Philippine Journal of Science
150 (6A): 1593-1606, December 2021
ISSN 0031 - 7683
Date Received: 29 Jun 2021

Level of Awareness of Smart Manufacturing Technologies and its Nexus to Adoption among Micro, Small, and Medium Enterprises in the Philippines

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With the rapid developments in the manufacturing industry, micro, small, and medium enterprises (MSMEs) need to equip with smart manufacturing (SM) technologies to keep abreast with the fourth industrial revolution (FIRe). This paper sought to assess the level of SM awareness among MSMEs in the Philippines and its correlation to technology uptake. The data were obtained from the survey gathered from 496 cooperators of the Department of Science and Technology's (DOST) Small Enterprises Technology Program (SETUP), a government initiative that assists MSMEs in upgrading technologies. This study employed mixed methods of quantitative [principal component analysis (PCA), index construction, and Pearson's r test] and qualitative [triangulation method using key informant interviews (KII)] analyses to provide an understanding of the variations of awareness and adoption of nine SM-enabling technologies. The degree of differences was classified into high, average, below average, and poor. Results revealed that medium-sized companies have a higher level of awareness and adoption than micro and small businesses. However, MSMEs have generally poor technological knowledge and implementation of SM. Among the SM technologies, cloud computing and 3D printing are the most critical technologies that can explain the variability of awareness and adoption. These findings can contribute to the plans of DOST to upgrade the SETUP program that aligns with the emerging need of FIRe.

Keywords: DOST SETUP, fourth industrial revolution, smart manufacturing, SME, technology awareness and adoption

INTRODUCTION

Advanced technologies have revolutionized the manufacturing sector's operation, where traditional methods are replaced with more digital, intelligent, and connected systems (Kang *et al.* 2016). This advancement is characterized as SM, which emerged from the FIRe. SM is the interconnectivity of machines that provide real-time responses to the changing manufacturing needs by employing various information and communication technologies (ICT). It enables an integrated production system that improves operational performance and increases productivity (Kang *et al.* 2016; Phuyal *et al.* 2020).

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Despite various advantages of SM, MSMEs are still at the advent of this transformation. In a global study conducted in over 25 countries, a few MSMEs have fully implemented approaches towards FIRe, and the majority are in their development stage (Flores *et al.* 2018). Moeuf *et al.* (2017) reveal that MSMEs still neglect cutting-edge technologies and only utilize machinery that is less costly and least revolutionary. This slow shift has been attributed to several challenges. Knowledge and financial constraints were identified by Masood and Sonntag (2020) as the ultimate barriers. Sommer (2015) and Rauch *et al.* (2019) highlight the undeveloped capabilities of MSMEs in staff proficiencies and technological capacity that influence this issue. The owner and employees' awareness about the technology is also critical to SM implementation (Mittal *et al.* 2019; Yu and Schweisfurth 2020). These hindrances are also observed in the Philippine context – characterized by a lack of knowledge and skills competencies, a weak technology base, and poor infrastructure (WEF 2018). With the growing demand for inclusive digital transformation, governments are crafting policies and programs to support the business sector, focusing on MSMEs to remain competitive. Some of the recognized international efforts include the "Industry 4.0 Testlabs" of Australia, France for its "Industrie du Futur," Italy's "Impresa 4.0," Portugal for the "Indústria 4.0", Spain for the "Industria Conectada 4.0," and "Industry4WRD" of Malaysia (MITI 2018; Yang and Gu 2021).

In the Philippines, the complementing policy is the Inclusive Innovation Industrial Strategy (i^3s) (Aldaba 2018). Another government program specific to technology uptake is the SETUP of DOST. SETUP assists the MSMEs in implementing technological innovation to enhance their operations and increase productivity and competitiveness.

With the relevance of FIRe, the DOST plans to upgrade its current program to SETUP 4.0 (DOST 2020). Cooperators are likely to participate in FIRe as the former program showed a high impact on the enterprise's technology and innovation qualities (Rivera *et al.* 2020) and positively contributes to poverty reduction (Barroga *et al.* 2020). Following Mittal *et al.* (2019) and Sopadang *et al.* (2020), the transition will be positively realized if there is an understanding of the current position of businesses towards a technology shift. Thus, there is a need to investigate the level of MSME's awareness of SM and its correlation to adoption since it is not yet comprehensively explored. Given that knowledge is the first stage of technology uptake according to Roger's diffusion of innovation (DOI) theory (Sahin 2006), the evaluation of MSME's extent of awareness and implementation of the emerging technologies is an essential step for countries that are still in the planning phase of the shift.

This study identifies how aware Philippine MSMEs are in terms of SM and their level of adopting these technologies. Aligning to the purpose of this study and the complexity of SM, MSMEs involved are the SETUP cooperators – which have been exposed to technological innovations – signifying their disposition to incorporate new technologies. Specifically, this study addressed the following objectives: [1] determine the most important SM technologies that can explain the variability of awareness and adoption among MSMEs, [2] assess the level of awareness of SM technologies among MSMEs, and [3] evaluate the relation of awareness to the adoption of SM technologies among MSMEs.

