A reconceptualization of manufacturers' sustainable product-service business models: Triple bottom line perspective

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Abstract

As indicated by the World Business Council for Sustainable Development, the triple bottom line, which consists of the three dimensions of profit making, environmental protection, and social care, should be the goal of an enterprise's sustainable operation. PSS and past literature related to sustainability have mostly discussed related theory or conducted empirical research. Many recent studies have integrated the two aspects to describe sustainable business models, but they have mostly been based on case studies. Therefore, this research integrated qualitative and quantitative viewpoints to construct sustainable product-service business models and it was carried out in three phases. Phase1referred to conceptualization, in which past literature and focus group interviews were combined to construct the preliminary items and the questionnaire. Phase2 referred to measurement, in which the reliability and validity of the various questionnaire dimensions were verified. Phase3referred to verification, which was aimed at the integrative framework of sustainable product-service business models. AHP was used to analyze the relative importance and managerial implications of each dimension. The research results showed that sustainable product-service business models have four measurement dimensions: product-service sustainable development, scientific and technological sustainable development, social sustainable development, and organizational sustainable development. In the main dimensions of sustainable product-service business models, the dimension of scientific and technological sustainable development is more crucial than the dimensions of product-service sustainable development, social sustainable development and organizational sustainable development. In the minor dimensions, creating value from waste, new service delivery, delivering functionality rather than ownership, and developing scale up solutions are more crucial.

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1. Introduction

In recent years, due to changes in the international economic environment, especially the rise of developing countries, the original advantages of Taiwan's manufacturing industry have gradually disappeared. The current manufacturing industry is now following the path of importing servitization and taking service as an added value[1], so as to improve client loyalty and income through such services[2]. As the global science and technology and environment change, the industrial boundary has become increasingly ambiguous and the trend of industry convergence has become obvious. In addition, new applications arising from the breakthrough of digital technology,

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global competition caused by internet popularization, and the reduction of product life cycles have all promoted the trend of outsourcing and have had a wide impact on the development of the service industry related to manufacturing. In terms of the industrial structure, the current service industry accounts for more than 70% of Taiwan's GDP. Owing to the outward transfer of the manufacturing industry and its positive global layout, Taiwan's industries should be focusing on the development of the service industry. Servitization of the manufacturing industry could not only improve the added value of the manufacturing industry but also widen the gap with competitors by combining manufacturing and service. In order to prepare for the new era focusing on service, [3] argued that it is necessary to establish a conceptual basis in line with service science, and that emphasis must be transferred from the traditional goods-dominant logic to a service-dominant logic. [4]proposed the synthesis approach viewpoint for research innovation. Different from past researches where the technological innovation of the manufacturing industry and the innovation of the service industry were discussed separately, these scholars integrated their research findings on the innovation of the manufacturing industry with the innovation of the traditional manufacturing industry. As the interaction between the manufacturing industry and service industry are becoming increasingly frequent, researches related to the synthesis approach could supplement each other. The machine tool industry plays an important role in the world market, but is rather small among Taiwan's industries, and the main products are tools used for the machining of metals. Nevertheless, faced with the recent low-price competition of enterprises in Mainland China, global competition has presented the trend of moving from mass production to small customized production. Under the demand for reducing volume production and improving production elasticity, the production equipment suppliers that produce these machine tools are facing the reality that it is difficult to sell standardized products. Although low cost and highly customized production are the features of Taiwan's machine tools, the production of customized products with varying functions using a standard interface and a standardized product platform cannot meet the customer's needs. In the face of interactive costs becoming gradually higher than profits due to highly customized production, product manufacturers need to engage in operational activities based on understanding the difference of customer value and the measurement of value creation to increase the added value for customers and help customers solve their problems. Based on the above-mentioned discussion, the development of manufacturing servitization and product service systems in the business model of the machine tool industry in Taiwan is becoming increasingly worthy of exploration, and it was also the first research motivation of this research.

Enterprises are established depending on the environment and also have a great impact on the environment. Therefore, an enterprise's misgivings about the environment cannot merely stay in the level of to do no harm but the level of beyond greening, so as to pursue a sustainable global economy. Under such premise, a sustainable enterprise must be able to provide economic, social, and environmental benefits simultaneously to contribute to the world's sustainable development. Corporate social responsibility (CSR) has become a key factor for enterprises to create benefits and achieve sustainable operation, and it is regarded as a universal value. According to the WBCSD, the triple bottom line (TBL) of the three dimensions of profit making (profit), environmental protection (planet), and social care (people) should be the goal of an enterprise's sustainable operation [5]. With the continuous growth of the global population, the acceleration of global development, and the gradual increase of resource utilization and environmental effects, it has become obvious that the future is completely different from the past and that sustainable selection and utilization are required. It is necessary to realize that the ecological system and natural resources required by human beings have been exhausted. However, the free natural asset

