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RESEARCH PAPER

The Product-Service Systems Supply Chain Agility Readiness: an Exploratory Analysis of a Development of Construct and Instrument

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ABSTRACT
Supply chain agility (SCA) has emerged as a significant focus for industries and businesses, serving as a cornerstone for gaining a competitive edge and playing a pivotal role in supply chain management. This importance is further underscored in the context of Product–Service Systems (PSS), which involve the development of both products and services. Despite the existing body of research on SCA and PSS, there has been a notable dearth of empirical studies examining the readiness of PSS SCA. This study makes a substantial contribution by developing a valid and reliable framework to assess the readiness of PSS for supply chain agility. The process involves defining domains, generating items, analyzing agreement among raters, testing for response bias, and conducting exploratory and confirmatory factor analyses. Using structural equation modeling, the model's validity and reliability were evaluated through an online survey with 405 participants from official motorcycle service partners. The findings identify six key capability constructs: collaboration, knowledge transfer, service partner development, information sharing, logistic integration and supply chain agility. This examination of PSS SCA readiness and its constructs provides a validated tool for industry practitioners to enhance their supply chain agility.

KEYWORDS: *Supply chain agility; Instrument development; Product–service systems; Logistics; Information sharing; Dynamic capabilities.*

1. Introduction

Supply chain agility has been seen as a prominent factor for long-term profitability and competitiveness to sustain global competition [1]. Research on SCA is even more demanded than ever, especially in the uncertain, unpredictable, and full of disrupting business environments such as now, right after the COVID-19 pandemic [2]. Agility is the firm's capability to adapt to fluctuating quickly, erratic, and unstable working environments [3]. Thus, being agile means having characteristics of innovativeness, flexibility, responsiveness, and delivery speed [4], [5]. Hence, agility benefits companies to stay ahead of competitors to survive and win in the changing situation.

PSS is an integrated marketable value bundle of products and services to satisfy customer expectations [6]. Implementing PSS is anticipated to simultaneously deliver a product and services [7]. The capabilities required to provide PSS should include product and service development [8]. Hence, long-term collaboration among stakeholders (manufacturers, intermediaries, and

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service partners) in the supply chain (SC) to deliver PSS is crucial because the required capabilities to provide PSS have been built within SC network to achieve the SC goals, not individual stakeholders' goals within SC.

In its competition with other companies, manufacturers focus on supply chain management to ensure that their products remain competitive and agile. Several previous studies have identified the capabilities needed, including collaborating with key suppliers, internal and external integration, logistics process integration, and information sharing [4, 9–12].

Creating and delivering a combination of products and services necessitates a supply chain that previously concentrated solely on products to pivot its attention towards both products and services [13]. Consequently, with the aid of other stakeholders in the supply chain, particularly service partners, it significantly aids in addressing the manufacturer's incapacity in downstream network capabilities, specifically services. Research conducted by Story et al [14] for 19 UK manufacturers indicates that essential capabilities are required, including PSS innovation, customer-centric design, cooperation with service partners, and assistance for service partners. Ultimately, all these crucial capabilities can only be adequately met by providing service partner development and transferring knowledge to them.

Several other studies have also confirmed the same findings, emphasizing the importance of knowledge transfer and service partner development, especially to achieve effective alignment between products and services [15–17]. Specifically, it is mentioned that service partner development can be accomplished by providing detailed training related to the products. Additionally, service partners can assist manufacturers in the implementation of services closely linked to understanding customer expectations and market characteristics.

There has been limited exploration of a model that combines the supply chain capabilities of manufacturers, and service partners to provide PSS. The supply chain of products focuses on product distribution and product supply chain management, while the supply chain of services is limited to the development of supply chain management focused on services, primarily on the downstream supply chain. This study explores the capabilities needed from both the product and service aspects, an area that has been relatively underexplored until now.

This research investigates PSS SCA readiness construct and instrument development, this has neither been initiated in the literature nor studies have conceptualized as a valid model to measure it. An extensive literature review has been done to examine both literature PSS and SCA to develop an instrument for PSS SCA readiness. The objective of this study relate to the following research question:

RQ1 How to create a tool for assessing the readiness of PSS SCA?