This paper is divided into five sections. Section 1 presents the statement of the problem and the research objectives. Section 2 details literature on SM, its concept and enabling technologies, and the awareness and adoption of SM among MSMEs that support the theoretical framework and its hypotheses. The third section explains the conceptual framework and the material and methods used in the analysis. The fourth section discusses the relevant findings relative to the hypotheses. Finally, the conclusion and recommendations are provided in the last section of this paper.

Literature Review

As the forefront of Industry 4.0, SM is an outcome of continuous technological developments from the previous industrial revolutions (Phuyal *et al.* 2020). It is a concept created to enhance the competitiveness of the manufacturing industry through the convergence of technology, people, and information (Akinlabi *et al.* 2020). Manufacturing today allows machines to communicate with one another, where data is transmitted throughout the entire system, enabling them to control and respond to enterprises' varying problems (Kang *et al.* 2016; Mittal *et al.* 2019). The realization of SM depends on the integration of cross-cutting technologies such as the internet of things (IoT), cyber-physical systems (CPS), artificial intelligence (AI), radio frequency identification (RFID), robotics, big data analytics (BDA), cloud computing, 3D printing, and augmented reality (AR). These nine are the underlying technologies for SM utilized by early adopters and leading industrial economies like the United States, Germany, and Korea (Kang *et al.* 2016; Yang and Gu 2021). At present, the recent advances in new methods and technologies have evolved into different forms. Mittal *et al.* (2019) comprehensively listed 38 technologies associated with SM, but they showed resemblances of characteristics and interdependencies of functions. Considering the semantic similarity, it derived the same technologies as Kang *et al.* (2016) and Yang and Gu (2021). As suggested, the nine technologies are key to achieving a high level of smartness in a manufacturing firm and are, hence, considered in this study. The core technologies, their role in SM, and their compatibility with the qualities of MSMEs are further discussed below.

1) IoT. IoT is a group of physical objects linked together through the internet or local network (Hansen and Bogh 2021). In manufacturing, objects may refer but are not limited to machines, controllers, sensors, and products. Thus, the internet-based IoT connects all manufacturing things to reach an effective digital integration of the entire value chain – from planning to execution (Yang *et al.* 2019). Moeuf *et al.* (2017) found that IoT is one of the most utilized SM-enabling technology among MSMEs because of its lower upfront costs. Out of the 12 Industry 4.0 technologies measured by Hanafiah and Somroo (2021), IoT was seen to have significant value to smaller companies. However, Hansen and Bogh (2021) argue that the general uptake is still low. Given the limiting characteristics of smaller firms, successful implementations were the simplest ones and least expensive, linking fewer devices and sometimes applied to one machine only. Additionally, IoT is mainly confined to monitoring purposes, which is not considered the full spectrum of SM (Moeuf *et al.* 2017; Hansen and Bogh 2021).

2) CPS. Deemed as a very complex technology, CPS is the core of SM (Hanafiah and Soomro 2021). While IoT links physical things, CPS connects the virtual and physical worlds. It gathers information acquired from both systems, then analyzes the data in cyberspace and transmits solutions to real-world problems (Kim and Park 2017). The deployment of CPS requires many interactive devices incorporating various ICTs (Hanafiah and Somroo 2021; Yang and Gu 2021). Given the technology's multifaceted components, only one literature has recorded the use of CPS in MSMEs, which was utilized to control machines and planning purposes (Moeuf *et al.* 2017). It is widely recognized that a higher level of coordination between and across a manufacturing system consumes more time and capital to sustain the whole operation (Yang and Gu 2021), which is a barrier to adopting CPS (Moeuf *et al.* 2017). Jordan *et al.* (2017) suggest that the complexity of systems, lack of execution framework, and modeling methods discourage investments from smaller companies. Overall, there is little execution of advances in merging physical and digital technologies (Yu and Schweisfurth 2020).

3) BDA. As interconnected machines generate information, shop floors have surged with massive information called big data. The whole system of collection, integration, and evaluation of big data refers to BDA that turns varied information into a useful basis for sound business decisions (Frank *et al.* 2019). Evidence showed a significant level of interest of MSMEs to BDA. However, the majority do not employ any related technology (Liu *et al.* 2020). The lack of resources, insufficient knowledge, fear of investments, and unsuitability of big data to their business size were highlighted as the major concerns of this sector (Liu *et al.* 2020), which parallels the findings of Mouef *et al.* (2017) and Frank *et al.* (2019). Nevertheless, Liu *et al.* (2020) strongly suggest a positive impact of BDA on small enterprises, as long as supervision and appropriate tools are supported.

