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REDESIGN OF PRODUCT-SERVICE SYSTEMS APPLYING FAILURE MODE AND EFFECTS ANALYSIS AND IMPORTANCE PERFORMANCE ANALYSIS

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ABSTRACT
In order to advance the competitiveness, more and more enterprises developed an integrated solution called product-service system (PSS) instead of solely new product/service. However, most of new PPS failed due to the lack of systematic methodology. To solve this issue, this study proposed a new methodology based on feedback of losing/unsatisfied customers. Failure Mode and Effects Analysis (FMEA) technique and Importance-Performance Analysis (IPA) are conducted to identify critical customer needs. Several scenarios are developed for different customer requirements. The performance of new PSS is evaluated with Service Quality (SERVQUAL) survey. A clothes service case study is presented to demonstrate the benefit of new PSS and there is 20-50% improvement in customer satisfaction.

Keywords: product-service systems, FMEA, IPA, SERVQUAL

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1 INTRODUCTION

Nowadays, simply selling product cannot assure to satisfy customers' needs anymore. Because of the boundary of product and service or the manufacturing industry and service industry are gradually broken. To survive in this rival market, developing PSS becomes a new competitive business mode. However, PSS usually fails when customers are not delighted. This observation inspires this research. A new method which can re-design PSS according to feedback of losing/unsatisfied customers is presented with a clothes service case study.

Developing unique competitive advantage is essential for a company. The competitive advantage might be good quality, short delivery time, precise delivery time, or low price. According to the companies' output, two types of industry can be identified, these are manufacturing industry and service industry. Manufacturing industry produces tangible products with high consistency, while service industry provides intangible products. Service is experience-based activity that is able to increase more value both on product and customer.

Clothes are the most important things in human's life. But the recent using of clothes isn't environmentally friendly like high resource and high energy consumption. For the personal user, buying the washing machine and drying machine isn't affordable and environmental friendly. So this study will develop a PSS to solve this problem.

2 LITERATURE REVIEW

Originally, PSS was developed with an aim to minimize environmental impact. Nowadays, PSS is defined as "a marketable set of products and services capable for jointly fulfilling the user's need". The product/service ratio in this set can be various, either it is in terms of function fulfillment or economic value" [2]. Mont [3] constructed a theoretical framework for PSS and clarified the characteristics and barriers of PSS. Lee et al. [4] developed a method called Innovative Product Advanced Service Systems (I-PASS) which utilized Innovation Matrix, Application Space Mapping, and Quality Function Deployment to systematically transform core product competencies to a new PSS. However, I-PASS doesn't offer a step by step process while constructing a new PSS. Pawar et al [5] proposed a road-map to identify the new challenge of co-development of a new PSS. This study organized a group which included experts in the academia and several practitioners who work over 3 years in this field. This group surveyed and interviewed numerous stakeholders. Then, it used a methodology from literature review to relate CE-NET roadmap in order to find the existent literature on product-service development. Finally, it proposed a case with aircraft engines and defense aerospace to clarify and develop the theoretical framework. This study proposes a foundation of PSS development and emphasizes the challenge and ability for developing PSS.

Lia Patricio et al. [6] presented Multilevel Service Design (MSD) as a new interdisciplinary method for integrative design of complex service systems. MSD synthesizes contributions from different fields, and allows integrated service design with three hierarchical levels, which are the firm's service concept, the firm's service system, and the service encounter respectively. Morelli [7] conducted a research in partnerships within companies and stakeholders, and proposed a method that can present a map for player involvement, defining requirements and structure, and deploying blueprint of PSS. Yoon et al. [8] contributed to improve the applicability of evaluation methods for designing a new PSS. A new framework is developed and a new evaluation method for PSS is demonstrated with an empirical study.

