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Barrier analysis for product service system using interpretive structural model

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Abstract Product service system (PSS) has recently been proposed as a business model. The PSS model requires adjustments of not only internal company technology but also maintenance, service, and supply chain management of up- and downstream suppliers. The implementation of PSS faces a number of challenges. This paper focuses on the challenges in maintenance and remanufacturing. Implementation barriers were identified through a comprehensive literature review followed by expert confirmation. The complex relationships among these barriers were determined through expert panel discussion. Interpretive structural modeling is then used to partition the barriers into a hierarchical structure to facilitate strategic analysis. Results of the analysis were summarized to provide guidelines for PSS implementation.

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1 Introduction

In the early 1990s, the European Union (EU) pushed forward the environmental protection concepts of *integrated product policy* (IPP) and *extended producer responsibility* (EPR) to encourage companies to produce environmentally friendly products. IPP emphasizes optimal combinations in product design in order to improve the environmental performance of products during their life cycles. EPR aims to reduce the total environmental impact of a product. Thus, a producer must be responsible for the environmental impact of its product during the entire product life cycle. In particular, the recycling, reuse, and discarding of products must meet the requirements of low pollution, energy saving, resource saving, and high recycling rate. In recent years, based on environmental protection laws and regulations, the EU has required producers to take the concept of product life cycle and the guidelines of Eco-Design into account during product design to reduce their products' impact on the environment. These laws and regulations force producers to pay attention to the recycling and remanufacturing of products in relation to its design, manufacture, and customer usage, as well as supply chain management.

Many international companies not only actively design green products but also do their best to push forward a new business model, product service system (PSS), to supply "mainly the functions and services of a product" [41]. In other words, the producers emphasize that the functions and services of a product are being sold to the customers, rather than the product itself [11, 27]. The PSS model effectively improves service efficiency and reduces resource consumption and waste through repeated use and remanufacturing of products, raw materials, or components. Mont [28] stated that if companies implement the PSS model, they can improve the technical level of their products, reduce resource consumption, improve corporate benefits, enhance competitive advantages, and reduce the environmental impact of a product during its life cycle. Therefore, some companies have started the migration of their business model toward PSS by improving their product design and increasing the service functions and values of their products. This can provide ecological benefits, reduce pollution and resource consumption, provide the most useful products and services, and achieve sustainable development.

Although the concept of PSS has been discussed in the literature for over a decade, its actual implementation is limited. This is because the migration of a business model to PSS requires not only adjustment in company internal technology but also changes in maintenance, service, and supply chain management of up- and downstream suppliers. Significant challenges exist to implement these changes. The objective of this paper is to develop a systematic approach to provide guidelines for companies in PSS implementation. First, a comprehensive literature review is conducted to identify barriers to PSS implementation with a focus on maintenance and remanufacturing. These barriers are then confirmed through a survey of expert opinion. The experts also conducted a pair-wise comparison of the barriers to determine their relationships. Interpretive structural modeling (ISM) [49] is then used to partition the barriers into a multilevel structural hierarchy based on their relationships. The hierarchy presents a clear picture of the importance of each barrier and is conducive to strategic analysis. Finally, the barriers are analyzed and the results are summarized to provide guidelines for PSS implementation

2 Background

With the PSS business model, a company gains profit not only by selling its products but also by providing service to meet customer demand. Consumers consume the functions and services that come with the product but not the product itself. Therefore, the company owns the product and is responsible for after-sales service such as its warranty, maintenance, upgrade, recycling, and scrapping. Goedkoop et al. [13] defined the key elements of a PSS as follows:

- Product: a tangible commodity manufactured to be sold. It is capable of "falling on your toes" and fulfilling a user's needs
- Service: an activity (work) done for others with an economic value and often done on a commercial basis
- System: a collection of elements including their relations

Brezet et al. [5] group PSS into five categories based on service types, namely (1) supporting system, (2) sales service, (3) different product usages, (4) maintenance service, and (5) service after sale. On the other hand, Tukker [45] grouped PSS by orientation, described as follows:

1. Product oriented. The business model is based on product ownership transaction, although services are provided to improve the functionality of the product. It includes product-related service, advice, and consultancy.
2. Use oriented. The product is held by the provider or shared by a group of users. It includes leasing, renting or sharing, and product pooling.
3. Result oriented. The focus is on the result. Products are considered as a tool to achieve the desired results. It includes activity management, pay per service unit, and functional result.