RQ2 Do the six capabilities, which encompass collaboration, knowledge transfer, service partner development, information sharing, logistic integration, and supply chain agility, form part of the instrument for assessing PSS SCA readiness?

Hence, this study aims to develop the construct and instrument for measuring the PSS SCA readiness through the six capabilities that the stakeholders in the SC build to deliver PSS. Six capabilities include collaboration, knowledge transfer, service partner development, information sharing, logistic integration, and SCA. This contributes to the intersection between PSS and Supply Chain Management (SCM) literature, which is now an under-research area. This research could help practitioners understand the factors that influence the company's agility as a network and how to improve agility in its SC, including This involves determining how to prioritize capabilities according to the standard loadings obtained from this study.

2. Literature Review and A Conceptual Background

It is prominent to consider broader aspects of the SC to deliver PSS, as providing a bundle of Products and services requires a collaboration of service partners, intermediaries, and manufacturers. The intermediaries, known as the main dealers, as a term in the motorcycle industry, have a role as a mediator between manufacturers as producers and service partners as service providers [18]. The motorcycle industry is used as a context in this study. Service partners are direct agents to provide customers with a Product and service bundle. However, service partners usually have limited resources to develop their capabilities [7]. On the other hand, the manufacturer, as the SC's powerful partner, required service partner expertise to deliver PSS. Hence, the manufacturers collaborate with intermediaries to support their service partners to develop their capabilities to deliver PSS.

From the PSS and SCM, this research combines both two concepts. PSS literature mostly looks from a service perspective [10, 11], while SCM is the management of Product and data flow, starting from raw material procurement, production and transportation to final destination, mostly looks from a product perspective [20]. In the case of PSS, the supply chain scope is the flow of Product, service, and data. This study examines the capabilities required for delivering PSS to improve SC agility readiness.

From the perspective of multi-actor collaboration in the SC network for delivering PSS, long-term collaboration among stakeholders in the SC is compulsory [21]. For example, if manufacturers cannot deliver service by themselves. Cooperation with service partners is necessary. Lensed by the dynamic capabilities (DC) [22], it fits this study's development construct and instrument. Cooperation with two or more companies enables them to quickly collaborate to modify the operational capabilities to face the rapid changes in the market [23]. Dalenogare *et al.* [17] supported that collaboration with service partners is a prominent part of delivering PSS. Further, Baah *et al.* [12] showed that SC collaboration positively impacts supply chain readiness.

To support service partners, manufacturers, as the more powerful parties, assist their service partners through intermediaries for knowledge transfer and service partner development because manufacturers, as producers, own the technical knowledge [13]. Ayala *et al.*[15] confirmed that knowledge transfer and service supplier development significantly improves PSS development. Likewise, Rana and Ha-Brookshire [24] and Ayala, Gerstlberger and Frank [19] found that knowledge transfer and supplier development were confirmed to be positively related to supply chain agility readiness.

PSS is a concept of providing a bundle of products and services; thus, from the product side, supply chain integration, both material and information, is essential and plays the primary role in improving SCA readiness. Kim and Chai [25] and Baah *et al.* [12] showed that information sharing affects SCA. Most studies highlight that information sharing reduces costs, increases operational performance, and enhances product quality [26]. Still, they ignore the close relationship between information sharing and the capability to prevent disruption related to SCA's readiness [12]. Dealing with information sharing significantly impacts how the SC prepares for handling the disruption [27].

The flow of information sharing is as important as the flow of material [28]. The existence of both flow, information, and material is better in pair than standing itself [26]. A high level of coordination and integration among SC stakeholders is usually characterized by increased logistics-related communication and information sharing [29]. Thus, logistics integration refers to the capability to integrate logistics activities to create overall value for customers throughout the value stream [30]. The important thing is that the right amount of goods at the right place and time should be available to customers immediately. Abdelilah, El Korchi and Amine Balambo [31] also addressed that logistics integration became one of the predominant factors in supply chain agility readiness.

