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by Dian Retno Sari Dewi

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Assessing the Product–Service Systems Supply Chain Capabilities: Construct and Instrument Development

Dian Retno Sari Dewi[1*], Yustinus Budi Hermanto[2], Siddhi Pittayachawan[3], Elizabeth Tait[4]

[1]*Industrial Engineering Department, Widya Mandala Catholic University, Kalijudan 37, Surabaya 60114, Indonesia*
[2]*Faculty of Economics and Business, Darma Cendika Catholic University, Dr. Ir. H. Soekarno 201, Surabaya 60117, Indonesia*
[3]*School of Accounting, Information Systems and Supply Chain, RMIT University, 124 La Trobe Street, Melbourne, Victoria 3000, Australia*
[4]*School of Information and Communication Studies, Charles Sturt University, Boorooma, North Wagga, New South Wales 2650, Australia*

Abstract. Product–service systems (PSS) has become a major subject of concern for many industries because of their benefits and the possibilities to reduce negative environmental impacts and address environmental sustainability concerns. Despite the benefits of PSS, little empirical research has been conducted to investigate the PSS supply chain (SC) capabilities constructs. This study offers original contributions to the valid and reliable construct and instrument development to measure the PSS SC capabilities. A systematic approach was employed to develop and validate an instrument for evaluating the PSS SC capabilities. This comprises specifying domains of constructs, generating a sample of items, conducting interrater agreement analysis, testing non-response bias, and assessing the instrument using exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). The validity of the proposed model was tested using structural equation modeling based on a large-scale online survey from 447 participants working for motorcycle service partners. The result shows seven distinctive PSS SC capabilities constructs, namely knowledge assessment, partner development, co-evolving, reflexive control, re-conceptualization, innovative service delivery, and sustainable product–service capability. The development of the instrument contributes a validated tool for companies to measure their PSS SC capabilities.

Keywords: Instrument development; Product–service systems; Supply chain capabilities; Sustainability

1. Introduction

PSS SC capabilities are multifarious construct that addresses both PSS and environmental sustainability concerns. Annarelli, Battistella, and Nonino (2016) noted through their definition that PSS is defined as a business model offering a marketable bundle of products and services to fulfill customer needs by considering sustainability. Accordingly, new designs, methods, and processes to accommodate sustainable products and services should be cautiously investigated (Berawi, 2021a; Berawi, 2021b). While the implementation of PSS is expected not only to bring a competitive edge but also to reduce

*Corresponding author's email: dianretnosd@ukwms.ac.id, Tel.: +62 31 3891264
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the environmental impact, the PSS SC capabilities need to be built to sustain businesses and the extent to which the knowledge has progressed with the PSS SC capabilities, has rarely been found in the literature. To date, there are no studies that have conceptualized a PSS SC construct and developed a valid and reliable instrument to measure it.

The objective of this paper is to provide a valid and reliable instrument to measure and operationalize PSS SC capabilities. Therefore, this study can be seen as the first attempt to advance the PSS SC capabilities research through theorization, conceptualization, and measurement development. It contributes to the PSS literature in the area of environmental sustainability concerns and addresses an under-researched area at the intersection of PSS and Sustainable Supply Chain Management (SSCM). In terms of practical implications, this study could help practitioners in the automotive industry improve their PSS SC capabilities. Other industries and other developing countries with similar characteristics as Indonesia may also find this study beneficial to inform their practices.

2. Theoretical background

Manufacturers might not have the capacity to provide all-around services as they focus more on production; their resources and expertise to deliver PSS are limited (Ayala, Gerstlberger, and Frank, 2018). They choose to develop their SC capability first by, for example, transforming their business processes in order to enable PSS (Martinez *et al.*, 2010). Meanwhile, other manufacturers prefer to collaborate with intermediaries and a network of service partners instead (Dewi *et al.*, 2023; Dewi and Hermanto, 2022, Dewi *et al.*, 2020). This is because PSS is complex; for example, it needs expertise in customer relationship building and assessment of customer expectations about products and services (Moro, Cauchick-Miguel, and Mendes, 2022). Such requirements are likely to be met by a multi-actor SC network comprising manufacturers, intermediaries, and service partners instead of by manufacturers alone (Story *et al.*, 2017).