A number of methods for PSS development have been proposed in the literature [46]. Although the steps in these methods differ somewhat, they can be grouped into three main types:

1. Idea generation and selection: finding idea, suggesting steps to generate potential ideas, selecting the most promising idea, and design
2. Analysis and evaluation: evaluation of strengths and weakness, determination of priorities, and assessment of economic feasibility and environmental impact
3. Implementation: suggesting steps and pin-pointing influential factors in implementing PSS in public or private domain

Specific methods include the following:

- Innovation studio by Abdalla [1]
- Industrialized sustainable solutions by Manzini et al. [37]
- Sustainable product innovation by Kathalys [24]
- Innovation scan by Van Halen et al. [48]
- Design of eco-efficient service by Brezet et al. [5]
- Product service system innovation by Van Halen et al. [48]
- Sustainable home services by Halme and Sharp [18]
- Innovation workbook for sustainable service by James et al. [20]
- Sustainable product and service development by Maxwell and van der Vorst [25]
- Blueprinting for new PSS by Morelli [26]
- Product-oriented PSS realization by Yang et al. [51]
- Multicriteria evaluation by Omann [40]

The benefits and risks of PSS can be found in Micklethwaite [39], briefly summarized as follows:

- Benefits: (1) customer retention, (2) compete against low-cost imports, (3) financial savings, (4) more effective take-back, (5) moving toward sustainable enterprise, and (6) job creation

- Risks: (1) less products sold, (2) new responsibilities, (3) cross-industry collaboration may go further to embrace materials pooling, (4) financial risk, i.e., need for pre-investment, (5) difficult market conditions, (6) no legislative pressure, (7) no prior commitment to environmental improvement, (8) product characteristics, (9) fashion, and (10) resistance to change (both producer and customer)

Goedkoop et al. [13] developed a method to analyze the economic and ecological qualities of PSS. The authors provided basic observations and definitions, an outline of a new assessment method, and ten case descriptions. Sarkis [44] presented an overview of major barriers to PSS implementation with an illustrative example. Companies that are not industry leaders typically lack the information, knowledge, management, and technological abilities to improve/diverse their businesses and hence may struggle with PSS implementation [30]. Azarenko [2] analyzed the barriers toward PSS implementation from the perspectives of both the providers and customers. Besch [6] identifies a number of case studies and scenarios in her review of publications discussing PSS for office furniture. Different strategies were recommended for different product categories, for example, reuse/reconditioning for high-quality furniture, material recycling for low-quality high-volume furniture, and remanufacture and sale for office chairs.

The concept of PSS has been widely discussed over the past decade. A number of methodologies for PSS development are also available in the literature. However, actual PSS implementation is limited. This is because companies face a number of barriers in PSS implementation. The barriers could be both internal and external and could be technical and nontechnical. These barriers are also interrelated. The presence of multiple barriers and the complex relationships among the barriers create a daunting challenge for company management in making strategic decisions. Thus, it is necessary to clearly understand these barriers and their relationship so company management can device an appropriate strategic plan.

ISM was proposed by Van Halen et al. [48] to analyze and solve complex problems in social system engineering. It is mainly applied to various hierarchies of abstract problems and characterized by decomposing complex systems to several subsystems or elements [15]. ISM analyzes the correlation of all the elements in the system through discrete mathematics and graph theory, while combining concepts of behavioral science, mathematics, group discussion, and computerization. Through mathematical operations using binary matrices, a complete multilevel structural hierarchy can be generated automatically. Therefore, interpretive structural modeling can be used to analyze barriers to PSS implementation.

3 Identification of PSS implementation barriers

Barriers for PSS implementation were identified through a comprehensive literature review followed by expert panel confirmation. The panel has 14 members: Three of them are from a company that provides rental service for electrical tools, two are from a company that provides projector rental service, four are from a copy machine company, and the rest are from academia. A barrier is included in the final analysis only when it is identified by ten or more experts. The relationships among the barriers were determined through panel discussion. A total of 14 barriers were