SCA is defined as the SC capability to adapt quickly to fluctuating, erratic and unstable working environments. This capability is paramount to preparing for supply chain agility readiness. With the role of multi-actor collaboration in the SC, the capacity to adapt to erratic situations is better than working alone. SCA has several characteristics: flexibility, innovativeness, speed, and responsiveness [25], [32].

The crucial stage for enhancing a valid and reliable construct and instrument is determining a theoretical construct and items by arguing that PSS has offered a bundle of Products and services, the capabilities required for improving supply chain agility readiness that focuses on product and service development capabilities. Hence, the capabilities needed for PSS and SCA have shown the capabilities for network collaboration among service partners, intermediaries, and manufacturers.

3. Research Methods

This section describes the development of creating questionnaire items to form a survey for examining the construct and instrument development for PSS SCA. A valid and reliable instrument is a significant concern in quantitative research. The step of this research is in Figure 1.

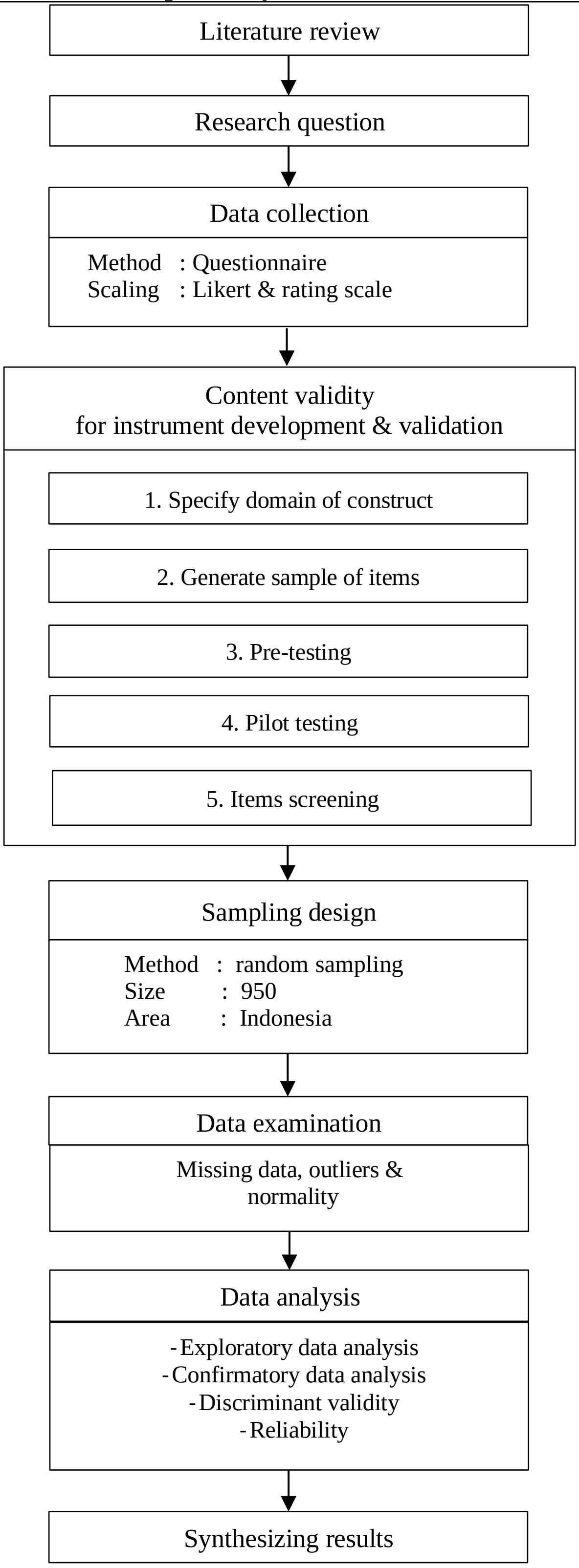

Fig. 1. The step of research

The instrument validation procedures in this research are adopted from Lewis, Templeton and Byrd [33], including five steps to ensure validity and reliability. The first step is the domain definition of each construct. The next step is generating a sample of items. Pretesting, pilot testing and interrater agreement are steps three to five. Then, after the five steps, data examination and preparation were conducted, including missing data, outliers and normality.