A review of PSS studies shows that they focus more on the development of PSS delivery capabilities (Story *et al.*, 2017; Kindström, Kowalkowski, and Sandberg, 2013), and less on the SC concept that is associated with the collaboration of many companies in the SC network to provide a broader perspective of product life cycle concept to achieve sustainability. Studies using dynamic capabilities emphasize service development; for example, Ayala Gerstlberger, and Frank (2018) proposed four capabilities i.e., service offering, resource, activity, and service supplier; whereas Raddats *et al.* (2017) proposed that the four capabilities should be service enablement, service development, knowledge assessment, and risk management. Story *et al.* (2017), on the other hand, claimed that capabilities should be customer-focused, comprising customer intimacy, coordination, and service delivery. Meanwhile, other studies have concentrated on innovative service delivery, suggesting that service quality, the capability to deliver PSS at the operational level and the capability to improve service capacities and facilities, are crucial (Kindström, Kowalkowski, and Sandberg, 2013). Overall, the SC capabilities examined in the literature have not fully performed PSS as most of the studies focus only on the economic aspect, and less focus on the environmental aspect.

From the SC concept and sustainability concern, this study looks into SSCM, which is a concept of management of material, information, capital flow, and collaboration among companies in the SC aiming to achieve sustainability (Seuring and Müller, 2008). For example, Beske (2012) proposed three more variables to complement the SC capabilities—knowledge assessment and collaboration—proposed by Defee and Fugate (2010). They argue that partner development, reflexive control, and re-conceptualization are needed to improve sustainability. Meanwhile, in their subsequent study, Beske, Land, and Seuring

(2014) enhanced their model by adding SSCM practices. This study uses the SC capabilities postulated by Beske, Land, and Seuring (2014) and Kindström, Kowalkowski, and Sandberg, (2013) as the proposed conceptual framework since both studies represent the overall SC capabilities required for PSS. Sustainable product–service capability is also a key determinant for sustainability concerns (Garetti and Taisch, 2012); hence, it is included in the PSS SC capabilities.

Defining a theoretical construct is a critical stage in developing a valid instrument. Based on the argument of the preceding two paragraphs, a bundle of product and service required not only focuses on service delivery but also covers the product life cycle. Hence, the *PSS SC capabilities* are defined as an SC network capability deliver through a bundle of product and service performance, covering the product life cycle to apply the responsibility of environmental sustainability. PSS SC capabilities demonstrate the capabilities of the SC network collaboration to deliver PSS to achieve the environmental sustainability criteria. Operationalization of the PSS SC capabilities constructs is guided by the extensive literature reviews from the PSS and SSCM capabilities perspective. This infers that the environmental sustainability aspects should be incorporated when generating items of the construct. Underpinned by the concept of dynamic capabilities (DC), a framework that postulates various PSS SC capabilities, including collaboration, knowledge assessment, partner development, reflexive control, innovative service delivery, re-conceptualisation, and sustainable product–service capability are developed. DC works best with two or more organizations collaborating on capabilities and resources in the SC to improve PSS SC capabilities together (Beske, 2012). The next paragraph discusses the domain definition of each construct.