Table 1 Identified barriers for PSS implementation

Aspect	Notation	Barriers	Reference
External	O_1	Lack of support from relevant laws and regulations	[4, 6, 16, 28, 31, 36, 38]
	O_2	Lack of market acceptance	[6, 31]
Internal	O_3	Lack of strategic planning	[6, 36]
	O_4	Rejection of change by internal personnel	[29]
	O_5	Lack of an ideal management information system	[10, 32]
	O_6	Lack of training and education	[29]
	O_7	Lack of technical personnel and support	[29, 41, 47]
	O_8	Lack of support from senior management	[17, 34]
	O_9	Lack of awareness related to PSS	[22]
Maintenance	O_{10}	Load increase in maintenance service system	[4, 6, 29]
	O_{11}	Difficulty in managing components for maintenance service	[23, 35, 43]
Remanufacturing	O_{12}	Different recycling time and quantity as well as product quality	[8, 19]
	O_{13}	Difficulty controlling and managing materials	[9, 23, 34]
	O_{14}	Lack of reverse logistics	[12]

identified, as shown in Table 1. These barriers are discussed in detail below.

There are two external barriers for a company wanting to implement PSS:

- *Lack of support from relevant laws and regulations.* Hanafiah et al. [16] pointed out that at present, there are no legislative requirements to manage product recycling. If a government authority actively promotes PSS, it can force customers to accept some resolution programs for services [3, 30, 49]. When enforced by governmental authorities, PSS not only includes the normative generalized concept but also general social rules and moral regulations, with the goal of establishing behaviors and life styles, enhancing public morality in relation to ecology, changing the inherent consumption habits for product ownership, and making producers and consumers accept the concept of sustainability. Thus, it is necessary to establish PSS friendly laws to form the main driving force of a sustainable society.
- *Lack of market acceptance.* Generally, customers do not purchase green products voluntarily or pay more to receive additional services. Thus, PSS would not be appropriate for high-volume low-value products. In addition, Hanafiah et al. [16] pointed out that low consumer purchasing power will lead to low interest for companies to commit research and development efforts for product remanufacturing. Further, because there is no stable customer base in the recovered product market, market demand uncertainty is also a barrier for a company to implement PSS.

Seven internal barriers for PSS implementation are identified as follows:

- *Lack of strategic planning.* The services provided through PSS commonly involve personnel dispatched to the customer's site to partake in operating flow. The two parties need to establish a stable strategic alliance as the basis for avoiding cooperative risk. It is also necessary for company management to establish long-term trust and a cooperative relationship with the customers. However, this increases the operating risk for the company. Thus, strategic planning will affect the target and quality assurance of the product during PSS implementation.
- *Rejection of changes by internal personnel.* When implementing PSS, company internal personnel must change the original consumption habit. The sale of a product is changed to the lease of a product, which will affect the traditional sales concept. This change can cause feelings of rejection and repulsion among company internal personnel.
- *Lack of an ideal management information system.* McCullar et al. [32] argued that an effective information and coordination system is still missing for end-of-life product management. For example, interaction is not considered in the design of a recycling system and service network for some electronic products; thus, no optimization analysis is conducted. Daugherty et al. [10] indicated that PSS must be linked with existing product sales information, so that product recycling status can be tracked to reduce the time and quantity uncertainties in recovering products. Management and control efficiency of components and parts in a warehouse must be increased, and a cooperative mechanism must be established based on trust. Effective application of information technology can reveal problems at an early stage, so that corresponding countermeasures can be introduced and future performances can be forecasted to serve as references for operating management.
- *Lack of training and education.* PSS is a novel concept. Thus, education and training should be carried out for technical personnel, service personnel, and retailers at the initial establishment stage. Retailers need a combination of education, training, and information systems for settling the problems faced by customers. In addition, Williams [50] stated that producers usually have no prior experience in the management and recycling of products or in the establishment of long-term cooperative relationships with customers. Meijkamp [33] pointed out that asking consumers to waive the idea of product ownership is the most common barrier. Thus, companies need to inform customers that they do not own the product, but only the functions of the product and the services provided by the manufacturer. Kurdve and Mont [21] argued that suppliers should develop mechanisms to monitor and handle a variety of situations during the product's life cycle.
- *Lack of technical personnel and support.* Mont [29] mentioned that when the producer is far away from consumers, the established PSS recycling system would increase product transportation mileage. If supplying only a few service contracts, the transportation cost would increase. Thus, cost is also a key factor for services carried out for a product. Recklies [42] also stated that an imperfect financial system would be the most important factor affecting the company and would place the company in an inferior position on the economic scale. In addition, Votta [47] pointed out that the fact that manufacturers monitor the use of their products would cause customer frustration. Thus, it is necessary to establish trust and the related service model, and a high cost needs to be paid to solve this problem.
- *Lack of support from senior management.* A successful PSS needs to be supported fully by senior management. Mintzberg [34] argued that support from senior management is the most effective driving force for a

company to carry out PSS. Hutchinson and Hutchinson [17] stated that the first step in a green project is the promise of senior management when formulating strategies. Active participation of senior management is the key success factor for improving a company's environmental performance [7].