Assessment of validity and reliability assessment are crucial steps after the data has been examined and evaluated. Exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were employed as the validity tests. Initially, the EFA was utilized with SPSS version 26 to assess the scale's dimensionality, followed by running the CFA in AMOS version 26 to look at the convergent and discriminant validity. Further, to evaluate the reliability, coefficient H, construct reliability (CR), and Cronbach's alpha were used. In the end, a standard method bias was assessed by CFA.

4. Results

A domain specification is needed to convey each construct in terms of understandable meaning and definite (step 1). The existing literature review must be transparent to ensure the implementation of its operationalization is correct. All domain definitions were adjusted to the context of PSS and SCA for the motorcycle industry in Indonesia. All domain definitions are in Table 1. Based on a thorough review of the literature on capabilities and substantial discussion with four academics, an initial pool operationalization of 34 items was produced, step 2 (Table 1).

The pretesting was aimed at empirical feedback to evaluate the instrument (step 3). This research recruited six academic experts in the SC as pretest participants. The pretest participants were asked to fill and complete the instrument, then followed this up with criticism and suggestions about content, understandability, terminology, ease of understanding and time taken. Furthermore, the pretest participants were expected to contribute advanced suggestions, including content enhancements or specific items to be added or removed. As a result, several items' wording was changed to simplify the meaning for participants to understand the questionnaire better.

A pilot test is step four, aiming to purify the instrument. Fifteen experts from the industry were asked to complete the questionnaire. After completion, they were asked to discuss the difficulties related to the instrument for enhancing the wording of the questionnaire statement. All participants fully understood all statements in the questionnaire; hence, no wording adjustment was required to the instrument.

Content validity testing, such as interrater agreement analysis, is the final step in the instrument development. The participants for interrater agreement in this research were a group of experts who knew the concepts involved. Twenty people with PSS and SC expertise were asked to participate. They were asked to fill out the questionnaire. Then, the statistical output of their responses was evaluated, and the items with low agreement were dropped from the instrument. The five-point rating scale was utilized to examine the relevance of each item in the constructs (i.e., 4 = extremely relevant, 3= substantially relevant, 2=moderately relevant, 1= minimally relevant, 0 = not relevant).

Finally, step five is interrater agreement. There were three criteria proposed for deleting items based on: (1) drop items when their mean value is below the mean center, (2) drop items left from (1) when $p > 0.05$, and (3) drop items left from (2) if power < 0.8 [30, 31]. The results indicate a mean value of 3.05–3.70, all p-value < 0.05, and a power of 0.80–1. For the three criteria above, all items are within the criteria, so no items are carried away from the list, and 34 items are kept for the final questionnaire.

Data collection commenced from December 2022 to June 2023. The questionnaire was developed using a six-point Likert and rating scale. It is distributed as an online survey using Google Forms. A sampling frame was generated from about 8,450 official motorcycle service partners. A head of the branch has represented a respondent who participated in this survey. The respondent must have more than one year of experience as a head of the branch office. Nine hundred fifty invitations were delivered to the service partners' email addresses using a simple random sampling within the sampling frame. Two follow-up emails were delivered as a necessary reminder. As a result, 405 responses were collected to be further analyzed. The following are the critical demographics from the survey participants' profiles. The leading players of a particular brand of Indonesia's motorcycle industry have become the majority of participants in this research (72,6%). Likewise, as Indonesia's most populated island, most participants are from Java island (70.6%). Most service partner companies could be characterized as small enterprises with fewer than ten employees (89.6%) and have a long-term partnership (more than ten years) with their manufacturer (67.2%). The participants are almost exclusively males (95.8%) and most have at least a senior high school education (99.3%).

Levene's test for equality of variance and a t-test for equality of means analysis was conducted to investigate potential non-response bias by comparing early and late participants. Each returned questionnaire was recorded complete with the date received. The early participants in the first round were 232 participants, while the latter who responded in round 2 were 173 participants. The results of the χ^2 test were considered non-significant as p-values have more than 0.05 for six constructs in the model. This confirmed that there is no bias detected in this study.