Collaboration (CO) is defined as a partnership activity of creating new resources where two or more parties jointly work together to achieve mutual benefit (Beske, 2012; Cao *et al.*, 2010). *Knowledge assessment* (KA) is the capability to access and understand the knowledge from the strongest partners in the SC (Beske, 2012). In this study, the service partners (characterized as small partners) are usually the weakest in the SC and do not have the capability to evaluate the knowledge available. They are mostly receiving knowledge from manufacturers through the main dealers. Hence, the operationalization of this construct is mostly based on knowledge sharing from the manufacturers through intermediaries to service partners. *Partner development* (PD) is defined as the capability to enhance the capabilities of service partners (including their sustainability performance) that enhance harmony across the SC (Seuring and Müller, 2008). Partner development programs are a way to share knowledge in the SC network (Beske, Land, and Seuring, 2014). *Re-conceptualisation* (REC) is defined as the capability to change what the SC does by moving toward closed-loop systems and servicing (Pagell and Wu, 2009). A product's take-back program, refurbished products, maintenance, adherence to environmental regulation, and advice on efficient use are all parts of closed-loop SC activities (Kusrini *et al.*, 2020; Coenen, van Der Heijden, and van Riel, 2018). *Reflexive control* (REF) is defined as the capability to gather, share information, monitor, and evaluate the performance of an SC. It aims to control SC functionality (Beske, Land, and Seuring, 2014). Partners' activities are controlled and audited through standards and certification by third parties such as ISO 14001 or the European Union Eco-Management and Audit Scheme (Beske, Land, and Seuring, 2014). *Innovative service delivery* (ISD) is defined as an inherently dynamic process, seeking to identify and exploit the benefits of service innovation, by offering a bundle product-service solution to fulfill customer needs (Kindström, Kowalkowski, and Sandberg, 2013). *Sustainable product–service capability* (SPSC) is defined as the capability of designing and using natural resources for manufacturing and service, by creating an integrated bundle of products and services, which is designed to be a powerful tool for developing a more sustainable solution (Garetti and Taisch, 2012). SPSC can be categorized into four stages following the product life cycle concept, namely product design and development, the manufacturing process, and product end-of-life management (Hanim *et al.*, 2017). Content validity is a basic requirement for instrument development (Jarva *et al.*, 2023). This was achieved through the intensive literature reviews delivered in this section. Using the PSS SC capabilities construct discussed above, an initial pool of items was created (35 items in total) and is presented in Table 1.

Table 1 Summary of domain of constructs and items

Code	Constructs	Reference
	Collaboration	
CO1	We work jointly on the product–service systems planning with our main dealer	(Beske, Land, and Seuring, 2014)
CO2	We maintain a long-term collaborative relationship with the main dealer based on mutual trust	(Boon-itt, wong, and wong, 2017)
CO3	Our logistics activities are well integrated with the main dealer's logistics activities	(Mandal *et al.*, 2016)
CO4	We have the same information technology platform as our main dealer that can share information	(Boon-itt, wong, and wong, 2017)
CO5	We share the measurement of customer satisfaction and expectation with our main dealer	(Haque and Islam, 2018)
CO6	We share demand forecasting and planning with our main dealer	(Hong, Zhang, and Ding, 2018)
	Knowledge assessment	
KA1	We have access to our main dealer's knowledge and technical expertise of the product	(Defee and Fugate, 2010)
KA2	Our main dealer enhances our knowledge about the benefit of sustainability	(Beske, Land, and Seuring, 2014)
KA3	Our main dealer provides us with knowledge of information technology to provide the bundle of product and service offerings	(Beske, Land, and Seuring, 2014)
KA4	We learn about customers' needs and requirements from our main dealer	(Kindström, Kowalkowski and Sandberg, 2013)
KA5	We learn about innovations related to product–service bundling from our main dealer	(Hong, Zhang, and Ding, 2018)
	Partner development	
PD1	Our main dealer has the capability to continuously improve our knowledge	(Beske, Land, and Seuring, 2014)
PD2	Our main dealer provides us with a variety of training courses to increase our capabilities	(Boon-itt, wong, and wong, 2017)
PD3	Our main dealer provides partner development programs to learn about the product–service systems	(Ayala, Gerstlberger, and Frank, 2018)
PD4	Our main dealer enhances service partner's capabilities to achieve the sustainability goal in our supply chain	(Beske, Land, and Seuring, 2014)
PD5	Our main dealer strengthens our technical expertise related to the product's service and maintenance	(Paiola *et al.*, 2013)
	Re-conceptualisation	
REC1	We have the capability to follow the environmental regulation determined by the Indonesian government	(Kumar, Subramanian, and Arputham, 2018)
REC2	Our main dealer offers a product take-back program	(Coenen, van Der Heijden, and van Riel,,2018)
REC3	We have advised customers on how to use our products in an energy-efficient manner	(Jadhav, Orr, and Malik, 2018)
REC4	We have suggested customers regularly maintain their products	(Dewi and Hermanto 2022; Dewi *et al.*, 2023)
REC5	Our manufacturing partner offers refurbished motorcycles	(Blome Paulraj, and Schuetz, 2014)