- *Lack of awareness related to PSS.* Because the public is accustomed to the old consumption model (paying attention to the product itself), they are hesitant to accept the PSS model. Thus, at present, most companies are not clear about the demand for PSS, and if the strategy is adopted hastily, there may be operating risks to a certain extent. In some supply chains that are formed by the core companies and their suppliers, it is possible that multiple suppliers provide services for the same core company. Due to the competitive relationship between different suppliers, if a company wants to retain control of its core competency, it will not share its PSS experience with other companies. Klocek [22] argued that a company would worry about exposing a business secret, such as its core advantage, production technology, financial status, and technical knowledge when developing a new product. PSS requires cooperation between up-, middle-, and downstream suppliers. If companies hold very different views on this matter, it will be more difficult to implement the system.

Two maintenance barriers were identified as follows:

- *Load increase in maintenance service system.* The creation of a maintenance service system is difficult because consumers' usage habits are unknown. Thus, it is difficult to predict what time a consumer will need maintenance service. To meet customer maintenance demands and increase maintenance service efficiency, many service stations need to be established. When maintenance is carried out, servicemen need to learn about customer usage before determining the product's problems. Sometimes, customers may be reluctant to provide information for fear that maintenance may not be free if problems are caused by incorrect usage. This would increase maintenance difficulty.
- *Difficulty in managing components for maintenance service.* In relation to the maintenance service for a product, it is difficult to control the quantity of replacement parts in stock due to different degrees of damage to a product. Production costs would increase from either an excess or a lack of components in stock [23, 35, 43].

Remanufacturing is defined as restoring a defective product to a new status through a series of process flows [14]. Three barriers for remanufacturing were identified as follows:

- *Different recycling time and quantity as well as product quality.* Remanufacturing includes recovering, disassembling, and cleaning a product. Beitz [8] indicated that product design must make it easy to determine the possibility of remanufacturing. Hundal [19] further proposed that quality data of the material used for a product be kept to ensure the possibility of remanufacturing.
- *Difficult controlling and managing materials.* Mahadevan et al. [34] stated that inventory management in remanufacturing is difficult. Thus, push-type inventory policy was recommended for increasing the number of recovered products. Bayindir et al. [9] proposed a model to evaluate the inventory cost of remanufacturing considering product life cycle, supplier lead time, equipment capacity, and remanufacturing operations. Kiesmeller [23] used mixed and random manufacturing and remanufacturing systems to analyze different inventories and lead times to develop an inventory policy.
- *Lack of reverse logistics.* According to Fleischman et al. [12], reverse logistics can be divided into two parts: (1) recovering products that are out of use and transporting them from the consumers to the manufacturer and (2) transporting the recovered products back to the consumers for use again after they are remanufactured. Activities required to support reverse logistics may include the following: inventory, ordering, replacing, transporting, issuing, disposing, repairing, remanufacturing, and verification.

4 Barrier analysis

After identifying the 14 barriers, the next step is to analyze their strategic importance so company management can develop appropriate guides to overcome these barriers. However, the barriers are interrelated and have complex relationships. There is no consensus among the experts regarding strategic importance of the barriers. Therefore, we ask the experts to conduct a pair-wise comparison of the barriers. The barriers are denoted O_i, where $i=1, 2,\ldots,14$, as shown in Table 1. When comparing two barriers O_i and O_j, we ask the experts to select from one of the following four types of relationship:

- Type V: barrier O_i has an effect on barrier O_j
- Type A: barrier O_j has an effect on barrier O_i
- Type X: barrier O_i and a reciprocal effect on barrier O_j
- Type O: barrier O_i has no effect on barrier O_j and vice versa

It is relatively easy for the experts to achieve consensus on the pair-wise comparison. The final relationship is shown in Table 2. ISM is then used to partition the barriers into a multilevel structural hierarchy using steps shown in Fig. 1.