EFA validates the dimensionality of the instrument, identifies opportunities for data reduction, and investigates the relationships between variables. Data is factorable if KMOMSA is between 0.5 and 1 [36]. The factorability assessment results tested using Kaiser's criterion confirmed that data is factorable with all constructs with KMOMSA above 0.843. Maximum likelihood extraction and rotation using Promax were used. One item C_7, was dropped due to insignificant factor loading. Six independent constructs made a one-factor solution that explicated 54.1 to 69.4% of a variance. Hence, the EFA process resulted in the deletion of one item of C_7.

This study used CFA to assess the convergent validity. First, Goodness of Fit (GOF) indices were examined for all the constructs. All constructs must meet recommended cut-off values to indicate good fit values: $\boldsymbol{p} > 0.01$, norm $\chi 2 \leq 2$, RMSEA< 0.05, SRMR< 0.07, CFI> 0.96 and TLI> 0.95 [33, 34]. A model best fits when it produces a suitable sample covariance matrix.

Tab. 1. Theoretical domain of constructs and items

Code	Domain of Construct and Items	References
Collaboration (C) is defined as a partnership activity of creating new resources where two or more parties jointly work together to achieve mutual benefit		
C_1	We sense and seize a long-term collaborative relationship with our main dealer partner based on mutual trust	[39]
C_2	We work jointly on the PSS planning with our main dealer partner	[39]
C_3	We collaborate with our main dealer partner to reconfigure PSS offering	[40]
C_4	We collaborate with our main dealer partner to identify and understand the customers' need	[7]
C_5	We have many different channel to communicate	[39]
C_6	We have agreement on the same SC agility readiness goals	[21]
C_7	We exchange knowledge and relevant information	[39]
Knowledge transfer (KT) is defined as the capability to transfer and access knowledge among stakeholders in the SC		
KT_1	Our main dealer partner transfer its knowledge of PSS to us	[15]
KT_2	Our main dealer partner share its knowledge about the benefit of being agile as our goal	[21]
KT_3	We receive knowledge about information technology that we use to deliver PSS	[18]
KT_4	Our main dealer partner continuously support us to share about our customers' expectations	[18]
KT_5	Our main dealer partner constantly transfer knowledge of innovations for a bundle of product and service	[15]
Service partner development (SPD) is defined capability to develop partner capacity by providing variety of training and reconfigure overall performance within SC		
SPD_1	Our main dealer partner has ceaselessly upgrade our knowledge	[18]
SPD_2	Several training courses has been prepared to us to increase our speed, flexibility, responsiveness and innovativeness	[18]
SPD_3	A service partner development programs has been provided by our main dealer partner	[19]
SPD_4	Our main dealer partner strengthen our capabilities to achieve supply chain agility	[19]
SPD_5	Variety training courses of product and technical service has been supplied to us	[41], [42]
Information sharing (IS) s defined as capability to sense and seize SC information for any stakeholders in the SC		
IS_1	We share delicate information to our service partner	[43]
IS_2	Our main dealer partner are transparent to share any information	[28]
IS_3	Information interchange is continuing and repeatedly	[25]
IS_4	Our main dealer partner continuously update us with recent information	[25]
IS_5	Our main dealer partner keep frequent meeting and communication	[25]

Logistics integration (LI) Is defined as the capability to integrate logistics activities to create overall values to customers		
LI_1	Our supply chain logistic activities are strictly collaborated	[44]
LI_2	Our main dealer partner logistics routines are effectively coordinated with ours	[44]
LI_3	We have a smooth coordination of logistics activities with our main dealer partner	[44]
LI_4	Our logistics coordination is specified by outstanding warehouse facilities and distribution	[44]
LI_5	The incoming and outgoing coordination of product distribution is completely harmonize	[44]
Supply chain agility (SCA) as the SC capability to quickly adopt to fluctuating, erratic and unstable working environment		
SCA_1	We always quickly improve our PSS level of customer satisfaction	[25]
SCA_2	We always quickly improve our PSS delivery reliability	[25]
SCA_3	We always quickly reconfigure PSS SC capabilities to adopt with changing market needs	[25]
SCA_4	We always quickly reconfigure SC resource capacity to respond to uncertain demand	[45]
SCA_5	We always quickly adapt PSS SC operation to decrease service lead time	[21]
SCA_6	We always quickly reconfigure our capabilities to customize customer order	[11]
SCA_7	We always quickly innovate our PSS offerings	new

