisfaction is selected.

4.2. Step two: setting control factors and solvable perturbations

To set control factors through selecting design elements for three required functions, authors have identified the type of the required function and select suitable elements as below.

For the requirement of renting a residence, authors regard it as a functional requirement of physical activities. The hardware is a residence, and the hardware related software is a renting contract, information for renting, payment system, communication and a renting platform.

For the requirement of providing comfortable environment, which is a functional requirement of physical activities. The hardware includes air-conditioner, bedroom items, kitchenware, toilet and shower, and the hardware related software is maintenance service.

For the requirement of experiencing landlord's life, which is a functional requirement of service activities. The humanware involves landlords, the humanware related software involves the skill of landlords, local travel culture.

4.3. Step three: setting noise factors

To analyse the potential noise factors, authors firstly used a typical cause-effect analysis to identify potential perturbations. The effect is set as decreased customer satisfaction and six typical root causes are set (see figure 4). Through analysis, nine perturbations are identified. Secondly, to screen out the noise factors and solvable perturbations from generic perturbations, we have made a simple assessment based on the severity and uncontrollability. The levels of the two dimensions are divided into three, namely High, Middle and Low. Based on the assessment of table 2, four noise factors are identified, namely technical breakdown, adverse customer behaviour, extreme weather, and unfriendly and noisy community. Further on, poor quality equipment and incompetence of landlords are considered as solvable perturbations. For mitigation, in term of poor-quality equipment, a general standard about the equipment of every residence is considered as a doable solution towards. In term of incompetence of landlords, a large-scale training is a doable solution.

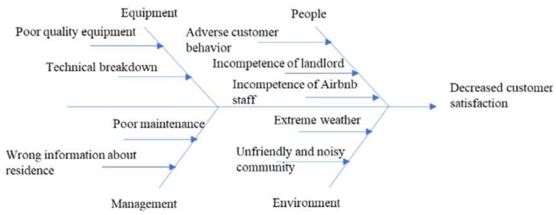
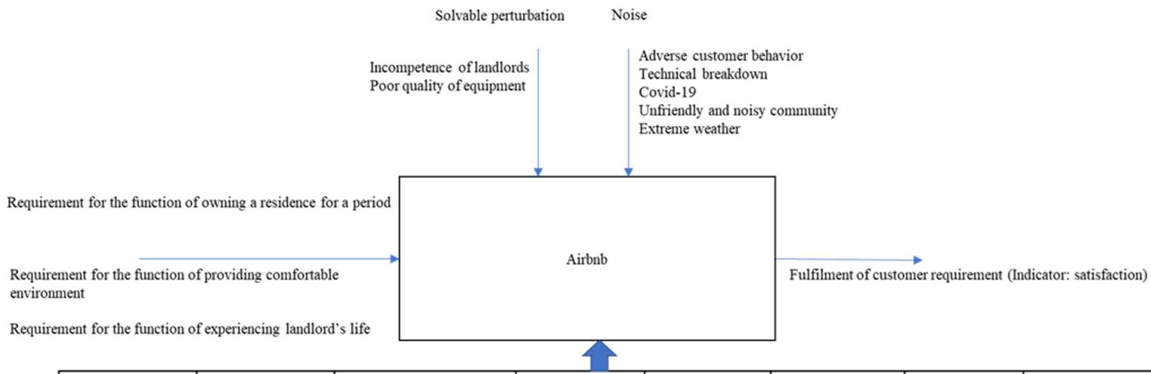


Fig. 4. The cause-effect analysis of decreased customer



Required physical function	Hardware	Hardware related software	Required service function	Humanware	Humanware related software	Solvable perturbation	Mitigation
Renting houses	A residence	Residence information/Renting platform/Renting contract/Payment system/ Airbnb platform	Experiencing landlord's life	Landlord	Skills/local travel culture	The incompetence of landlords	Large-scale training
Providing comfortable environment	Air-conditioner/ Bedroom items/Kitchenware/toilet/shower	Maintenance				Poor quality equipment	A standard of equipment quality

Fig. 5. A modified P-diagram for Airbnb design

Table. 2. The assessment worksheet of perturbations

Perturbation	Severity	Uncontrollability
Poor quality equipment	High	Low
Technical breakdown	High	High
Adverse customer behavior	Middle	High
Incompetence of Landlords	High	Middle
Incompetence of Airbnb staff	Middle	Low
Poor maintenance	Middle	Low
Wrong information residence	Middle	Low
Extreme weather	High	High
Unfriendly and noisy community	High	High

4.4. The Result of the case study

Based on the information of the above sections, this paper has built a modified P-diagram for Airbnb design. The detail of the diagram is showed in figure 5.