value has not been cognized in enterprise operation systems. Enterprises must adopt an overall method to cope with the challenges they will continuously face in the future, and their responses to environmental changes need to go along with economic and social changes. In terms of these changes, an enterprise's fundamental transformation is required according to its operation mission, strategy, and implementation aspects. The sustainable business model has provided some methods to reconceptualize corporate goals and value creation to further provide the required changes and reflect on value concepts. By means of redesigning the business model, mainstream enterprises can easily integrate sustainable development into their operational systems. As proposed by [6] and [7], business model innovation can systematically support and continuously create sustainable development [8]. The sustainable business model is gradually becoming seen as the key to providing social and environmental sustainability in enterprise systems[9]. Based on the exploration above, it was necessary to understand how to design a business model for the machine tool industry, which is faced with the pressure from the TBL of profit making, environmental protection, and social care, which was the second research motivation of this study.

[10]presented a study on the sustainability factors of PSS business models. Past researches had discussed the correlation between PSS business models and sustainability and they naively thought that the PSS business model is favorable to the TBL of profit, planet, and people, but in practice, it may be favorable only to economic benefits and may damage the environment. Previous research on manufacturing servitization and PSS mostly stated that the strategy application of manufacturing servitization is positively related to enterprise performance.[11]pointed out that most product manufacturers have increased the services provided and the costs from product manufacturing to the service industry, but that a relatively higher return of profits cannot be gained. The reason is that importation service industry will greatly increase operating costs and management complexity, thereby causing earnings growth to be lower than expected. This is known as the service paradox. Some research results also showed that the strategy application of manufacturing servitization is negatively related to enterprise performance, thus proving the existence of the service paradox. Such research mostly focused on the correlation between PSS and financial performance and did not highlight the correlation between PSS business models and sustainability. Thus, reinforcement was obviously necessary.[12]proposed the construction of a sustainable business model by means of service design and integrated research topics on servitization and sustainability. In recent several years, some scholars have successively begun to research sustainable product-service business models[13]–[15], but most of them focused on case studies and lacked empirical research and model construction, which was the third research motivation of this research.

Whereas business models, business model innovation, and SBM all lack conceptual clarity and consistency [16]–[18], there are few empirical researches into sustainable business models[6], [8], [19] and the researches integrating sustainable business models and PSS are insufficient.[20]adopted a literature review to develop sustainable business model archetypes which had an extremely high reference value. On the basis of this model and theory, this research combined the theories of manufacturing servitization and PSS to conceptualize, measure, and verify a sustainable product-service model for machine tool industry, which was the fourth research motivation of this research.

According to the above-mentioned research motivations and the viewpoint of [21],product servitization consists of the product, service, and infrastructure, as well as a system jointly developed by the movers that has interactive relations, is competitive, meets the customer's needs, and has less environmental impact than traditional business models. Previous literature on PSS

and sustainability mostly described theories or conducted empirical research. In recent years, a number of scholars have integrated the two aspects to describe sustainable business models, but they have mostly conducted case studies. Based on the above research gap, this research integrated qualitative and quantitative viewpoints to construct a sustainable product-service business model. The research was carried out in three phases. Phase 1 referred to conceptualization, in which past literature and focus group interviews were combined to construct the preliminary items and the questionnaire. Phase 2 referred to measurement, in which the reliability and validity of the various questionnaire dimensions were verified. Phase 3 referred to verification, which was aimed at the integrative framework of sustainable product-service business models. AHP was used to analyze the relative importance and managerial implication of each dimension.

2. Construction of sustainable product-service business models

2.1 Phase 1: Conceptualization of sustainable product-service business models

1. Literature review and focus group interviews

During the process of constructing the models, a literature review and focus group interviews were implemented to formulate the first draft of the scale, and then experts and scholars were invited to assess the content validity. After the assessment of the dimensions and item fitness, the formal scale was completed and the samples were drawn for testing. In the test, the valid samples were selected and exploratory factor analysis was used for construct validity, in which items with a lower explanation rate were deleted and common factors were drawn to name the dimensions and adjust the items. Lastly, the constructed scale was tested for reliability and validity. The core literature of this research was based on the following literature and opinions. [20]adopted a literature review to develop sustainable business model archetypes that included the technological, social, and organizational dimensions, with a total of 53 items. [22]divided servitization of the manufacturing industry into three main forms: (1)product oriented; (2) use oriented; and (3)result oriented forms. According to the three main forms listed above,[23] promoted 12 servitization levels: (1) design and development service; (2) system and solution; (3) retail and distribution service; (4) maintenance and support service; (5) installation and implementation service; (6) financial service; (7) service industry and real estate; (8) consultation service; (9) outsourcing and operational service; (10)procurement service; (11) leasing service; and (12) transportation and freight transport service. However, if sustainability is considered, PSS may produce related benefits to manufacturers and consumers. First, the product's added value can be improved through repairs or upgrading. The costs will be increased slightly, but the after-sale profit can be gained and it can help consumers allocate their consumption combination elastically. Second, the interactive and reciprocal relationships with consumers can be continuously maintained to further gain demand information so that consumers can adopt diverse produce choices and payment methods. Third, enterprises can participate in the entire product life cycle, which can directly save the costs caused by the improper use of products and reduce risks during purchase and use.