Code	Constructs	Reference
	Reflexive control	
REF1	Our main dealer shares information with us about product–service offerings	(Haque and Islam, 2018)
REF2	Our main dealer and we have systems for monitoring and evaluating supply chain performance	(Mandal *et al.*, 2016)
REF3	Our main dealer evaluates our performance by its standards	(Beske, Land, and Seuring, 2014)
REF4	We are capable of fulfilling certifications required by the main dealer for evaluating our performance	(Beske, Land, and Seuring, 2014)
	Innovative service delivery	
ISD1	We always improve service quality to fulfill customer needs	(Ayala, Gerstlberger, and Frank, 2018)
ISD2	We always deliver our service on time	(Kindström, Kowalkowski, and Sandberg, 2013)
ISD3	We are proficient to deliver an innovative bundling of product–service, particularly in providing maintenance and repair services	(Paiola *et al.*, 2013)
ISD4	We manage service capacity with uncertain demand	(Boon-itt, wong, and wong, 2017)
ISD5	We always improve service management facilities	(Ayala, Gerstlberger, and Frank, 2018)
	Sustainable product-service capability	
SPSC1	Our manufacturing partner designs products that will prolong the life of materials	(Hanim *et al.*, 2017)
SPSC2	Our manufacturing partner designs products that will enable repair, rework, and recycling	(Blome Paulraj, and Schuetz, 2014)
SPSC3	Our manufacturing partner designs products that facilitate disassembly	(Hanim *et al.*, 2017)
SPSC4	Our manufacturing partner adheres to environmentally related programs, standards, and regulations	(Hanim *et al.*, 2017)
SPSC5	We prolong the service life of products by providing maintenance and support to customers	(Hanim *et al.*, 2017)

3. Methods

To develop the PSS SC capabilities framework and to ensure the validity and reliability of the framework, the procedure developed by Lewis, Templeton, and Byrd (2005) is utilized. The first stage is to specify the domains of each construct. The second stage for developing better measures is to generate items that capture the domain as specified (Jarva *et al.*, 2023). The third and fourth stages are pre-testing, followed by a pilot test, and the fifth stage is item screening (Lewis, Templeton, and Byrd, 2005). In the sixth stage, sample design and data collection are covered. The seventh stage is data analysis to test the validity and reliability of the instrument.

EFA and CFA were employed as the validity tests. Initially, the EFA was utilized by SPSS version 26 to assess the dimensionality of the measurement, followed by running the CFA in AMOS version 26 to evaluate the convergent validity, discriminant validity, and factorial validity. To evaluate the internal consistency and reliability, coefficient H was utilized. Finally, common method bias was tested with CFA (Podsakoff *et al.*, 2003).

4. Results and Discussion

The first stage as mentioned in the methods is to specify the domain of each construct. The purpose of the domain specification step is to deliver a clear conceptual meaning and definition of each construct by specifying its dimensions (Jarva *et al.*, 2023). This required a review of the existing literature and, when suitable, taking items from existing measurements. Each construct was modified to accommodate the context of the Indonesian motorcycle industry. This has been done in the theoretical background section.

The second stage presents the operationalization of the seven theoretical constructs discussed in the previous section. Based on a comprehensive review of the literature on SC capabilities and considerable discussion with two academics, an initial pool of 35 items from 7 constructs was created (Table 1).

In the third stage, a pre-test was conducted as the first attempt aiming for empirical feedback to evaluate the instrument (Lewis, Templeton, and Byrd 2005). Five academic experts were recruited for pre-testing. An adjustment to the instrument was then undertaken, which included changes in the terminology and modified sentences. There were no added new items and deleted irrelevant items so the initial pool of 35 items remained.

Next, a pilot test was undertaken to purify the instrument (Lewis, Templeton, and Byrd, 2005). Ten persons from official motorcycle service partners were asked to fill out the instrument. A questionnaire written in English was translated into Bahasa and then back-translated to English to ensure the meaning was the same in the Bahasa and English version. The participants were asked to complete the instrument. Once complete, the participants were asked about their difficulties in completing the instrument and gave suggestions regarding the improvement of item statements. The pilot study confirmed that the motorcycle service partners did not recognize the authority of manufacturers as they did not have a direct relationship with the manufacturers. Instead, the main dealers as intermediaries acted as the manufacturer's representatives and they were the ones expected to provide the SC capabilities to the service partners. Again, an adjustment to the wording and terms was applied to the instrument (Lewis, Templeton, and Byrd, 2005) and 35 items remained.