Vargo and Lusch [16] clarified significant issues in Service-Dominant (S-D) logic subject. This study modified and added Foundational Premises (FPs) from the original FPs to solve the issues of word and concept through reemphasizing previous modifications, discussing frequently raising issues and providing elaboration in cases. Lusch and Vargo [17] clarified and refined 5 recurring and contentious issues of the nature and scope that are attempted to understand in S-D logic. This study considered that two components of value co-creation are co-creation of value and co-production. They can make the consumer be endogenous and they are different from the Good-Dominant (G-D) logic. "Servitization of business" is a new feature for corporation strategy and it could create a new relationship between corporation and customers. Vandermerwe and Rada [18] proposed a road-map to the "servitization" from "goods or services", "goods+ services" to "goods + services + support + knowledge + self-service". This study considered that "servitization" is driven by customers and it is a competitive tool for corporation. It could set up barriers to competitors, third-parties, customers, creating dependency,

differentiating the market offering and diffusing new innovations. Lusch et al. [19] considered that primary tenets of service-dominant logic are: "(1) the conceptualization of service as a process, rather than a unit of output; (2) a focus on dynamic resources, rather than static resources; and (3) an understanding of value as a collaborative process between providers and customers." This study clarified different within G-D logic and S-D logic. The characteristics of S-D logic include "service provision", "value produced in use", "delivered by value network", "manipulate, act on, operant resource" and "customers are value co-producer".

Failure Mode and Effects Analysis (FMEA) is a tool of reliability analysis which is widely applied in industry [11-12]. It could improve efficiency and productivity by providing diagnostic information. At product design stage, FMEA doesn't only meet the customer needs but it enhance the quality and reliability of product or process [13]. Additionally, FMEA could prioritize risks and failure points in the design project [14]. Thus, this study employees FMEA to develop a new PSS. The traditional methodology didn't comprehensively evaluate and control complex service process in security management. Wang et al [15] proposed a study to build a security management service blueprint to describe all of the security service process through visual graph. The potential failure modes and their effects are found through the service blueprint in this study. Then, the Risk Priority Number (RPN) was calculated by evaluating the severity (S), occurrence (O) and detection (D) through the three scale criteria. Finally, parameter of "S", "O", "D" and "RPN" are transformed into a membership function by Aggregate Fuzzy Score (AFS), then, this study got an RPN of each failure mode and rank these failure modes.

3 METHODOLOGY

This study proposed a multi-step approach to re-design a PSS. First, feedbacks from losing/unsatisfied customers are collected and the failure modes found from the service process will be analyzed. In next steps, an incidence matrix of failure mode will be established by using SERVQUAL survey and IPA. Therefore, we can figure out the key failure mode. Then, with the analysis of relationship between the key failure mode and original service providers, a PSDM (Product-Service Development Matrix) will be built up. According to the key failure mode, we are able to develop a viable new service that can make customer delight. Finally, a new service blueprint that presents the new PSS will be built up. The process is shown in Figure 1.

Step 1. Conduct Survey of Unsatisfied Customers

In the first step, a survey will be conducted to collect customers' unsatisfied experience in clothes service.

Step 2. Search Failure Modes from Service Process and Calculate the RPN

In this step, the service process is organized as a service blueprint to assist with the analysis on process flow that customers have experienced, "onstage owner action" and "backstage owner action". According to the feedbacks of losing/unsatisfied customers obtained through interview or questionnaire, the failure modes in service process are pointed out. Then we can evaluate the "Severity", "Occurrence" and "Detection" of each failure to calculate the RPN.

Step 3. Construct SERVQUAL Scale and IPA

With 24 questions that cover five service quality dimensions (Tangible, Responsiveness, Reliability, Empathy and Assurance) in SERVQUAL Scale [9], we design a suitable service quality questionnaire for our target industries. (each question called "SERVQUAL item"). This questionnaire reveals the differences between Degree of Expecting and Degree of Feeling. By applying statistics and IPA tool, we can gain the improvement priority from the IPA phase under different service conditions. Figure 2 is the IPA Matrix, if the SERVQUAL item is located at the first quadrant called "Keep up the good work". This condition means that the SERVQUAL item with high performance and high importance. Then we can set the weight for these SERVQUAL items.