By integrating the above-mentioned literature basis, this research collected and summarized a large amount of related literature and then used the conclusion of a focus group interview (eight experts, including four experts from academic circles and four practical experts from the machine tool industry) to construct and formulate the evaluation dimensions and items in this research. This research preliminarily drew up the four measurement dimensions (product-service sustainable development, scientific and technological sustainable development, social sustainable development, and organizational sustainable development) and 65 items of sustainable product-

service business models, namely 12 items for product-service sustainable development, 21 items for scientific and technological sustainable development, 19 items for social sustainable development, and 13 items for organizational sustainable development.

2. Assessment of content validity

In terms of the first draft of the scale dimensions and items completed in the aforesaid statement, six experts and scholars were invited to carry out an assessment of the content validity and relevance. They were requested to assess the relevance of all the evaluated dimensions and the dimensions to which each item belonged. In case of irrelevance, adjustments on wording and the addition or deletion of items were suggested to establish the content validity of the scale. After the expert's assessment of the first draft of the scale and the integration of the suggested revisions, the formal questionnaire was finally completed. The original items were significantly revised in wording without losing the original meaning of the measurement indicators, making it easy for Taiwanese employees to fill in the questionnaires and providing good content validity. The formal scale included four evaluation dimensions with a total of 45 items.

2.2 Phase 2: Measurement and verification of reliability and validity of each questionnaire dimension

1. Research Samples

The research subjects of this study were from the Taiwanese machine tool and component industry and the formal distribution subjects were eight representative machine tool and component enterprises in Taiwan (respectively including Tongtai Machine & Tool, Victor Taichung Machinery Works, Yeong Chin Machinery Industries, Fair Friend, Quaser Machine tools, Hiwin Technologies, Keyarrow (Taiwan), and Winson Machinery). A total of 50 questionnaires were distributed in each company, with 400 questionnaires distributed in all. In the end, 268 valid questionnaires were retrieved and the effective recovery rate was 67%. The respondents were middle and senior managers of the companies.

2. KMO and Bartlett test

This research adopted exploratory factor analysis. In order to confirm whether the data were suitable for the factor analysis, it was necessary to firstly calculate the Kaiser-Meyer-Olkin measure of sampling adequacy before the factor analysis. Based on the viewpoint of [24], if the KMO measure of sampling adequacy is greater than 0.6 and the P-value of the Bartlett Test of sphericity is close to 0, factor analysis can be conducted. In addition to the judgment of the adequacy of the original data of the KMO value, the Bartlett test of sphericity was used to analyze whether the number of factors was suitable. If the p value statistics were smaller than the significant level, it would indicate the factor analysis model selected was suitable. According to the data shown in Table 1, the Kaiser-Meyer-Olkin measure of sampling Adequacy of each dimension was greater than 0.6 and the P-value of the Bartlett test of sphericity was 0, thus indicating significance. It could therefore be known that the research variables and dimensions of this study were suitable for factor analysis.

Table1 KMO and Bartlett Test

Dimension	Kaiser-Meyer-Olkin measure of sampling adequacy	Bartltett's sphericity test significance
Product-service sustainable development	0.913	0.000***
Scientific and technological sustainable development	0.930	0.000***
Social sustainable development	0.856	0.000***
Organizational sustainable development	0.868	0.000***

***$p < 0.001$

3. Screening of scale items

As for the valid samples in this research, exploratory factor analysis was applied to screen the items and principal component analysis was used to delete the items with lower explanation power. After the factor analysis of the original materials, the community was retained, namely, the items with a validity greater than 0.6 and a factor loading greater than 0.5. Factor analysis was then conducted on the retained items to screen according to the above-mentioned conditions. The screening was repeated until the retained items showed that the community was greater than 0.6 and the factor loading was greater than 0.5. Later, principal components analysis was used to extract the common factors and choose common factors with an eigenvalue greater than 1.0. Orthogonal rotation was carried out against the common factors with the use of the varimax solution to make the factor loadings of the item variables in each common factor after the rotation differ by more than 0.3, so as to gain the component elements of the factor. By reference to the connotation and loading of the component elements of the factor, the common factors were renamed to facilitate their identification and naming.