4) Cloud computing. This technology enables shared real-time access of information and resources over the internet using the cloud-based approach. It is a vital element to incorporate intelligence in traditional manufacturing companies as it provides effective means of collaboration and network connectivity (Xu 2012; Moeuf *et al.* 2017). The use of cloud computing for managing data is suggested to be cost-effective that offers a value proposition for companies, especially to MSMEs (Liu *et al.* 2020). It is manifested in the systematic review of Mouef *et al.* (2017), where cloud computing is the most popular technology accounted on SM-related published articles. Its reported use was in document sharing, resource optimization, distributed production, and collaboration. Yu and Schweisfurth (2020) also found a significant degree of cloud application among MSMEs in the German regions. In Denmark and Finland, IT services are availed from the cloud (Schröder 2016). Considering cloud computing as the most means of SM among small companies (Schröder 2016; Mouef *et al.* 2017; Yu and Schweisfurth 2020), this study positions this technology with high prominence among MSMEs.

5) AI. AI has become prevalent given the exponential growth and availability of datasets. Through understanding data patterns, AI enables machines to perform human-like tasks such as decision making and providing real-time responses to the production demands (Phuyal *et al.* 2020). In effect, manufacturing companies can benefit from reduced downtime of factories, improved energy management, and optimized production (Yang and Gu 2021). Developed countries slowly employ AI practices. Large-sized firms take the lead, given their technical knowledge, competence, and adequate human and financial resources (Hanafiah and Somroo 2021). Whereas MSMEs defer in accepting AI due to their absence of expertise, some are unaware of this technology (Hansen and Bogh 2021). Smaller firms are disadvantaged with the lack of access to funding and skills development. On a different note, Schröder (2016) revealed that the implementation rate of AI is still low, regardless of business size and sector. This situation is usually observed in countries that lag behind digital transformation.

6) Robotics. Robots play a critical role in the modern industry – performing predefined tasks to ensure accuracy and productivity in production. With AI development, the traditional robots have intensified into a new type of collaborative robot (cobot) capable of adapting to the environment (Goel and Gupta 2020). Cobot is designed to create a cooperative workspace between robots and humans, assisting workers in the repetitive and heavy mechanical tasks on the factory floor. Cobots are ideal for smaller companies than industrial robots that are heavy and expensive (Goel and Gupta 2020). Although there is an opportunity for robotics in the MSMEs sector, Hanafiah and Somroo (2021) found this as the least technology used relative to other enabling ICTs. It further recommended that robotics is best applied in larger firms than medium-sized companies. Mannan and Khurana (2012) identified ignorance of the technology, lack of technical competencies, and unwillingness to invest as the limiting features of MSMEs for robotics.

7) RFID. RFID, according to the study of Pramanik *et al.* (2020), is a sensor technology used to identify and locate objects through radio waves. It is embedded with tags stored with information varying from different objects. RFID tags are mainly employed to monitor product flow throughout the supply chain – from the plant site to the distribution phase (Pramanik *et al.* 2020). It has seen to be simultaneously studied along with CPS (Jordan *et al.* 2017) and IoT (Flores *et al.* 2018) due to its sensor ability implanted to machining tools that allow recording of data during the entire production process. According to Strueker and Gille (2008), MSMEs are better off with RFID since they have lower implementation barriers than bigger ones. Large companies entail numerous integration processes; thus, more coordination problems are faced. Moeuf *et al.* (2017) also noted several cases of RFID usage among MSMEs, but a high non-usage scale was accounted for in the study of Hanafiah and Somroo (2021).

8) 3D printing. This technology is often referred to as additive manufacturing, which generates a three-dimensional object from a digital file printed through successive layers of materials (Pramanik *et al.* 2020). 3D printing is mostly used for prototype testing and validation, ideal for manufacturing companies as it offers cost reduction, flexibility, and faster production of products in small quantities (Yang and Gu 2021). This technology is widely studied by small businesses because of its compatibility with their characteristics. Marzi *et al.* (2018) reveal a significant improvement to the overall competitiveness of MSMEs – notably, increased product innovativeness, profits, and created competitive advantages to other businesses. Moreover, triangulation further confirmed that 3D printing among manufacturing MSMEs has transformed their supply chain with efficient strategies and growth paths (Shah and Mattiuzza 2018). With the rising trend of 3D, MSMEs gradually recognize its importance to their operation. In the Philippines, the government started to invest in 3D by establishing an R&D institution focusing on this technology (DOST 2019).

9) AR. AR allows users to visualize data through computer-generated graphics while interacting in the real world (Deac *et al.* 2017). Training simulations and maintenance are highlighted as the main fields that AR frequently address (Damiani *et al.* 2018). Muller *et al.* (2018) suggest the opportunity for MSMEs in industrial maintenance to use mobile AR systems to support their clients. Given their limited number of technicians, mobile AR systems could extend services to customers to configure machine breakdowns remotely. Thus, the technology provides value in terms of time reduction and efficiency in their service operation. However, despite advantages, AR is underutilized by most MSMEs. Hanafiah and Somroo (2021) reported low utilization of AR and tagged it as one of the least used among the 12 technologies considered. Similar findings were also observed by Yu and Schweisfurth (2020), which is influenced by the resistance of small companies to new technologies related to product development.