In this diagram, authors have shown how to enable the three customer requirements, namely renting houses, comfortable environment, and experiencing landlord's life to be fulfilled in a robust way by designers. To achieve this target, authors divide the above requirements into two types of functional requirements including service activities and physical activities. After that, a series of control factors, namely humanware, hardware and their related software are identified. For the requirements of renting house, hardware is a residence, and related software involves residence information, contract, online system and payment system. For the requirement of comfortable environment, air-conditioner, bedroom items, toilet, kitchenware and shower are considered as essential hardware, and the related software is the maintenance plan to maintain the quality of the above items. For the requirement of experiencing landlord's life, the humanware of landlord is essential, and the local culture and skill of landlord are related software. Then, authors have identified the noise factors and solvable perturbations based on a cause effect analysis and an assessment of severity and uncontrollability. Five perturbations are regard as noise factors, namely adverse customer behavior, technical breakdown, Covid-19, unfriendly and noisy community, and extreme weather. Two solvable perturbations, namely the incompetence of landlords and the poor-quality equipment are considered as possible to be prevented in the stage of design. It is suggested to consider large-scale training and providing a standard for equipment quality as mitigations. Overall, this case study has well illustrated how to improve the performance of PSS and identify and mitigate noise factors with the support of P-diagram.

5. Discussion

5.1. The finding and meaning of this research

In this paper, authors have found a set of definitions and rules to identify key factors for robust PSS design. This diagram could enable PSS designers to consider the existence of noise factors and their influence on PSS. The case study shows that it is doable to divide the control factors of PSS design into hardware, humanware and their related software. Further on, PSS noise factors could be screened out from PSS perturbations.

Indeed, in the field of PSS, designers usually designed in the ideal environment of PSS without noise. Therefore, previous studies have lacked discussion on noise and disturbance, not to mention how to control noise. Designers tend to overlook potential perturbations. This lead PSS become a vulnerable system. Thus, it is meaningful to guide researchers to conder PSS design in a robust level, and this conceptual diagram is a meaningful starting point for the achievement of robust PSS (RPSS) that is insensitive to the effect of noise factors in the stage of design.

5.2. A guideline for identifying unpredictable events as noise factors

In the real PSS business, unpredictable events have serious influence on the vulnerability of PSS. Compared with known events, unpredictable events are hard to predict its details, or even its existence..

Thus, this paper suggests designers to follow one guideline to identify unpredictable events, namely using ambiguous speech to describe unpredictable events. This description requires designers to provide information about potential affected PSS components and potential threat sources. In this case study, adverse customer behavior is a good example. Although designers do not know when a customer will behave adversely, they can prepare based on the knowledge that the customer will wreak the product.

5.3. Limitation

Despite of the finding in the field of factors identification and definition, this research still exist limitation.

First at all, in the case study, the identification of factors related to robust design is based on the support of available information about requirements and well-known events. For a new robust PSS design, designers are required to analyse requirements and noise factors by questionnaires, discussion and expert interviews. Therefore, this case could not become completely effective for all potential cases in the future.

Second, there is a limitation relating to identifying the signal and response factors. The major barrier comes from the complex stakeholder relationship in PSS. In this case, there is usually a phenomenon that there is a conflict among multiple requirements. For example, for a PSS business, the requirement of provider firm is usually the low cost and high income. However, for local community, the requirement is usually the low pollution and more job positions, which would increase the cost. Thus, when there is a conflict between two signal factors in P-diagram for PSS, designers need to make a prioritization.

5. Conclusion

In this research, authors have demonstrated a modification of P-diagram to enable researchers and designers to balance out the effect of control and noise factors in the design stage. Despite of some limitation regarding factors identification, this study is a meaningful starting point for the development of PSS towards robust design, which firstly guide researchers to consider the existence of PSS noise factors and perturbations in the stage of design. In the future, a feasible methodology to design for robust PSS and a guideline for mitigating PSS perturbations are expected.

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