The analysis results are shown in Table 2~5. After the questionnaire on sustainable product-service business models determined the evaluated dimensions and items through exploratory factor analysis, a total of four dimensions and 45 items were gained. Four factors were screened in the exploratory factor analysis of product-service sustainable development: industrial value chain innovation, new service delivery, service transformation, and customized service; three factors were screened in the exploratory factor analysis of scientific and technological sustainable development: maximizing material and energy efficiency, creating value from waste, and substituting with renewables and natural processes; three factors were screened in the exploratory factor analysis of social sustainable development: delivering functionality rather than ownership, adopting a stewardship role, and encouraging sufficiency; and two factors were screened in the exploratory factor analysis of organizational sustainable development: repurposing for social environment, and developing scale up solutions.

4. Reliability test

This research analyzed the internal consistency of the recovered questionnaires after the test of the formal scale, and the internal consistency coefficient was used to calculate the Cronbach's α coefficient and the item-to-total correlation coefficient to analyze the internal consistency of each dimension to confirm the consistency of the internal structure of the scale and the isomorphism type. The Cronbach's α coefficients of each evaluation dimension in this scale are listed in Table 2~5. It could be seen from the table that the Cronbach's α coefficient of the sub-dimensions belonging to the four evaluation dimensions in this scale exceeded the 0.7suggested by [25]. In addition, the item-to-total correlation coefficient lay between them and most coefficients were greater than 0.7. Thus, the internal consistency of the scale was high, indicating that the evaluation dimensions of the scale had high internal consistency.

Table 2 Exploratory factor analysis of product-service sustainable development

Dimension (Cronbach' s α)	**Item**	**Factor loading**	**Eigenvalue**	**Cumulative Variance Explained**	**Item-Total Correlation**
Industrial value chain innovation service (0.83)	Remote monitoring service	0.877	2.071	18.46	0.735
	Whole plant planning service	0.924			0.773
	Combined upstream and downstream service	0.670			0.850
New service delivery (0.88)	Service upgrading service	0.742	1.663	36.4	0.857
	Innovative processing service	0.706			0.878
	Service to reduce shut-down maintenance time	0.815			0.858
Service transformation (0.92)	Service to maintain accurate delivery dates	0.759	1.219	52.5	0.862
	Service to improve CP and CV values	0.802			0.88
Customized service (0.84)	Service to provide processing and proofing service	0.754	1.284	69.5	0.721
	Service with small amount and diversity	0.846			0.821

Table 3 Exploratory factor analysis of scientific and technological sustainable development

Dimension (Cronbach' s α)	Item	Factor loading	Eigenvalue	Cumulative Variance Explained	Item-Total Correlation
Maximise material and energy efficiency (0.882)	Cradle 2 Cradle	0.906	3.928	68.88	0.82
	Increased functionality (to reduce total number of packaging)	0.758			0.74
	Lean manufacturing	0.850			0.66
	Additive manufacturing	0.653			0.52
Create value from waste (0.864)	Low carbon manufacturing/Solution	0.807	3.064	67.67	0.86
	Extended producer responsibility	0.856			0.78
	Industrial symbiosis	0.850			0.76
	Circular economy, close loop	0.728			0.72
	Reuse, recycle, re-manufacture	0.686			0.71
	Take back management	0.771			0.68
Substitute with renewables and natural processes (0.924)	Green Chemistry	0.864	2.498	89.72	0.92
	Zero emissions initiative	0.859			0.92
	The Natural Step (Blue economy, Bio-mimicry)	0.958			0.88
	Move from non-renewable energy sources	0.918			0.86

Table 4 Exploratory factor analysis of social sustainable development

Dimension (Cronbach' s α)	Item	Factor loading	Eigenvalue	Cumulative Variance Explained	Item-Total Correlation
Deliver functionality rather than ownership (0.92)	Product-oriented PSS-maintenance extended warrantee	0.911	2.486	82.64	0.842
	Use oriented PSS-Rental, lease, shared	0.925			0.863
	Result-oriented PSS-Pay per use	0.895			0.782
Adopt a stewardship role (0.88)	Biodiversity protection	0.809	3.823	76.84	0.642
	Ethical trade(fair trade)	0.895			0.868
	Choice editing by retailers	0.899			0.782
	Radical transparency about Environmental / societal impacts	0.898			0.863
	Resource stewardship	0.868			0.784
Encourage sufficiency (0.94)	Consumer Education(Models); Communication and awareness	0.952	2.609	88.72	0.782
	Demand management (including cap & trade)	0.946			0.883
	Responsible product distribution / promotion	0.899			0.892