Step 4. Define Key Failure Modes by Using Correlation Matrix

The relation between service quality and failure modes are analyzed by applying Correlation Matrix. Based on the weights from IPA, score of all failure modes will be calculated and the key failure modes can be identified. The result of step 4 serves as an input data in step 5.

Step 5. Analyze the Relationship between Key Failure Modes and Service Provider

The purpose of this step is to confirm the relation between key failure modes and service providers. When the new product service system is re-designed, we provide the findings to the original service

providers and support them to develop the integrated product service system according to the key failure modes.

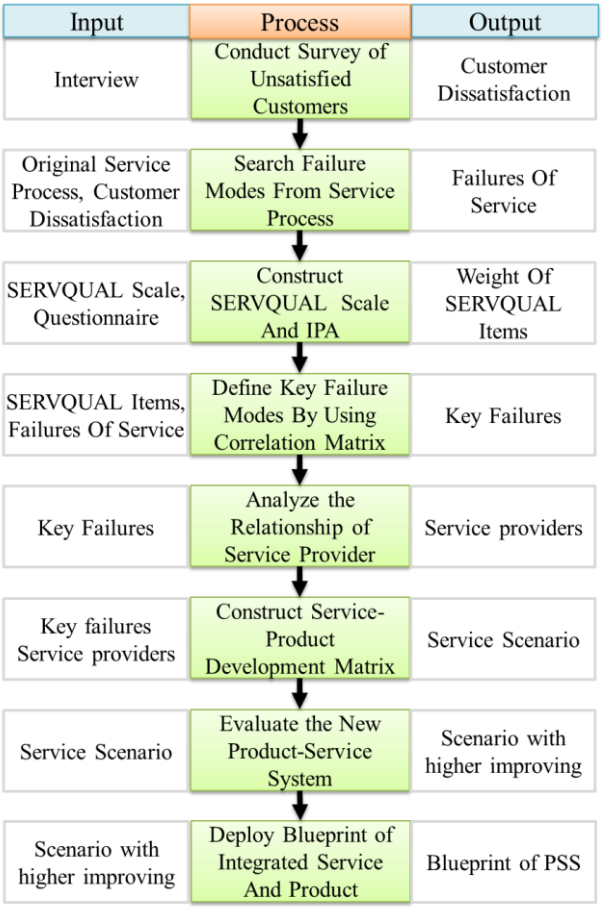

Figure 1. Methodology of PSS Re-Design

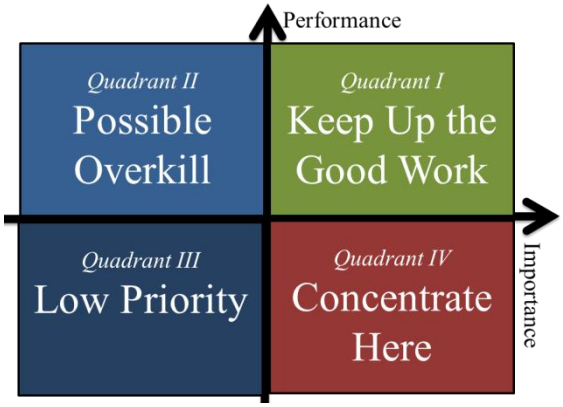

Figure 2. IPA Matrix

Step 6.Construct Service-Product Development Matrix

In this step, an innovative method called Service-Product Development Matrix is applied to build up a new service system. As shown in Figure 6, the horizontal axis is the failure mode and the corresponding service provider, both includes original and new services; the vertical axis is the brainstormed service. The relation between the originals and the new service providers are marked as "O" if the service is provided by this service provider, or marked as "Product type" if products are included in the service. To develop new PSS, this matrix is fully used to analyze the relation among each actor in this study.