Conversely, the model requires re-specification if errors are found. The standardized residual covariance and modification indices (MI) are examined to re-specify the model. A considerable value of residual covariance was advisable because the hypothesized model did not establish a particular covariance well. This can be carried on by dropping one of the related items and re-running the measurement model [36]. The MI indicates that the model structure may need to be changed. A MI value greater than 4 is a potential source of model re-specification [46]. However, as a caution, the items deleted from the constructs should have low validity, which can be checked from the result of the interrater agreement so that the deletion of the items has not obstructed the meaning of the construct. The model re-specification process resulted in the deletion of 4 items: C6, SPD1, IS5 and LI5. Finally, the convergent validity result is displayed in Table 2.

Tab. 2. Convergent validity test result

Components	Items	Factor loading	p	χ^2	RMSEA	SRMR	CFI	TLI	CR	Cronbach's alpha	H
C	C_1	0.823	0.04	2.00	0.05	0.034	0.993	0.991	0.900	0.899	0.903
	C_2	0.817									
	C_3	0.752									
	C_4	0.796									
	C_5	0.825									
KT	KT_1	0.856	0.191	1.485	0.035	0.014	0.998	0.997	0.922	0.922	0.923
	KT_2	0.842									
	KT_3	0.844									
	KT_4	0.807									
	KT_5	0.840									
SPD	SPD_2	0.872	0.179	1.635	0.040	0.009	0.998	0.996	0.901	0.901	0.905
	SPD_3	0.843									
	SPD_4	0.808									
	SPD_5	0.814									
IS	IS_1	0.797	0.394	1.037	0.010	0.001	1.00	1.00	0.873	0.871	0.878
	IS_2	0.733									
	IS_3	0.843									

	IS_4	0.804									
LI	LI_1	0.739	0.147	1.698	0.042	0.021	0.996	0.995	0.872	0.867	0.881
	LI_2	0.725									
	LI_3	0.853									
	LI_4	0.842									
SCA	SCA_1	0.810	0.012	1.898	0.045	0.027	0.987	0.992	0.928	0.928	0.935
	SCA_2	0.842									
	SCA_3	0.824									
	SCA_4	0.833									
	SCA_5	0.873									
	SCA_6	0.657									
	SCA_7	0.788									

To guarantee that the construct has the most substantial relationships with its items and not with any other construct in the structural model [47], discriminant validity among six constructs was attained, with AVE value of each construct bigger than the square correlation values (Table 3). Coefficient H, construct reliability (CR) and Cronbach's alpha were used for reliability measurement. The results for coefficient H in this study ranged from 0.878 to 0.935, CR values from 0.872 to 0.928, and Cronbach's alpha results from 0.867 to 0.928 confirmed a satisfactory outcome for reliability (Table 2).

Tab. 3. AVE and square inter-construct correlation

Construct	IS	C	KT	SPD	LI	SCA
IS	0.795					
C	0.392	0.802				
KT	0.385	0.759	0.838			
SPD	0.373	0.705	0.777	0.834		
LI	0.634	0.474	0.454	0.513	0.794	
SCA	0.508	0.315	0.336	0.433	0.680	0.806

The six constructs corroborated standard factor loading of 0.657–0.873, p-value 0.02–0.39, RMSEA 0.01–0.045, SRMR 0.02–0.055, CFI 0.987–1.0, and TLI 0.991–1.0. After fulfilling the requirements of dimensionality, convergent, and discriminant validity, this study investigates factorial validity, which examines whether a set of latent variables demonstrates an underlying pattern. The results of the full CFA model affirmed a good fit of the measurement model with normed $\chi 2$ = 1.505, SRMR = 0.019, RMSEA = 0.035, CFI = 0.978, and TLI = 0.975.