Table5 Exploratory factor analysis of organizational sustainable development

Dimension (Cronbach' s α)	Item	Factor loading	Eigenvalue	Cumulative Variance Explained	Item-Total Correlation
Repurose for society environment (0.864)	Hybrid businesses, Social enterprise (for profit)	0.880	5.131	68.92	0.682
	Alternative ownership: cooperative, mutual, (farmers)collectives	0.855			0.642
	Social and biodiversity regeneration initiatives ('net positive')	0.987			0.843
	Base of pyramid solutions	0.858			0.824
Develop scale up solutions (0.893	Localization	0.831	2.078	68.74	0.726
	Home based, flexible working	0.751			0.636
	Incubators and Entrepreneur support models	0.813			0.642
	Licensing Franchising	0.963			0.662
	Open innovation (Platforms)	0.856			0.564
	Crowd sourcing / Funding	0.647			0.692

5. Validity test

The validity test was done according to the content validity and construct validity, which are described separately below:

(1) Content validity

In terms of the questionnaire developed by this research, the dimensions and items in the preliminary questionnaire were drawn up according to a large amount of literature through the focus group interviews and expert opinion consultation. The items were then assessed and revised by experts in the field to form the formal questionnaire. After the formal questionnaires were completed, exploratory factor analysis was carried out in the samples distributed to relevant enterprises to screen the items with higher explanation power. The development process was strict, and the scale had good content validity.

(2) Construct validity

The construct validity was classified into convergent validity and discriminate validity. The convergent validity measured the related variables by using different measurement methods and its correlation degree was higher, while the discriminate validity measured the two different concepts. No matter whether the measurers used the same or different methods, correlation analysis was conducted against the measurement results and the correlation degree was lower. Therefore, in order to further verify this part, this research usedAMOS17.0 software to verify the structural equation modeling.

a. Convergent validity

Based on the suggestions and arguments of [26], this research used three types of indexes as the assessment of the hypothesis model. This research intended to conduct confirmatory factor analysis against the four dimensions. For the absolute fit measures, AGFI and GFI needed to be greater than 0.8 and RMSEA needed to be smaller than 0.08; for the relative fit index, NFI and CFI needed to be greater than 0.90; and for the parsimonious fit measures, PNFI needed to be greater than 0.50 and the normed chi-square needed to be smaller than 3. Aimed at product-service sustainable development, scientific and technological sustainable development, social sustainable development, and organizational sustainable development, this research conducted convergent validity analysis and the results showed that the measurement of the first-order four-factor model was better than the first-order one-factor analysis, indicating that this research had reasonable convergent validity, as detailed in Tables 6~9 below.

Table 6 Assessment of fitness of product-service sustainable development

First-order confirmatory factor model of product-service sustainability	**χ^2**	**Df**	**χ^2/df**	**GFI**	**CFI**	**NFI**	**PNFI**	**AGFI**	**RMSEA**
First-order 1-factor analysis	25.875	9	2.875	0.856	0.77	0.657	0.492	0.788	0.108
First-order 4-factor model (there is the correlation between the factors)	15.558	6	2.593	0.919	0.86	0.88	0.582	0.898	0.103
Suggested value	The smaller, the better	The bigger, the better	<5	>0.8	>0.9	>0.9	>0.5	>0.8	<0.08
Verification result	-	-	Good	Good	It is OK to be close to 0.9	It is OK to be close to 0.9	Good	Good	It is OK to be close to 0.08

Table 7 Assessment of fitness of scientific and technological sustainable development

First-order confirmatory factor model of Scientific and technological sustainable development	**χ^2**	**Df**	**χ^2/df**	**GFI**	**CFI**	**NFI**	**PNFI**	**AGFI**	**RMSEA**
First-order 1-factor analysis	38.298	13	2.946	0.985	0.932	0.797	0.579	0.889	0.105
First-order 3-factor model (there is the correlation between the factors)	31.031	11	2.821	0.989	0.955	0.887	0.682	0.898	0.064
Suggested value	The smaller, the better	The bigger, the better	<5	>0.8	>0.9	>0.9	>0.5	>0.8	<0.08
Verification result	-	-	Good	Good	It is OK to be close to 0.9	It is OK to be close to 0.9	Good	Good	Good

Table 8 Assessment of fitness of social sustainable development

First-order confirmatory factor model of Social sustainable development	χ^2	Df	χ^2/df	GFI	CFI	NFI	PNFI	AGFI	RMSEA
First-order 1-factor analysis	25.36	10	2.536	0.895	0.842	0.787	0.579	0.859	0.104
First-order 3-factor model (there is the correlation between the factors)	14.008	8	1.751	0.959	0.955	0.857	0.622	0.898	0.076
Suggested value	The smaller, the better	The bigger, the better	<5	>0.8	>0.9	>0.9	>0.5	>0.8	<0.08
Verification result	-	-	Good	Good	Good	It is OK to be close to 0.9	Good	Good	Good