Step 7. Evaluate the New Product-Service System

To evaluate the performance of the new system, we calculate the total scores from the failure modes solved by new services. The scores are calculated based on five service quality dimensions of new service providers. The formula is shown in the following:

$$\boldsymbol{PN_i = Q_j \times W_j} \quad (1)$$

PN_i: The performance of i new product-service.

Q_j ： RE-estimated of the "SERVQUAL" of the new service scenario of failure mode j

W_j ： The corresponding IPA weighting of j service quality item

The formula shown below is to compute the degree of feeling about the original service quality in relation to the failure mode

$$\boldsymbol{PO_i = Q_j \times W_j} \quad (2)$$

PO_i ： Performance of original service which new service solved the key failure.

Q_j ： The score in Degree of Performance, about the j service quality item solved by new service.

W_j ： The corresponding IPA weighting of j service quality item

Step 8: Deploy the Blueprint of the New Product Service System

Finally, a service blueprint of new product service system can be generated and the format of the improved PSS is shaped in this step.

4 CASE STUDY

A clothes factory located in Hsinchu City, Taiwan, they would like to extend their business model from washing service to PSS, which includes clothes rental, storage and washing service. Therefore, a clothes-washing service, which integrates self-washing, laundromat, and traditional laundry are redesigned in this study. The proposed methodology will be presented step by step in this chapter.

Step 1&2. Survey of Losing Customers and Search Failure Modes from Service Process

This case is about the service process of dealing with clothes, including daily washing, daily storage, repaire, and disposal (Figure 3). This study interviewed 25 customers and four clothes service providers in Hsinchu city and recorded the script as a base to collect all possible failure modes. For some customers' requirements, there are some services which don't currently have a single provider, such as daily storage. This research marked one failure mode named "No Service Provider Failure Mode" with the capital F_N (F_N 1, F_N 2, F_N 3). This mode would be separated from the existing service providers' failure modes in the SERVQUAL Scale.

According to this process (see Figure 3), it includes "Self-washing", "Laundromat", "Traditional laundry", "Daily storage" and "Repairing". (Figure 4) Then, we can find 25 "Failure Modes from service provider" (F) and 10 "No Service Provider Failure Mode" (F_N) (see Table 1)

Then, we evaluate the RPN through the Severity, Occurrence and Detection, the failure mode with high RPN are shown as Table 3.

Step 3. Construct SERVQUAL Scale and IPA

In this case study, 24 service quality assessment items of a clothes retailer are generated in the SERVQUAL table. Questionnaire was used to evaluate the "The Expect Degree" and "The Actual Degree" of the customers. The questionnaire is shown in Table 2.

According to the result of questionnaire, IPA analysis is conducted to distinguish the performance and importance of services from customers' viewpoint. The horizontal axis is "The Expect Degree" and the vertical axis is "The Actual Degree". In figure 5, we put the result value of the 24 service quality assessment items into a two-dimensional matrix. The result is divided into 4 blocks. The first quadrant "Maintained" is located on the upper right area which represents the high expect degree and high actual degree service. Service provider should keep up the good work for service in this area. The second quadrant on the upper left area is called "Excessive Efforts" which means that customers feel slight importance. The lower left quadrant is "Low Rank" which shows that customers do not feel importance. The fourth quadrant named "Focus Consideration" which can be improved to enhance customer satisfaction. After reviewing the literature and discussing with experts, we assign the corresponding weight values which are 1.5, 0.5, 1 and 2 to 4 blocks.

Step 4. Define Key Failure Modes by Using Correlation Matrix

According to the last section, we know that IPA weights of both service quality items of retailer and no provider which are correlated to the " No Service Provider Failure Mode". In this step, we use the correlation matrix to calculate the total score of failure mode using IPA weights. Table 3 shows the relationship between failure mode and SERVQUAL item (Only show Failure mode from service

provider (F)). We take the failure modes with high score in the SERVQUAL and RPN analysis. We found 10 key failure mode in this case..