Barrier O_3 is related to all other barriers. Therefore, it is placed in the initial set $S^*=\{O_3\}$. Relationships among the

Table 2 Pair-wise relationship of the barriers

No	O_{14}	O_{13}	O_{12}	O_{11}	O_{10}	O_9	O_8	O_7	O_6	O_5	O_4	O_3	O_2	O_1
O_1	O	O	O	O	O	O	V	O	O	O	V	V	V	
O_2	O	O	O	O	A	A	V	O	O	O	V	V		
O_3	V	V	V	V	X	X	X	X	X	X	X			
O_4	O	O	O	O	O	A	A	O	A	A				
O_5	V	V	V	V	V	V	V	V	V					
O_6	A	O	O	O	O	A	A	A						
O_7	X	O	O	A	A	O	V							
O_8	A	O	O	O	O	A								
O_9	V	O	O	O	O									
O_{10}	O	O	O	V										
O_{11}	O	V	V											
O_{12}	A	V												
O_{13}	X													
O_{14}														

remaining barriers are then converted into a binary relationship matrix **M** as shown in Table 3. In Table 3, a "1" in row i and column j indicates that barrier O_i has an effect on barrier O_j. Note that a barrier has an effect on itself. The reachability matrix of **M** is then calculated as shown in Table 4. The procedure for deriving the final multilevel structure hierarchy is shown in Table 5. In Table 5, $R(O_i)$ is the reachable set of O_i and $C(O_i)$ is the precedence set of O_i. When $R(O_i)=R(O_i) \cap C(O_i)$, $R(O_i)$ is placed in a set corresponding to the level and excluded in the analysis of subsequent levels. The result showed that the barriers can be partitioned into seven levels as follows:

$S_1=\{O_4\}$
$S_2=\{O_6\}$
$S_3=\{O_8\}$
$S_4=\{O_7, O_{12}, O_{13}, O_{14}\}$
$S_5=\{O_2, O_{11}\}$
$S_6=\{O_1, O_9, O_{10}\}$
$S_7=\{O_5\}$

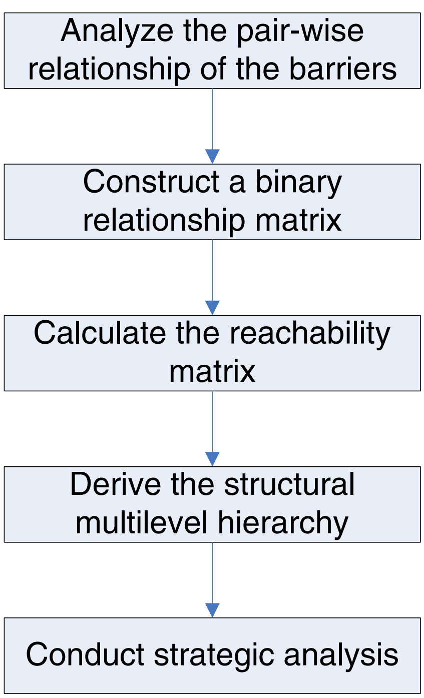


Fig. 1 ISM analysis procedure

After ISM analysis, the relationships among the barriers are illustrated graphically using a multilevel structure hierarchy chart as shown in Fig. 2. This chart is then used to guide strategic analysis of maintenance and remanufacturing problems faced by a company when introducing PSS. Results of the analysis are summarized as follows:

- Lack of strategic planning (O_3) either affects or is affected by the other barriers. Therefore, it is the major barrier to maintenance and remanufacturing in PSS implementation. Overcoming this barrier is the company's top priority. Government decree (O_1) will have a significant impact on a company's strategic planning.
- When conducting strategic planning, the company must focus on the following: maintenance cost, maintenance time, distance to the maintenance station, real-time monitoring of the defect rate, product damage status, and demand history. An important factor to consider during strategic planning is the status of the company's information system (O_5).
- Before implementing PSS, the company must consider uncertainty factors including market acceptability (O_2) and the demand for maintenance service (O_{11}).