5. Discussions

The PSS, SCM, and dynamic capabilities theories have been developed to conceptualize the model for this study to measure PSS SC agility readiness. Further, the development of constructs and items, along with definitions, assist the application of PSS, as a SC network collaboration among manufacturers, intermediaries (main dealers), and service partners to improve the SC agility readiness. This study has developed a ready instrument for Product-Service Systems Supply Chain Agility readiness with six constructs: collaboration, knowledge transfer, service partner development, information sharing, logistics integration, and supply chain agility, comprising 29 items. Such a structure evaluates PSS agile readiness at different levels among SC stakeholders.

- The collaboration consists of items that describe the partnership relationship of creating new capabilities for all stakeholders in the SC: manufacturers, main dealers, and service partners. These items relate directly to the manufacturer's inability to deliver PSS by itself. Then, the manufacturer requires close partners to work hand in hand to provide customers with a Product and service bundle. The collaboration requires long-term partnerships to plan, join, and have many different channels to communicate closely.
- Knowledge transfer reflects the company's capability to transfer and give access to knowledge to SC stakeholders, including knowledge of delivering a bundle of products and services, innovation, customers' expectations, and the capability of being agile.

- Service partner development embraces the capability of all stakeholders in the SC to have the same capabilities to improve SC agility readiness. The most influential stakeholder in the SC is manufacturers; they usually support the leading dealers and the primary dealers, as intermediaries, support the service partners. The manufacturers have continuously provided training courses on technical Products and services to increase speed, flexibility, responsiveness, and innovativeness.
- Information sharing can sense and seize information from any stakeholder in the SC. These capabilities have strongly affected the SC agility readiness, including sharing delicate information, transparent sharing, information interchange, and continuously updating recent information to service partners.
- Logistic integration is crucial to the SC agility readiness to coordinate all logistic activities in the SC effectively. This construct relates directly to the collaboration of supply chain activities, logistics routines coordination with main dealer partners, smooth logistics activities, and excellent warehouse facilities and distribution.
- Supply chain agility embraces the capability to quickly adapt to speed delivery, innovation, flexibility, and responsiveness. These items highly relate to the SC agility readiness.

6. Conclusions

This study has revealed the capabilities required for PSS SC agility readiness. It proposes 29 PSS SCA measurements with six capabilities: collaboration, knowledge transfer, service partner development, information sharing, logistics integration, and supply chain agility. The model is developed based on the capabilities shared among SC networks, including service partners, intermediaries, and manufacturers, to improve supply chain agility readiness. Further, this study contributes to the theory by improving knowledge about the power of capabilities built in the SC network collaboration among stakeholders. Likewise, this study clearly defines each capability construct that contributes to improving supply chain agility readiness. Finally, this study contributes a ready instrument whose item parameters are adequately validated based on DC theory. As a result, the practitioner can utilize the instrument for planning and decision-making, managing and measuring the current capabilities to move forward with improved capabilities. Further, the standard loadings of items related to supply chain capabilities to gauge the importance of each capability in enhancing SCA can also be used by the practitioners to determine the priority based on the resources.

Given the knowledge-intensive nature of the motorcycle industry, it's crucial to establish long-time collaboration and transfer of knowledge and service partner development that reflects the capability of the SC to cooperate in delivering PSS. Likewise, information sharing, logistic integration and supply chain agility are the other three capabilities to shape the PSS SCA readiness. Despite contributions having been explained, the instrument measurement in this study has been dedicated to the motorcycle industry in Indonesia. Thus, broader industries and geographical areas may have resulted in different outcomes. Also, the dynamic changing of an environment may affect capabilities over time, which should be looked at in future research using the study's longitudinal approach. To the best of our knowledge, research examining capabilities in the SC network is developing, so only a few studies have focused on developing PSS SC agility readiness capability. Thus, this study provides rigorous theory and validated PSS SC agility readiness instruments.

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