Table 9 Assessment of fitness of organizational sustainable development

First-order confirmatory factor model of Organizational sustainable development	χ^2	Df	χ^2/df	GFI	CFI	NFI	PNFI	AGFI	RMSEA
First-order 1-factor analysis	27.837	9	3.093	0.878	0.86	0.795	0.579	0.79	0.114
First-order 2-factor model (there is the correlation between the factors)	15.472	8	1.934	0.944	0.971	0.861	0.659	0.889	0.085
Suggested value	The smaller, the better	The bigger, the better	<5	>0.8	>0.9	>0.9	>0.5	>0.8	<0.08
Verification result	-	-	Good	Good	Good	It is OK to be close to 0.9	Good	Good	It is OK to be close to 0.08

b. Discriminate validity

Discriminate validity analysis is used to verify the correlation between different constructs. This research adopted discriminate validity using the AVE evaluation model and compared different dimension measurements. The AVE value (diagonal value) of all potential dimensions needed to be greater than the square (non-diagonal value) of the correlation coefficient between other potential dimensions. Tables 10~13display this principle and show that each dimension had discriminate validity [27].

Table10 Discriminate validity of product-service sustainable development

Potential Dimensions	Industrial value chain innovation service	New service delivery	Service transformation	Customized service
Industrial value chain innovation service	**0.57**			
New service delivery	0.45	**0.55**		
Service transformation	0.38	0.35	**0.49**	
Customized service	0.46	0.46	0.39	**0.51**

Table11 Discriminate validity of scientific and technological sustainable development

Potential Dimensions	Maximise material and energy efficiency	Create value from waste	Substitute with renewables and natural processes
Maximise material and energy efficiency	**0.53**		
Create value from waste	0.46	**0.59**	
Substitute with renewables and natural processes	0.43	0.5	**0.53**

Table12 Discriminate validity of social sustainable development

Potential Dimensions	Deliver functionality rather than ownership	Adopt a stewardship role	Encourage sufficiency
Deliver functionality rather than ownership	**0.5**		
Adopt a stewardship role	0.46	**0.59**	
Encourage sufficiency	0.43	0.4	**0.53**

Table13Discriminate validity of organizational sustainable development

Potential Dimensions	Repurose for society environment	Develop scale up solutions
Repurose for society environment	**0.64**	
Develop scale up solutions	0.53	**0.63**

2.3 Phase 3: Verification of the integrative framework of sustainable product-service business models and analysis of the relevant importance of each dimension.

Based on the questionnaire in phase 2, the integrative framework of sustainable product-service business models for Taiwan's machine tool industry was developed. The main dimensions of the analysis framework were product-service sustainable development, scientific and technological sustainable development, social sustainable development, and organizational sustainable development. The minor dimensions were industrial value innovation service, new service delivery, service transformation, customized service, maximizing material and energy efficiency, creating value from waste, substituting with renewables and natural processes, delivering functionality rather than ownership, adopting a stewardship role, encouraging sufficiency, repurposing for social environment, and developing scale up solutions. Empirical research was conducted according to the viewpoints of senior managers in the machine tool industry. A total of 24 AHP questionnaires were distributed and the research results are shown in Figure 1. In order to verify whether the opinion of the AHP method adopted by this research was in line with the hypothesis, the consistency ratio (C.R.) was used for the test; if $C.R. \leq 0.1$, it would indicate that the consistency had achieved an acceptable level. The C.R. value in this research was 0.01, indicating that the consistency had achieved and acceptable level. The following five propositions were put forward:

Proposition 1: In the main dimensions of the sustainable product-service business model, compared with the dimensions of product-service sustainable development, social sustainable development, and organizational sustainable development, the dimension of scientific and technological sustainable development was more crucial.

Proposition 2: In the dimension of scientific and technological sustainable development of the sustainable product-service business model, the minor dimension of creating value from waste was more crucial.

Proposition 3: In the dimension of product-service sustainable development of the sustainable product-service business model, the minor dimension of new service delivery was more crucial.

Proposition 4: In the dimension of social sustainable development of the sustainable product-service business model, the minor dimension of delivering functionality rather than ownership was more crucial.

Proposition 5: In the dimension of organizational sustainable development of the sustainable product-service business model, the minor dimension of developing scale up solutions was more crucial.