Table 3 Binary relationship matrix of the barriers

No	O_1	O_2	O_4	O_5	O_6	O_7	O_8	O_9	O_{10}	O_{11}	O_{12}	O_{13}	O_{14}
O_1	1	1	1	0	0	0	1	0	0	0	0	0	0
O_2	0	1	1	0	0	0	1	0	0	0	0	0	0
O_4	0	0	1	0	0	0	0	0	0	0	0	0	0
O_5	0	0	1	1	1	1	1	1	1	1	1	1	1
O_6	0	0	1	0	1	0	0	0	0	0	0	0	0
O_7	0	0	0	0	1	1	1	0	0	0	0	0	1
O_8	0	0	1	0	1	0	1	0	0	0	0	0	0
O_9	0	1	1	0	1	0	1	1	0	0	0	0	1
O_{10}	0	1	0	0	0	1	0	0	1	1	0	0	0
O_{11}	0	0	0	0	0	1	0	0	0	1	1	1	0
O_{12}	0	0	0	0	0	0	0	0	0	0	1	1	0
O_{13}	0	0	0	0	0	0	0	0	0	0	0	1	1
O_{14}	0	0	0	0	1	1	1	0	0	0	1	1	1

- The company should urge internal personnel to understand company policy related to PSS (O_9) in order to reduce internal rejection (O_4) and gain support from senior management (O_8). In addition, developing a good management information system can enhance internal education, training, and communication efficiency (O_6).
- Progressive PSS implementation might be necessary to counter the lack of technical personnel and support (O_7). Establishing a recycling management system can be helpful in monitoring component usage and forecasting product recovery (O_{13}) and tracking the recycling process in a timely manner (O_{12}). This will help reduce the risk of missing products or valuable components, imbalance in the supply and demand of materials and components, and other uncertain factors.
- To increase market acceptance (O_2), the company should establish a central recycling center, strengthen reverse logistics (O_{14}), expedite product inspection and decomposing, evaluate the types, quantity, and operability of changed parts, improve and coordinate post-processing handling measures, and formulate specific rules and procedures.
- The company should consider setting up a special research foundation to support PSS-related research and R&D for remanufacturing. The foundation would provide training to much needed technical personnel (O_7) to support PSS implementation.

To evaluate the usefulness of the analysis results, we conducted a case study with the Taiwan subsidiary of an international company. The company engages in the development, manufacture, marketing, servicing, and financing of document equipment, software, solutions, and services. Its name is omitted for confidentiality reason. In addition to equipment sales, the Taiwan subsidiary provides mixed copy machine leasing and pay per copy service for consumers. Approximately 55% of the revenue comes from

Table 4 Reachability matrix

No	O_1	O_2	O_4	O_5	O_6	O_7	O_8	O_9	O_{10}	O_{11}	O_{12}	O_{13}	O_{14}
O_1	1	1	1	0	1	0	1	0	0	0	0	0	0
O_2	0	1	1	0	1	0	1	0	0	0	0	0	0
O_4	0	0	1	0	0	0	0	0	0	0	0	0	0
O_5	0	1	1	1	1	1	1	1	1	1	1	1	1
O_6	0	0	1	0	1	0	0	0	0	0	0	0	0
O_7	0	0	1	0	1	1	1	0	0	0	1	1	1
O_8	0	0	1	0	1	0	1	0	0	0	0	0	0
O_9	0	1	1	0	1	1	1	1	0	0	1	1	1
O_{10}	0	1	1	0	1	1	1	0	1	1	1	1	1
O_{11}	0	0	1	0	1	1	1	0	0	1	1	1	1
O_{12}	0	0	1	0	1	1	1	0	0	0	1	1	1
O_{13}	0	0	1	0	1	1	1	0	0	0	1	1	1
O_{14}	0	0	1	0	1	1	1	0	0	0	1	1	1