Evidently, these nine cross-cutting technologies offer various advantages to improve manufacturing companies. Literature suggests the importance of MSMEs to capitalize on SM technologies to stay competitive in a highly advanced industry. According to Noteboom (1994), MSMEs are more flexible in adapting to innovation than large entities, which are efficient but slower in accepting new technology. It may explain why MSMEs have shared high interest but generally have poor adoption (OECD 2021) and awareness (Safar *et al.* 2020) of emerging technologies.

The decision of whether firms will adopt technology has been defined by Rogers (1995, 2003) through his DOI theory. The adoption process involves five stages: [1] awareness, [2] interest, [3] evaluation, [4] implementation, and [5] adoption. The adoption starts to realize when awareness of the technology's presence, technical usage, and function is established (Sahin 2006). Thus, knowledge is a critical component to understand the innovation adoption behavior of firms, but it does not imply that having the necessary knowledge means adapting to new technology. Other aspects that influence the decision could be the behavioral perceptions, organizational characteristics, and compatibility, which are part of the different technology acceptance models reviewed by Taherdoost (2018). For instance, the sex of the owner (male), higher educational completion, and access to the export market are more likely to adopt technology innovation (Barroga *et al.* 2019).

Flores *et al.* (2018) found a significant appreciation and benefits of FIRe; nonetheless, MSMEs have generally low technical familiarity with the Industry 4.0 concept and its ICT components (Safar *et al.* 2020). It further revealed that companies with no initial information tend to negatively connotate new technology while those with cognition have favorable opinions. Hence, awareness reflects the readiness and capability to integrate Industry 4.0 technologies into an organization's system. Sommer (2015) also argues that SMEs are more likely to become victims rather than beneficiaries because they cannot meet the financial, technological, and staffing requirements.

Moreover, evidence shows that awareness can be affected by organizational characteristics such as firm size. Smaller enterprises are deemed to experience more knowledge and information-related hindrances than bigger enterprises (Trianni *et al.* 2016). In this regard, smaller businesses have tighter budgets to spend on training and knowledge-based activities, thus limiting their sources of information. The idea of Industry 4.0 was also first spread and disseminated among larger companies, which they took leverage (Schröder 2016). Hanafiah and Somroo (2021) added that larger organizations tend to perform better since smaller companies focus more on business competition rather than improving the organization's internal culture. It may imply that the smaller the firm is, the lower the awareness of Industry 4.0 technologies. Therefore, the influence of business scale on technological awareness is worth examining.

Technology uptake is remarkably low among MSMEs. As the technology becomes more complex, the adoption gap among MSMEs increases (OECD 2021). They tend not to exploit all Industry 4.0 resources and resort only to those simple and less costly, which are the least sophisticated for digital transformation (Mouef *et al.* 2017). According to the literature, the most utilized SM-enabling technologies are cloud computing and IoT, while the least applied are AR, robotics, and CPS (Jordan *et al.* 2017; Yu and Schweisfurth 2020; Hanafiah and Somroo 2021). Revolutionary machinery requires significant resources that hinder most MSMEs from implementing such technologies (OECD 2021).

Similar to awareness, size is also a critical variable to assess implementation. Bigger businesses are more likely to acquire SM. As larger companies have adequate financial and organizational resources to capitalize on new technologies (Premkumar and Roberts 1999). In Malaysia, a study confirmed that the smaller the enterprises are, the lower the implementation of SM technologies (Hanafiah and Somroo 2021). Moreover, the correlational analysis also verified that larger businesses are statistically associated with technology use (Thong and Yap 1995). With this, the study predicts that medium enterprises are more inclined to implement technologies than micro and small enterprises. Knowledge and expected benefits of technology are the drivers for implementing Industry 4.0 technologies (Yu and Schweisfurth 2020). If there is high information in a specific technology and its benefits are recognized, the company will more likely implement and invest in it. Findings were consistent with Kartiwi (2007) and Safar *et al.* (2020), which highlighted that the lack of knowledge is one of the main barriers to implementing new technologies. This may implicate that awareness correlates with adoption. Thus, this study infers that higher awareness of technology would lead to a higher likelihood of adoption. Overall, the level of awareness and adoption may vary in every firm. MSMEs can be categorized according to these levels: "poor," "below average," "average," or "high." Hence, this study proposes that:

> ***Hypothesis 1:*** Cloud computing and 3D printing are the most important technologies that can explain the variability of awareness and adoption.
>
> ***Hypothesis 2:*** Medium-sized companies are more aware of SM technologies than micro and small enterprises.
>
> ***Hypothesis 3:*** Medium-sized companies are more likely to adopt SM technologies than micro and small enterprises.
>
> ***Hypothesis 4:*** The higher the level of awareness, the more likely to adopt SM technologies.
>
> ***Hypothesis 5:*** MSMEs have poor awareness and adoption of SM technologies.