In the fifth stage, an interrater agreement survey with 20 participants who have expertise in the SC field was asked to participate (Lewis, Templeton, and Byrd, 2005). These experts were the head of the SC, the head of the service department, the main dealer head of service partners from the motorcycle industry, and academic experts. The five-point rating scale was used to evaluate the relevance of items (i.e., 0 = not relevant, 1= minimally relevant, 2=moderately relevant, 3= substantially relevant, 4 = extremely relevant).

A mean score was evaluated to discover the level of homogeneity in the rating given. If raters do not have an agreement and the value of the mean score is below the mean point then the items must be dropped (Lindell, 2001). Similarly, the result of interrater agreement corresponding with the p-value must be below 0.05 (Lindell, 2001). An index to evaluate a single target using a multi-item rating scale was used (Lindell, 2001). A test of the equality variances is proposed to delete items with a low level of interrater agreement. The variance of rater means scale scores are employed as the numerator of the agreement index. A chi-squared test can direct whether an item has a r^*_{wg} value significantly different from zero by comparing the variance of rater mean scale scores and expected variance under the uniform distribution. The inter-rater agreement r^*_{wg} was estimated by Lindell (2001)'s formula. There were three criteria suggested for dropping items: (1) drop items when their mean value is less than the midpoint, (2) drop items left from (1) when p> 0.05 and (3) drop items left from (2) when power < 0.8 (Sud-on *et al.*, 2013). The results show a mean value of 3.05–3.70, all p-value < 0.05, and a power of 0.80–1. According to the three criteria for dropping items discussed above, no items were removed so a total of 35 items remained in the final questionnaire.

In the sixth stage, 1,300 invitations were sent using a simple random sampling to collect the data from the Indonesian motorcycle service partners. The population was established by the researcher by collecting service partner data from the website of the five motorcycle brands with the proportion of their market share (AHM 75%, YIMM 22%, SIM 1%, KMI 1%, and TVS 1%); a sampling frame is about 6,800 service partners. This study used a combination of a six-point Likert and rating scale. The questionnaire was distributed online in the Bahasa version and sent to the list of email addresses that were generated in the sampling frame. Two follow-up emails were then sent when necessary, after the first email. The data collection was undertaken between August 2019 and July 2020. The online survey was developed electronically using Qualtrics. The survey participants were managers or heads of Services in the official service partners of the motorcycle manufacturers in Indonesia. The inclusion criteria for these managers were that they must be working in this field for at least one year. A total of 447 responses were recorded for analysis.

With the frequency of 447 participants, the sample's demographic profile indicates that 87.5% are service partners with the employee less than 10. This was within our expectation since most service partners are categorized as small or medium enterprises. The majority of the surveyed motorcycle service partners are based in Java (65.5%), followed by Sumatera (14.1%), Sulawesi (7.2%), Kalimantan (5.6%), Bali-NT (5.6%) and Maluku-Papua (2%). Interestingly, many service partners have collaborated with the manufacturers for more than ten years (63.3%).

To further ensure that the data are free from non-response bias, the t-test for the equality of means on seven constructs was conducted by comparing early (n = 226) and late waves (n = 221). The result showed the early and late waves were not statistically significant with p-values greater than 0.05 for the six constructs. These output results affirmed that non-response bias was not a concern in this study.

In the seventh stage, an instrument assessment was conducted through EFA followed by CFA. EFA was utilized to evaluate the measurement properties of all constructs. The factorability of the data was tested using Kaiser's criterion (eigenvalue >1) and parallel analysis to investigate the number of factors that can be extracted (Bandalos *et al.*, 2009). Maximum likelihood extraction and Promax rotation were utilized to verify the scale's dimensionality. Seven constructs produced a one-factor solution which explained 53.4 to 68.8 % of the variance, so the seven constructs were considered valid by Howard and Henderson (2023). During the process of assessing the dimensionality through EFA, no items were deleted, because no factor loading was below 0.4 which is considered statistically significant (0.435– 0.869).