Table 5 ISM analysis of the barriers

Level	O_i	$R(O_i)$	$C(O_i)$	$R(O_i) \cap C(O_i)$
1	1	1, 2, 4, 6, 8	1	1
	2	2, 4, 6, 8	1, 2, 5, 9, 10	2
	4	4	1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	4
	5	2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	5	5
	6	4, 6	1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	6
	7	4, 6, 7, 8, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
	8	4, 6, 8	1, 2, 5, 7, 8, 9, 10, 11, 12, 13, 14	8
	9	2, 4, 6, 7, 8, 9, 12, 13, 14	5, 9	9
	10	2, 4, 6, 7, 8, 10, 11, 12, 13, 14	5, 10	10
	11	4, 6, 7, 8, 11, 12, 13, 14	5, 10, 11	11
	12	4, 6, 7, 8, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
	13	4, 6, 7, 8, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
	14	4, 6, 7, 8, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
2	1	1, 2, 6, 8	1	1
	2	2, 6, 8	1, 2, 5, 9, 10	2
	5	2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	5	5
	6	6	1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	6
	7	6, 7, 8, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
	8	6, 8	1, 2, 5, 7, 8, 9, 10, 11, 12, 13, 14	8
	9	2, 6, 7, 8, 9, 12, 13, 14	5, 9	9
	10	2, 6, 7, 8, 10, 11, 12, 13, 14	5, 10	10
	11	6, 7, 8, 11, 12, 13, 14	5, 10, 11	11
	12	6, 7, 8, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
	13	6, 7, 8, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
	14	6, 7, 8, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
3	1	1, 2, 8	1	1
	2	2, 8	1, 2, 5, 9, 10	2
	5	2, 5, 7, 8, 9, 10, 11, 12, 13, 14	5	5
	7	7, 8, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
	8	8	1, 2, 5, 7, 8, 9, 10, 11, 12, 13, 14	8
	9	2, 7, 8, 9, 12, 13, 14	5, 9	9
	10	2, 7, 8, 10, 11, 12, 13, 14	5, 10	10
	11	7, 8, 11, 12, 13, 14	5, 10, 11	11
	12	7, 8, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
	13	7, 8, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
	14	7, 8, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
4	1	1, 2	1	1
	2	2	1, 2, 5, 9, 10	2
	5	2, 5, 7, 9, 10, 11, 12, 13, 14	5	5
	7	7, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
	9	2, 7, 9, 12, 13, 14	5, 9	9
	10	2, 7, 10, 11, 12, 13, 14	5, 10	10
	11	7, 11, 12, 13, 14	5, 10, 11	11
	12	7, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
	13	7, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
	14	7, 12, 13, 14	5, 7, 9, 10, 11, 12, 13, 14	7, 12, 13, 14
5	1	1, 2	1	1
	2	2	1, 2, 5, 9, 10	2
	5	2, 5, 9, 10	5	5

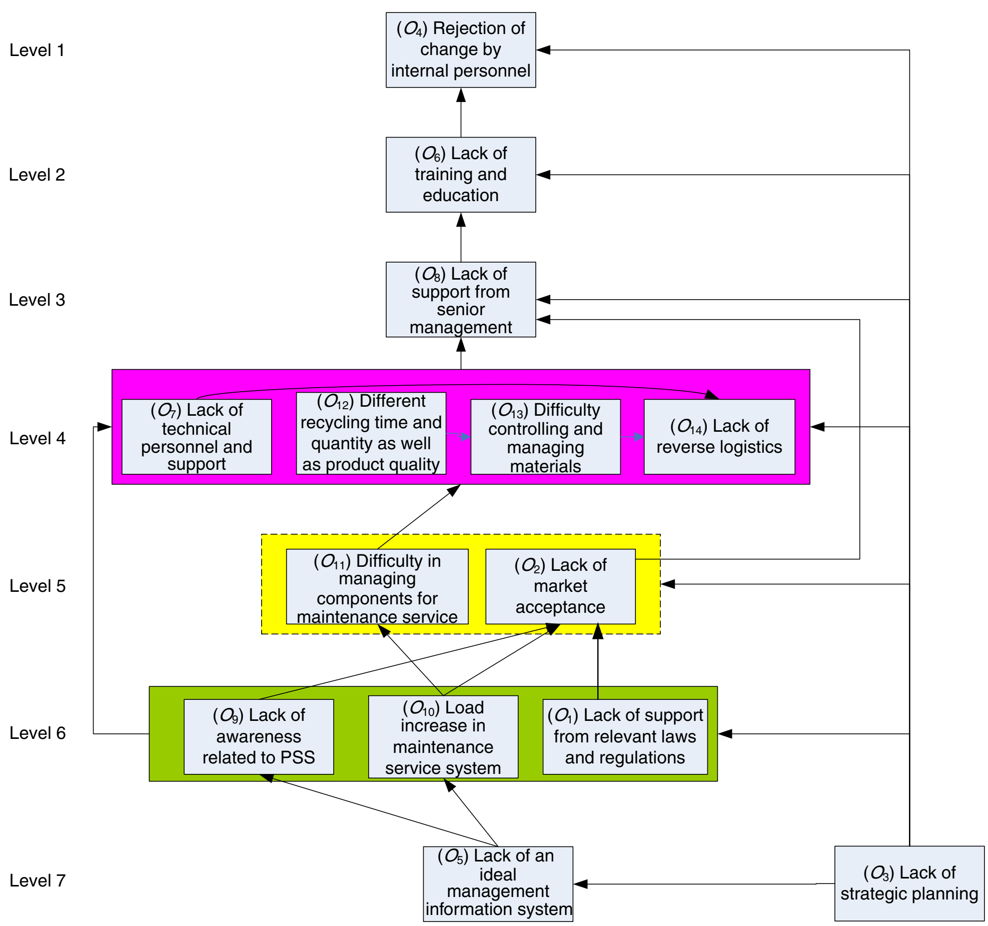
Table 5 (continued)