To understand the awareness and adoption of the nine technologies, Figure 1 below demonstrates the framework of the study and how it addresses the hypotheses

MATERIALS AND METHODS

The study covered the DOST SETUP cooperators across the 16 regions of the Philippines, which have availed the program from 2002–2020. The optimal sample size was identified through the standard sample size formula (Equation 1) to provide a good data representation for the analysis of this study.

$$n = \frac{\frac{z^2 p(1-p)}{e^2}}{1 + \left(\frac{z^2 p(1-p)}{e^2}\right)} \tag{1}$$

The study used non-probabilistic sampling to determine the SETUP Cooperators respondents under the manufacturing sector involved in the primary processing of their products/services. Respondents have undertaken a survey with a questionnaire modified from a readily available Industry 4.0 Readiness Assessment from IMPULS Foundation of the German Engineering Federation (IMPULS 2015; Lichtblau *et al*. 2015). The survey consisted of questions focusing on the degree of awareness and adoption of

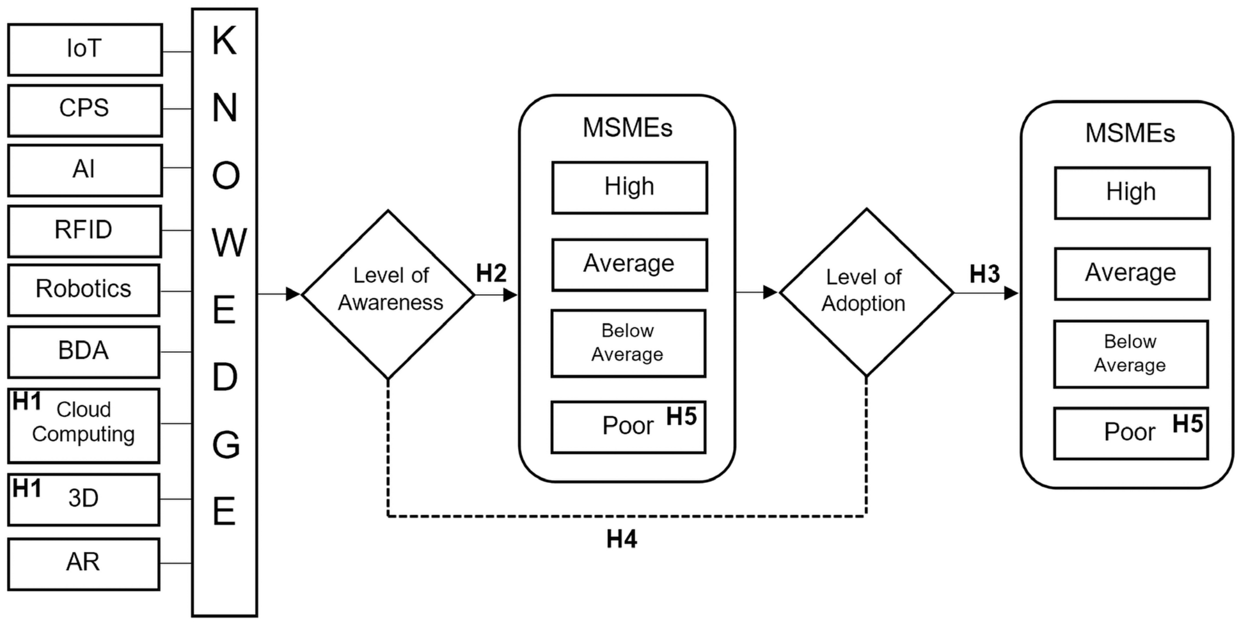

Figure 1. The conceptual framework of the study with mapping of hypotheses.

the nine SM technologies. To establish reliability, the questionnaire has undergone pilot testing. This was done to ensure that the situation of the Philippine MSMEs was captured. In the survey, a varying degree of awareness of the nine SM technologies was explored: [1] first time to hear, [2] vaguely familiar, [3] familiar, and [4] very familiar. At the same time, MSMEs were asked if they have adopted or not adopted the technologies.

Data Analysis

This study utilized explanatory mixed-method research, which employed quantitative tools (PCA, index construction, and Pearson's r test) and validates the results with qualitative (triangulation method using KII) analysis. Pearson's r test was used to assess the association of two variables with mean scores in the Likert scale. With the aid of R software (R Core Team 2021), PCA reduced the dimensions of the dataset, where it maintained the interpretability of its variance and identified the most important SM technologies for MSMEs that can explain the variations. After this, indices were constructed regarding the enterprises' level of awareness and adoption of technologies. The indicators and variables used were summarized in Table 1.

PCA

The PCA is a well-established technique for variability assessment through dimensionality reduction. Since each variable is considered a different dimension, PCA extracts the most important information from the survey's multivariate data and expresses this as a set of new variables called the principal components (PC). The new variables correspond to a linear combination of the original variables containing the highest possible variance. In other words, the largest variances are the most "principal" (Kassambara 2017). In this study, the number

Table 1. Summary of indicators with corresponding variables in the analysis.