-F4: It's not convenient to parking or park for charge in Metropolitan area.
-F3:Delivery of clothes is easy to get wet when raining.
-F2:It's embarrassed when customer take a basket of clothes walking on the road.
-F1:The way from home to the shop is too far away.
-F12:Next customer would leave around or stain the cleared clothes.
-F15:The standards of the valuation are not the same.
- F_N 1:Daily storage space isn't enough.
- F_N 2:The weather is damp to be moldy.
- F_N 5:The rainy make the clothes not to dry
- F_N 3:People don't have time to clean out and storage their clothes.

Step 5. Analyze the Relationship between Key Failure Modes and Service Provider

Based on the failure modes identified in the previous step, we put them into a matrix and determine the relations with the service providers.

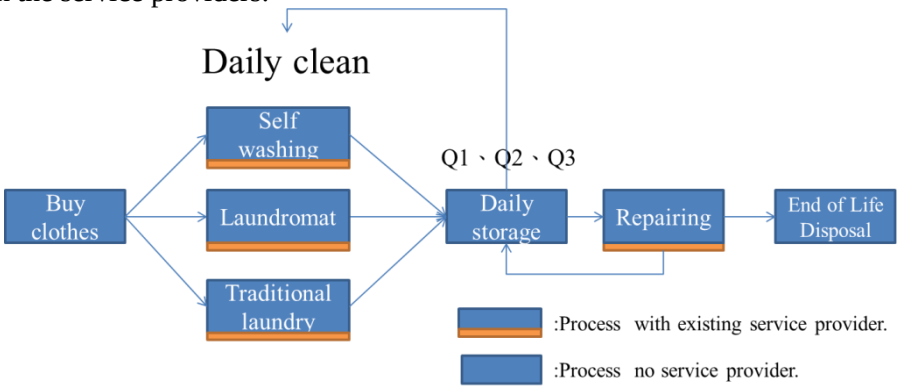

Figure 3. Main Process of Clothes Service

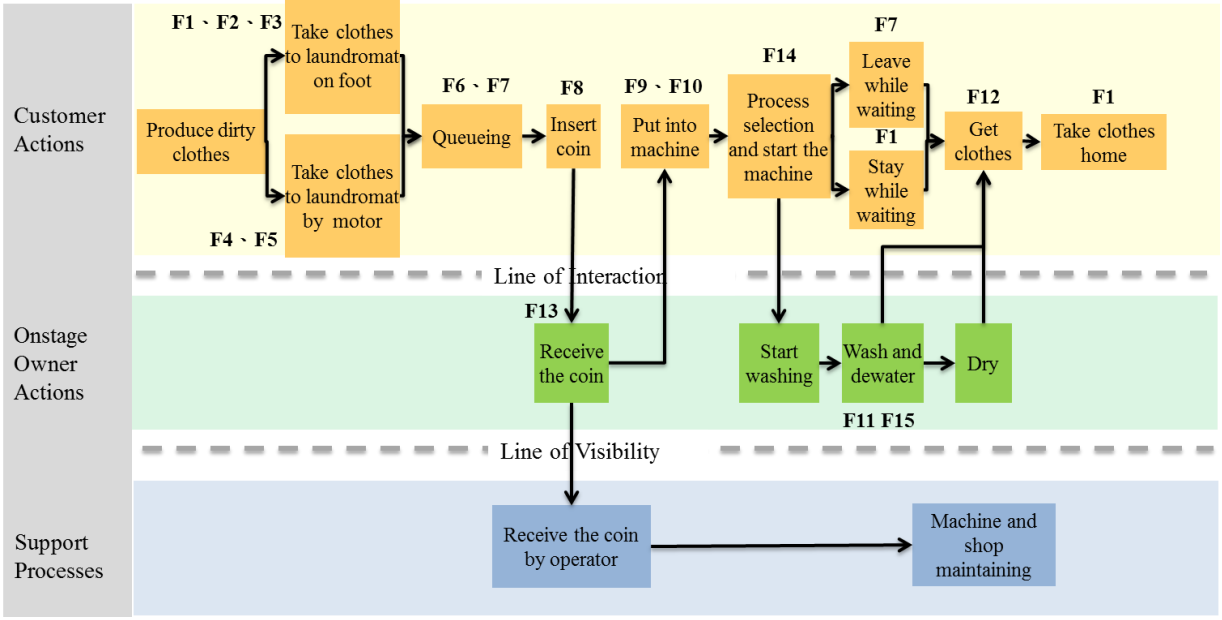

Figure 4. Blueprint of Laundromat

Step 6. Construct Service-Product Development Matrix

Referring to the key failure modes and analysis of service providers, we put the results into a service-product development matrix (Figure 6) and develop three service scenarios, as shown in the following.

Scenario1：

When customers purchase clothes, the clothes company provides a delivery laundry service leagued with the convenience stores network, the service includes washing, drying, ironing, and neatly folding

service. Customers only need to stop by the convenience store and receive the cleaned clothes. Therefore, this product (clothes) is integrated with service provided by convenience stores.

Scenario2：

When customers purchase clothes, the clothes company provide door-to-door clothes cleaning. Within this service, dirty clothes is collected at customers' residences, then the clothes are washed, dried, dehumidified and folded, and delivered back to customers' house.

Scenario3：

In addition to Scenario 2, the company provides clothes storage service. Customers indicate that when the clothes are needed, and the clothes will be delivered to the customers' residences the next day. Therefore, customers don't have to worry about the space in their closet.

Table 1. Failure mode of service process

Self washing	**Traditional laundry**	**Repairing**