Level	O_i	$R(O_i)$	$C(O_i)$	$R(O_i) \cap C(O_i)$
	9	2, 9	5, 9	9
	10	2, 10	5, 10	10
	11	11	5, 10, 11	11
6	1	1	1	1
	5	5, 9	5	5
	9	9	5, 9	9
	10	10	5, 10	10
7	5	5	5	5

equipment sale, whereas the remaining 45% comes from service activities that include lease, maintenance, and financing. The company intends to increase revenue of the service segment and identified three barriers, namely governmental decree, market acceptance, and demand for maintenance service. This is consistent with our analysis result. In other words, the top priority in company strategic planning is to deal with barriers O_1, O_2, and O_{11}. It is very important for company salesperson to demonstrate the economic value of equipment leasing to customer.

Currently, 40% of the company employees are maintenance personnel. They must respond to customer problems within 48 h and solve the problems within 5 days. Customer problems include maintenance, repair, toner cartridge order, and customer complaints. In order to meet service goals, the company needs a powerful customer service information system (O_5) so that maintenance personnel can have easy and quick access to customer information. Most customer problems could be solved directly on the phone. For problems that require on site

Fig. 2 Multilevel structure hierarchy of the barriers



visits, having all the information at the same time would facilitate scheduling and hence ensuring that service goals are met.

The company has decided to provide internal training every year for employees to understand company service policy. The effect of training is threefold: (1) more technical personnel (O_7) will be educated, (2) internal rejection (O_4) will be reduced, and (3) support from senior management (O_8) will be strengthened. The company also provides a progressive maintenance management system to monitor all the copy machines for component usage. This is a key part of the company's information system (O_5).

Currently, the percentage of remanufactured components ranges from 20% to 95%. Quality of the remanufactured components will be monitored and controlled in a timely manner (O_{12}). The company has also built a reverse logistics (O_{14}) network to collect end-of-life (EOL) copy machines. The network includes four collection stations across Taiwan. EOL machines will be disassembled and processed based on environmental protection regulations as well as confidentiality considerations (confidential data might reside in the storage device of the copy machine).

5 Conclusions

Companies face many uncertainties and risks when implementing PSS due to the lack of sophisticated theories and practices to support maintenance and remanufacturing activities. Without correct guidance, the outcomes will most likely be multiple failures and wasted funds. This study applied ISM to analyze the barriers to PSS implementation with emphasis on maintenance and remanufacturing. It used literature review as the research basis and utilized domain experts to guide model building and analysis. The barriers were partitioned into a multilevel hierarchy to allow clear visualization of their relationships. The relationship hierarchy served as a useful reference for company strategic decision making. In summary, there are three major barriers to the PSS business model, namely (1) lack of support from related laws and regulations, (2) lack of awareness related to PSS, and (3) load increase of maintenance service systems. When implementing PSS, a company should focus on strategic planning and the development of a complete management information system.

Our expert panel consists of members from different companies and the academia. Therefore, the analysis results should be generally applicable to different companies. However, our research focuses on maintenance and remanufacturing activities in PSS. Therefore, the results are applicable to high-value products, but not to low-value high-volume products where maintenance and remanufacturing do not make much economical sense. For a specific company who is interested in implementing PSS, we suggest that the management team follow a similar procedure for strategic analysis. The barriers identified may vary from company to company depending on the target product and company emphasis, but the procedure to analyze the barriers based on ISM partitioning would remain the same. Visualizing the hierarchical structure of the barriers would be very helpful in company strategic planning and decision making.

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