Indicator	Variable
Business Scale	Micro
	Small
	Medium
Awareness to technology	First time to hear
	Vaguely familiar
	Familiar
	Very familiar
Adoption to technology	IoT
	CPS
	AI
	RFID
	Robotics
	BDA
	Cloud computing
	3D Printing
	AR

of PCs was determined by looking at the scree plot, which displays the eigenvalues from largest to smallest (H1).

Index Construction

Two (2) indices per MSMEs were constructed according to their level of awareness and adoption. First, the awareness index (A_w) per respondent (where $w = 1$ to k respondents) is the summation of the technology awareness X_{wz} (where X_{wz} is 1 if the first time to hear, 2 if vaguely familiar, 3 if familiar, or 4 if very familiar on SM technology z), divided by the product of the total number of technologies T and maximum familiarity level F. Hence, the awareness index is expressed as:

$$A_w = \frac{\sum_{w=1}^{k} X_{wz}}{T * F} \tag{2}$$

Then, parameters were set and categorized according to the following fractile intervals:

1. Poor awareness of SM if $0 < y_i \leq a$
2. Below average awareness of SM if $a < y_i \leq b$
3. Average awareness of SM if $b < y_i \leq c$
4. High awareness of SM if $c < y_i \leq 1.0$

With this, MSMEs' level of awareness can be classified into "poor," "below average," "average," and "high." Second, the adoption index (A_d) per respondent (where $d = 1$ to k respondents) is the summation of the SM technology adopted X_{dz} (where X_{dz} is 1 if adopted the technology z or 0 if otherwise) divided by the total number of technologies T, which can be formalized as:

$$A_d = \frac{\sum_{d=1}^{k} X_{dz}}{T} \tag{3}$$

The same intervals and classification were utilized in the adoption index:

1. Poor adoption of SM if $0 < y_i \leq a$
2. Below average adoption of SM if $a < y_i \leq b$
3. Average adoption of SM if $b < y_i \leq c$
4. High adoption of SM if $c < y_i \leq 1.0$

The analysis was further disaggregated according to the enterprise's business scale. This step streamlined the validation of the two hypotheses (H2 and H3) of the study. The overall weighted index of each business scale was averaged to determine MSMEs' overall awareness and adoption (H5). To address the fourth hypothesis, this study employed the Pearson's r test to assess the strength of the linear relationship of awareness and adoption.

Triangulation Method

The significant findings from the quantitative analysis were verified through the triangulation method using KII of micro, small, and medium SETUP cooperators. It was administered through an interview with the aid of a structured questionnaire. The triangulation method using KII captured a comprehensive understanding of the enterprise's awareness and adoption of SM technologies and their underlying influences. Other major concerns that arose from the quantitative results were further assessed in this section.

RESULTS AND DISCUSSION

Out of the population of 7,497 SETUP cooperators, 496 MSMEs responded to the survey. Of the 496 respondents, 140 are micro enterprises, 321 are small, and the remaining 35 are medium enterprises. Generally, the respondents are from the food processing industry, as shown in Table 2. Following the standard sample size formula (Equation 1), the respondents gathered is more than the recommended sample size of 366 with a 95% confidence level and 5% margin of error. Thus, it indicates that the sample size used in this study is a significant representation of the population of MSMEs with DOST-SETUP assistance.

Given the differences in the dataset, they were reduced using PCA without losing significant information. Based on the scree plot, the first dimensions or PC1 of both the awareness and adoption have the highest explained variances. This indicates that 59.85% of the variation in the awareness is explained by the first dimension (Figure 1a). Likewise, in the adoption, the majority (25.6%) of the variation is explained by PC1 (Figure 1b). At this portion, this study considers the PC1 as the point of analysis since the remaining percentages are all relatively small and comparable in size, following Kassambara (2017).

Using the two PC1, the nine technologies were ranked based on their contribution to their corresponding PC in awareness and adoption (Table 3). The two most recognized technologies are cloud computing and 3D printing. Cloud computing has the largest contribution at 0.84, indicating the most significant variable to awareness. It means that MSMEs are most knowledgeable on cloud computing among the SM-enabling technologies, which parallels Mouef *et al.* (2017). Following Lui *et al.* (2020), handling information through the cloud network has been beneficial for MSMEs because of its affordability and compatibility; thus, it is deemed a good start to digitize operations. The second notable technology is 3D printing with a 0.82 contribution. As the technology is globally associated with manufacturing companies (Shah and Mattiuzza 2018), 3D printing is rapidly gaining attention

Table 2. Respondents per industry type and business scale.