F_N4: washing machine is not cost-effective for the self-user F_N5: bad weather causes not air-dry F_N6: no place to air-dry F_N7: dryer is not cost-effective for self-user F_N8: washing machine may damage the clothes that should be hand-washing F_N9: dryer may damage the clothes that should be air-dry F_N10: wash different color clothes separately is not cost-effective for self-user	F1:too far away from laundry F3:clothes may gotten wet during carrying on rainy day F4:urban parking areas are not good to stop or be charged F5:inconvenient to transport dirty clothes by motorcycle F15: The standards of the valuation are not the same. F16:not enough for washing mode F17:not verify for communicating F18:not clean for clothes F19:clothes are broken in washing F20:Confused with clothes of others F21:mistake of communicating F22:working over time F23:bad attitude	F17:not verify for communicating F20:Confused with clothes of others F21:mistake of communi-cating F22:working over time F23:bad attitude F24:Stop production of material F25:gap of price with cus-tomer
		Daily storage
		F_N1: not enough capacity to storage F_N2: mildew tended F_N3: no time to arrange clothes

Laundromat	
F1: too far away from laundry F2: carrying dirty clothes on streets make customers embarrassed F3: clothes may get wet when carrying on rainy day F4: urban areas parking is not good to park or be charged F5: inconvenient to transport dirty clothes by motorcycle F6: inappropriate queuing causes long waiting time F7: boring during waiting F8: customer has no charges	F9: clothes of the last customer is still in machine F10: washing machine is gotten dirty by the last customer F11:some clothes cannot dry (do not offer clothes drying service) F12: next customer would leave around or stain the cleared clothes. F13: coin stuck in machine F14: wrong setting of washing machine (not well set as customer expect, causing wrong cloth washing order).

Step 7. Evaluate the New Product-Service System

According to the equation (1) in section 3, the score of scenarios in new services and the score of original one will be calculated, and the percentage of improvement should be included into the calculation.

Taking the scenario 1, laundry service with delivery by convenience store, as example, the solved failure modes are F1, F12, Q3 and Q5. The weighting total scores are 5.5, 5.5, 2.5 and 3.5 respectively. We evaluate the percentage of score from scenario 1 that can satisfy the failure mode one by one,

which are F1: 70%, F12：95%, Q3：60% and Q5：100%. There is one new service provider, so we put 1 into the formula. Hence, the score of new service is 13.075.