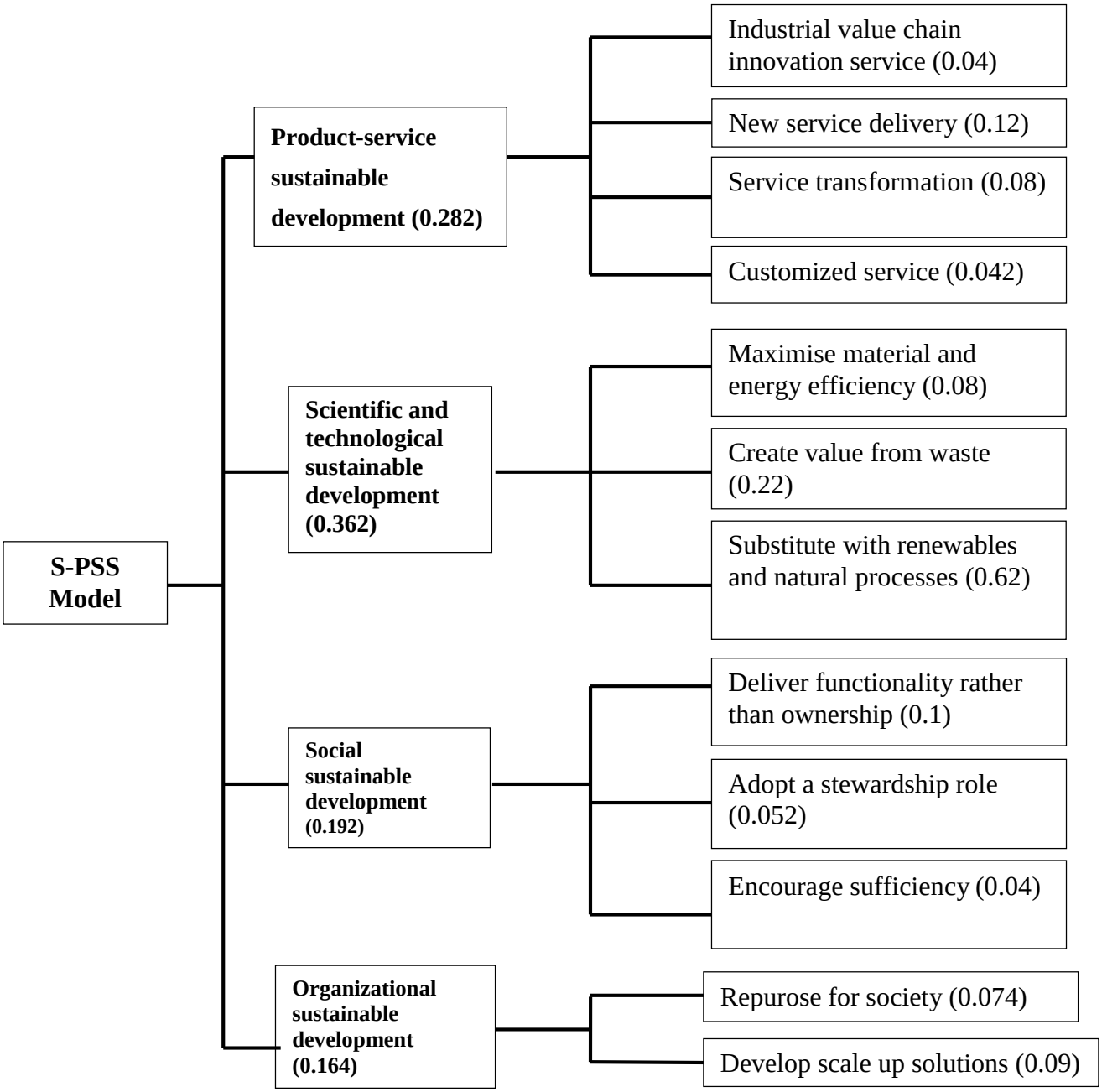

Figure1. The integrative framework of sustainable product-service business models

3. Conclusion and Suggestions

3.1 Conclusion

In recent years, Taiwan has promoted the 5+2 Policy to improve industrial competitiveness and develop towards a new economic model with innovation, employment, and allocation as the core. 5+2 industries refer to five industries, including Silicon Asia, biotechnology and medical care, green energy, smart machinery, and defense & aerospace, and two additional industries, including new agriculture and circular economy. In order to promote the establishment of a cyclic social system, it is necessary to import the cycle concept into the process from raw material acquisition and production to consumption. Under the condition of an extreme lack of natural resources, Taiwan should adopt the innovative business model of a circular economy to reduce the demand for external resources and enhance resource utilization efficiency in the move toward sustainable development. Taiwan's economic transformation process depends on the machine tool industry, commonly known as machine tools; if there is no machine tool industry, other industries will not be able to continue. In recent years, the trend in the machine tool market has been transformed from the seller to the buyer. In response, the government has promoted the "Three Industries Four Upgrades" policy, and issues related to manufacturing servitization have become hot topics in the machine tool industry in the midst of industrial competition, especially in the machine industry, which is highly dependent on selling products. After the standardization process, servitization should be used to create more differentiated competition and improve the added value of products. The research results in this study echoed the four research motivations mentioned in the introduction. In addition to echoing past studies such as [13]–[15], [20], this study made a great breakthrough on the basis of empirical research and operation. The important findings from the three study phases are described as below:

3.1.1 Phase 1: Conceptualization of sustainable product-service business models

Six experts and scholars were invited to conduct an assessment of the content validity and relevance, and the wording of the original items was significantly revised without losing the original meaning of the measurement indicators, so that Taiwanese employees could easily fill in the questionnaires and have good content validity. The formal scale included four evaluation dimensions with a total of 45 items. The extracted items and contents could provide a reference value to the conceptualization of sustainable product-service business models.

3.1.2 Phase 2: Measurement of the reliability and validity of various questionnaire dimensions

In addition to the literature of [20];[22] and[23], the development model in this research added

the in-depth thinking of Taiwanese scholars and experts regarding the measurement dimensions and indicators of sustainable product-service business models. The difference between the dimensions and items in the final questionnaire was not caused by technology; it was because the experts and scholars considered different national conditions, cultures, and enterprise features for the evaluation and assessment of the items and deleted or revised items during the process of constructing the questionnaire. Therefore, the items and wording of each dimension of the sustainable product-service business models established by this research had the significance of Taiwan localization. In terms of the academic level, the sustainable product-service business models constructed by this research had better applicability in the test of Taiwanese enterprises. The effects of cultural differences were also minimized, which was an advantage in the development of sustainable product-service business models for the localized machine tool industry. Follow-up researches can use this model as an evaluation tool to discuss the relevant variables. In practice, this model could be used as a guideline and basis for companies to improve sustainable innovation or manufacturing servitization planning and execution.

3.1.3 Phase 3: Verification of the integrative framework of sustainable product-service business models and analysis of the relevant importance of each dimension,

Based on the questionnaire in phase 2, the integrative framework of a sustainable product-service business model was developed for the Taiwanese machine tool industry. The group decision making analysis was conducted through the viewpoints of 24 senior managers in the machine tool industry. In group decision making, it is necessary to integrate the preferences of the group members. Under the reasonable hypothesis condition, the geometrical mean was used as the function of integrating the group decision making. The calculation of weight in the AHP method mainly consists of conducting a pairwise comparison between each hierarchy and the hierarchical element to calculate the eigenvector of the pairwise comparison matrix and then calculate the relative weight between each element. Therefore, the AHP method can accurately measure the difference between each element compared with the traditional weight calculation method. Thus, this research applied the AHP method to gain the weight of each dimension and indicator. The important results showed that in the main dimensions of the sustainable product-service business model, the dimension of scientific and technological sustainable development was more crucial compared with the dimensions of product-service sustainable development, social sustainable development, and organizational sustainable development. It was obvious that enterprises would hope to develop a sustainable business model meeting the TBL of profit making (profit), environmental protection (planet), and social care (people) through the great breakthrough of scientific and technological sustainable development.

3.2 Suggestions

1. Suggestions for the industrial field

For Taiwan's machine tool industry, the importing of new service development has transformed from an option to a trend. Due to rapid changes in market and client demands, the machine tool industry must also consider market trends and potential client demands and provide the necessary services to the clients in addition to providing high-quality products. At present, many advanced manufacturing industries have developed a number of innovative business models such as machine real-time monitoring, networking, virtual-real integration, external sensors, real-time parameter analysis, big data analysis, modular systems, and remote repair. The future machine tool industry should develop sustainable innovative business models under the guidance of industry 4.0 and intelligent manufacturing. As defined by [28], "intelligent plants refer to the organization having the kinetic energy to provide a set of manufacturing solutions and focus on establishing a flexible and adaptive manufacturing procedure which can solve the problem that manufacturing facilities are faced with complex and real-world dynamics and rapidly changing boundary situations to reduce unnecessary labor and resource waste". The managerial implication of sustainable product-service business models embodies the above-mentioned concept.

2. Suggestions to follow-up researchers

Due to the characteristics of multiple goals, difficult measurements, ambiguity, and involvement in the cognitive behavior of sustainable product-service business models, it was necessary to integrate experts with different interests and specialties in the academic field and the enterprise field to establish a set of complete and strict measurement models. Follow-up researchers can consider the characteristics and differences of different industries and respectively consult experts in different industries to gain their opinions and then respectively construct the measurement dimensions, weights, and indicators to which each industry belong according to different industries. Lastly, the empirical results should be compared, analyzed, and summarized to make the measurement model become more accurate and mature.

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