CFA using AMOS (version 26) was utilized to evaluate the convergent, discriminant, and factorial validity of the measurement. Convergent validity is the degree of agreement for a set of indicators to measure the same construct. The convergent validity test consisted of three steps. First is to calculate the chi-squared values of each construct; and second, if the chi-squared rejects a factor at $p<0.01$ then we use the modification indices to identify common factors among items. As a precaution, the items that were dropped should have a low validity (i.e. from the validity index of the interrater agreement). This process resulted in 7 constructs and 29 items. It dropped 6 items: CO4, CO6, PD4, REC5, ISD2 and SPSC1. These findings are confirmed as evidence of convergent validity (Hair *et al.*, 2010) with the goodness of fit indices cut-off values: $p > 0.01$, norm $\chi^2 \leq 2$, RMSEA< 0.05, SRMR< 0.07, CFI> 0.96 and TLI> 0.95. Discriminant validity among the seven constructs was achieved as the value of AVE for each construct was greater than the value of the square correlation between the respective construct with the other constructs. Since the measurement model of the constructs in this study is congeneric, coefficient H is considered the best measurement of reliability for this case (Hancock and Mueller, 2001). The result confirmed that the scales were reliable as H in the range of 0.859–0.926 (H>0.80). The seven constructs reported factor loading 0.50–0.87, p-value 0.173–0.467, RMSEA 0.00–0.038, SRMR 0.004–0.018, CFI 0.997–1.0, and TLI 0.994–1.0. Finally, factorial validity examines whether a set of latent variables demonstrate an underlying pattern by evaluating the fit statistics of the full measurement model. The results confirmed a good fit of the measurement model that supported the factorial validity of the measurement (normed $\chi 2 = 1.557$, SRMR = 0.025, RMSEA = 0.035, CFI = 0.977, and TLI = 0.974).

This study, drawn from the PSS, SSCM, and dynamic capabilities theories, develops the PSS SC capabilities model. The theories provide a stringent foundation for the conceptualization of PSS SC capabilities. Likewise, the definition of PSS SC capabilities helps to conceptualize that the implementation of PSS covers the whole product life cycle to apply the responsibility of environmental sustainability. This follows the recent definition of PSS by Annarelli, Battistella, and Nonino (2016) to consider the sustainability in offering the PSS. The proposed model provides that PSS SC capabilities can be measured by seven constructs: collaboration, knowledge assessment, partner development, reflexive control, re-conceptualization, innovative service development, and sustainable product–service capability. The final solution is comprised of 29 items to support the seven constructs.

5. Conclusions

Studies investigating PSS SC capabilities among manufacturers, intermediaries, and service partners are relatively recent, hence a developing research area. There are few research papers published in this field, therefore this study contributes by developing the PSS SC capabilities model and identifying its constructs. The model is based on previous literature on PSS and SSCM. This study contributes to the theoretical development of the body of knowledge by conceptualizing the PSS SC capabilities as holistic capabilities of a network comprised of manufacturers, intermediaries, and service partners. Likewise, the study contributes clear definitions of PSS SC capabilities applying the environmental sustainability concept so that, by this definition, PSS SC capabilities can be used as part of solutions to improve sustainability. The theoretical hypothesis for the PSS SC capabilities is that they comprise seven constructs that demonstrate network SC capabilities to deliver PSS by considering the environmental sustainability concerns. This study has significant contributions in defining the PSS SC capabilities and developing the dimensions that comprise it. Furthermore, it provides ready-instrument development whose properties are sufficiently validated. A rigorous procedure subsequently assessed the instrument's reliability and validity. The model can be used by other researchers to build the theoretical relationship model and can help practitioners as a decision tool to develop strategies, and manage and measure the PSS SC capabilities required by taking into account the environmental sustainability notion. Future tests and refinement of the proposed model will be beneficial to the knowledge development of PSS SC capabilities. Given the state of a PSS SC capabilities changes over time, it would be interesting to take a longitudinal approach to examine how the SC capabilities changed and evolved during the process of delivering the PSS. This can be achieved by continuously exploring the relationship between PSS SC capabilities components and other antecedents.

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