Based on equation (2), we compare the score of failure mode in original services, the improvement percentage is 121.1%. After Calculation, improvement percentage of Scenario 2 and Scenario 3 is 148.4% and 158.6%.

We found that Scenario 1 solves the problem of laundromat for the far distance. So it is better than the current service. Scenario 2 not only completely solves the problem that the distance is too far but it also solves the problem that customer don't have enough time to receiving clothes. So the score of scenario 2 is better than the score of Scenario 1. Furthermore, the Scenario 3 solves the problem that customers don't have enough storage space, so Scenario 3 has the best score.

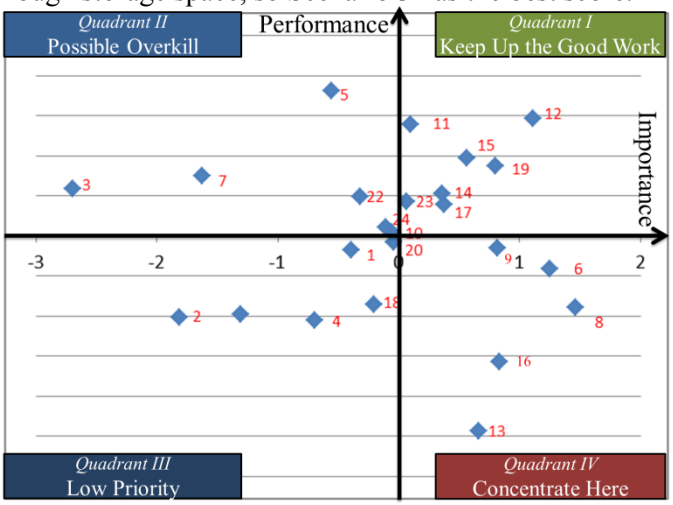

Figure 5.IPA Matrix of Clothes Service

Table 2. The questionnaire of SERVQUAL

Tangible	**Empathy**
1. Retailer use information technology to manage the order of customers.	12. Assure the arrive of the product's safety.
2. The environment of the shop is clean.	13. The spread of the retailer's stronghold is convenient to the customer.
3. The clothes and looks of the clerks are clean and tidy.	14. The opening time of the shop could satisfy the needs of customer.
4. The shop has clear price list and service items guide.	15. Customers could ask the state of the laundry services through telephone or the Internet.
Responsiveness	
5. The clerks could react quickly according to the mistakes.	16. Customers could specify the pick up time of their clothes.
6. The clerks could react quickly depending on the kinds of needs of customers.	17. Retailer understands thoroughly about every customers in order to provide personal sale promotion.
7. The service attitude of the clerks are good.	18. The clerks are nice and sweet.
8. The clerks value the feeling of customer.	19. The clerks have the motivation to help customer solve their problems.
Reliability	**Assurance**
9. The clerks satisfy the need of customer when possible.	20. The laundry services are trusted.
10. According to the different needs of customer, provide the correct laundry services.	21. When something affects the customer equity, the clerk would inform the customer clear.
	22. The clerks are well-trained and know the process well.
11.The clerks satisfy the need of customer as much as possible.	23. Transaction security.
	24. Retailer has enough professional knowledge.

Service Provider	F4		F3		F2		F1		F12	F15	Q1	Q2	Q5	Q3	The Additional Provider	
	P1	P2	P1	P2	P1		P1	P2	P1	P2	X	X	X	X	Conveni-ent store	Logistics
Scenario 1							✓	✓	Washing machine				Dehu-midifiers	✓	✓	
Scenario 2	✓	✓	✓	✓	✓	✓	✓	✓	Washing machine	✓			Dehu-midifiers	✓		Clothes Box
Scenario 3	✓	✓	✓	✓	✓	✓	✓	✓	Washing machine	✓	✓	Dehu-midifiers	Dehu-midifiers	Wareho use of clothes		Clothes Box

Figure 6. Service-Product Development Matrix

Step 8. Deploy the Blueprint of the New Product Service System

The improvement percentage of scenario 3 is higher than other two scenarios. In this paper, scenario 3 will be represented in service blueprint. According to scenario 3, we draw the scenario with a service blueprint in Figure 7.