Industry type	Business scale			
	Small	Micro	Medium	MSMEs
Animal feeds	0	1	1	2
Automobile	1	2	2	5
Beverage	6	4	0	10
Electronic components	0	1	0	1
Food processing	173	68	17	258
Footwear	0	2	0	2
Iron, steel, and metal fabrication	27	22	1	50
Leather	0	1	1	2
Other Manufacturing	59	24	7	90
Paper	0	1	1	2
Petroleum/fuel products	0	0	1	1
Printing service	29	4	1	34
Rubber, plastic, and glass	0	0	1	1
Textiles	7	0	0	7
Wearing apparel	8	3	1	12
Wood/furniture	11	7	1	19
Total	321	140	35	496

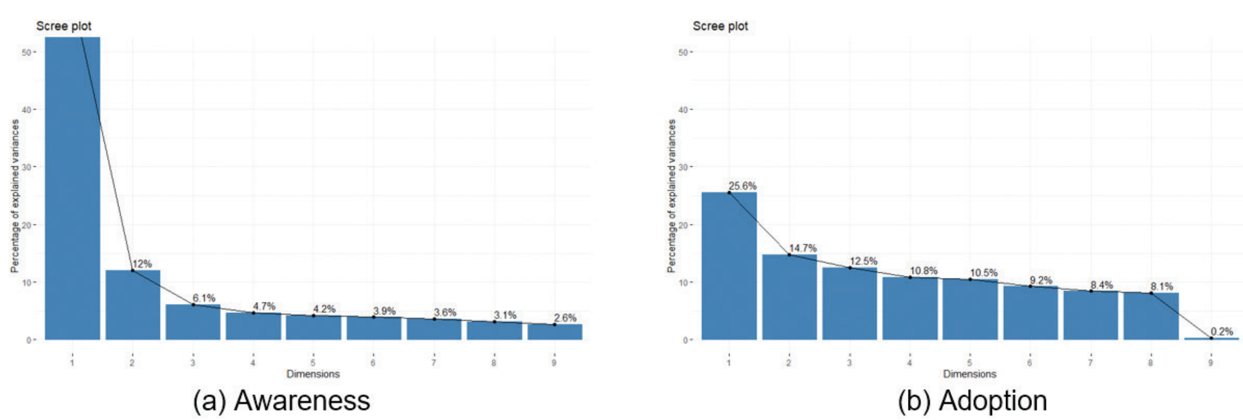

Figure 1. Explained variances of dimensions of awareness and adoption.

in the Philippines. The government's initiatives on FIRe lean towards strengthening the 3D footprint in the country (DOST 2019), which may have influenced its increased awareness.

In terms of technology uptake, the IoT is the most adopted with a contribution value of 0.91 to its PC, which corresponds to 158 adopters. This confirms the study of Hanafiah and Somroo (2021), which puts IoT as the most utilized technology. However, this trend does not align with the awareness result, which ranked eighth among the technologies. Ideally, high adoption should relate to high awareness and *vice versa* but not in the case of IoT. According to Hansen and Bogh (2021), any physical devices connected to the internet are referred to as IoT, which is not known to most companies. Therefore, the adoption of IoT technology may not correspond to its level of understanding. With the second-highest contribution value in adoption (0.90), AR is the next accepted technology. It has been integrated by 154 MSMEs into their operation, which accounted for 31% of the population. AR has a similar trend with IoT, where the adoption rate is high but with low awareness among MSMEs. Cloud

Table 3. Awareness and adoption of SM technologies among MSMEs using PCA.

SM technology	Awareness		Adoption	
	Rank	Contribution (λ_k)	Rank	Contribution (λ_k)
IoT	8	0.659	1	0.908
CPS	9	0.638	5	0.406
AI	5	0.792	6	0.300
RFID	6	0.791	9	0.220
Robotics	4	0.801	8	0.276
BDA	3	0.821	7	0.290
Cloud computing	1	0.838	3	0.533
3D printing	2	0.822	4	0.446
AR	7	0.771	2	0.899

computing is the third most adopted at 0.53 contribution. Expectedly, it is one of the leading technologies acquired because of its prominence. As highlighted in the findings of Liu *et al.* (2020), the cloud is the least expensive among SM technologies, making it more appealing for MSMEs to implement in their businesses. Nevertheless, the general uptake accounts for only 6.25% of the total population. Thus, this study proposes the importance of enterprises to leverage their awareness and cost-effectiveness to implement the technology. However, as discussed previously, other factors may limit the implementation, which needs more investigation.

The next in the adoption rank is 3D printing, which corresponds to 5.85% of the population. This is the fourth most adopted SM technology, which contradicts Hanafiah and Somroo (2021), where 3D printing is the least utilized technology in Malaysia among MSMEs. This shows a positive outcome of the increasing government efforts as the country aims to lead in the additive manufacturing industry within ASEAN (DOST 2019). However, the country still has a long way to fully implement this technology in MSMEs.

Moreover, the least obtained technologies were CPS, AI, BDA, robotics, and RFID with correlation values of 0.41, 0.30, 0.29, 0.28, and 0.22, respectively. These advances are deemed more complicated technologies that may have caused its neglect of usage among enterprises, as highlighted in the studies of Mannan and Khurana (2012), Jordan *et al.* (2017), Mouef *et al.* (2017), Lui *et al.* (2020), and Hansen and Bogh (2021).