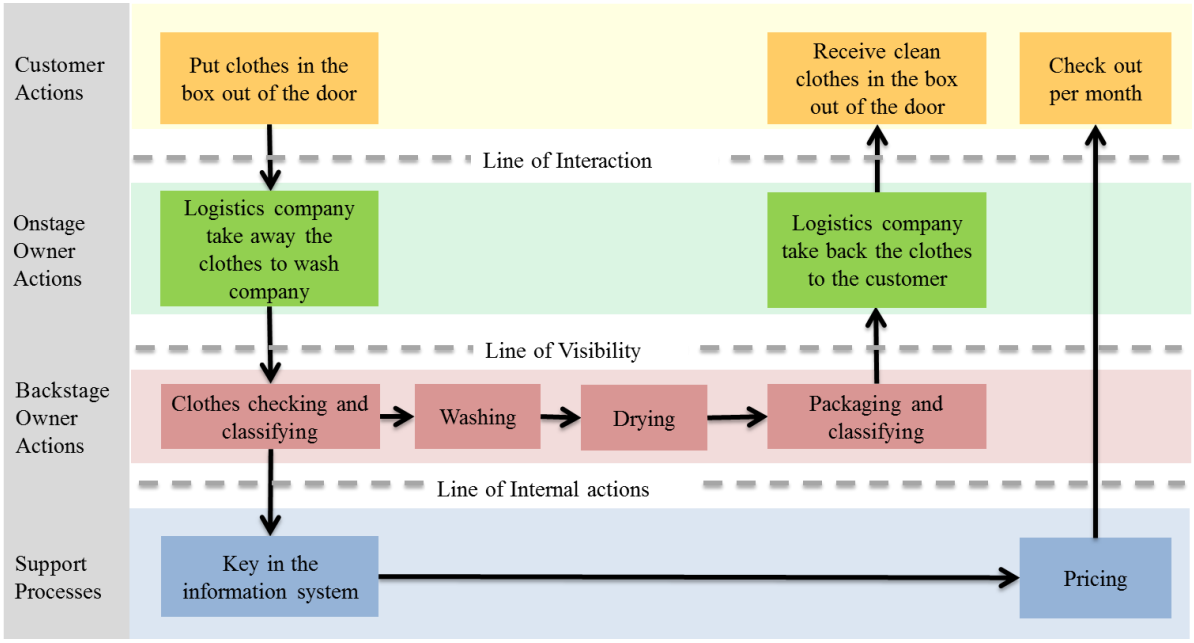

Figure 7. Blueprint of Scenario 3

5 CONCLUSION

This article has proposed a PSS redesign methodology by analyzing the failure modes in the existing processes with systematic thinking. During the process, service providers can review and reflect the weakness of current services by using FMEA, IPA and a Service-Product Development matrix. By eliminating key failure modes, the re-design PSS will provide a better service quality.

According to the proposed approach, PSS developers could find the unmet customer needs by the analysis of existent product. PSS developers could understand the gap between existing capacity and actual customer needs.

Above all, this study proposed a system thinking of service innovation for PSS development. Although the proposed approach provided a systematic thinking, it restricted the scope of innovation. There is also a lack of breakthrough innovation.

Future research can address broader types of customers such as students, white or blue-collar worker and housewives …, etc. In future research, it could make the product life cycle to be more phases. It could provide more service scenarios. Based on more concepts and scenarios, it could develop service family to meet variety of customer groups. For this purpose, it must evaluate the cost and benefit before combining the service concepts to service scenario. The ultimate goal is to generate a system to combine these service concepts in the feasible service scenario. It will assist PSS developers in

developing innovative PSSs. In addition, estimation of service cost function can be considered in this method so that the service providers are able to set a price for a new PSS.

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