In general, the contribution of each technology to its corresponding PC does not signify the level of MSMEs' awareness and adoption. Therefore, it needs further assessment to identify the level of knowledge and the depth of adoption through index construction. Using equal fractile intervals, indices between (0, 0.25] are considered as poor, (0.25, 0.50] as below average, (0.5, 0.75] as average, and (0.75, 1.00] are respondents with high awareness or adoption.

Table 4 summarizes the level of SM awareness among MSMEs. Out of the total samples, 29 MSMEs are highly aware of SM technologies, while 49 have poor knowledge. High awareness means the most desirable level of knowledge with the full understanding of SM and its technologies, while poor classification is the complete opposite. The majority (235) of the SETUP cooperators are classified with below-average awareness, followed by an average level with 183 MSMEs.

Table 4. The level of SM awareness among MSMEs by business scale (n = 496).

Business scale	Frequency (n)	Awareness level				Overall weighted index	Overall awareness level
		Poor	Below average	Average	High		
Micro	321	35	167	104	15	0.231	Poor
Small	140	13	54	62	11	0.251	Below ave.
Medium	35	1	14	17	3	0.263	Below ave.
MSMEs	496	49	235	183	29	0.248	Poor

Based on the overall weighted awareness index, the medium-sized enterprise shows the highest index among the business scales, which accounts for 0.26. This result implies that medium-sized companies are more knowledgeable of SM technologies than micro and small enterprises. This conclusion confirms the second hypothesis of this study. According to Trianni *et al.* (2016), the size of the company matters when acquiring new information. Bigger companies tend to have more resources in the form of financial, trading partners, or organization capabilities that expand their knowledge horizon in their business field. These advantages may have influenced their awareness, but it is important to note that the index falls under the below-average, which is only a decimal higher to poor. Similarly, small-sized enterprises have a below-average awareness, while micro-sized businesses are classified with poor knowledge. This puts the overall awareness level of MSMEs as poor.

The lack of knowledge of MSMEs about SM is a major stumbling block in adoption. For most MSMEs, digitalization is an unfamiliar jargon that is too complex and expensive for their businesses. Hence, MSMEs are typically unaware of where to obtain useful information on digitalization, as the sources are usually scattered and not easily accessible. Moreover, having a poor awareness level could result from the MSMEs' unwillingness to change business processes. Given that SM awareness has critical implications for adoption, this study contributes an added value to the body of knowledge, specifically the awareness of MSMEs concerning the opportunities and demands of SM. The emergence of the current COVID-19 pandemic offers an opportunity for a resurgence of enterprises with a high awareness of SM technologies.

The same categories were utilized in the adoption index. The findings show that none of the MSMEs highly adopted cross-cutting technologies (Table 4). Only four enterprises or 0.81% of the respondents have an average uptake, while 9.88% (49) are below average. The adoption rate of most businesses (89.31%) is poor, which indicates that they have implemented zero to two technologies. Of the 443 poorly adopted, 61.91% of which did not accept any technology, 7.90% have one technology, and 26.19% have two technologies that are concentrated mainly in IoT and cloud computing, which are the simplest forms of SM.

Medium companies still lead in the SM technology implementation at 0.27 index (Table 5). It substantiates the third hypothesis of this study that medium-sized businesses are more likely to adopt than micro and small enterprises. The literature argues that smaller companies are more open to innovation; however, this does not imply that they have implemented it. As business increases in size, they are likely to amplify ICT budget, upgrade outdated equipment, and invest in emerging technologies (Premkumar and Roberts 1999). On the other hand, micro and smaller companies focus their limited resources on more immediate concerns such as product generation and coping mechanisms, given the impact of the COVID-19 pandemic and other unforeseen circumstances. In effect, many of them defer from acquiring sophisticated innovation until it has been made affordable and proven to significantly impact their operations.

This study further reveals that initiatives are already starting; however, the implementation is generally poor, regardless of the business scale. This conclusion validates that the findings of the World Economic Forum (2018), where the Philippine businesses lag in the industrial shift as the global manufacturing industry transitions to more intelligent factories. Most MSMEs admitted that they are not yet ready for revolutionary changes in their organizations. The top barriers raised by the respondents are the high costs of technologies, lack of infrastructure, absence of skilled employees, and lack of knowledge.

This study attempts to prove the influence of awareness on implementation. As the awareness of SM technologies rises from micro to medium-sized businesses (from 0.23 to 0.25 to 026), the possibility of adoption also increases (Table 6). However, based on the Pearson's r test, the correlation among the MSMEs shows a very weak correlation at 0.113 but it has a *p*-value of 0.012, suggesting a significant correlation at a 5% level of significance. The analysis manifests a weak correlation between awareness and adoption, thus having a minimal relationship between the two variables. Following Sahin (2006), it indicates that having the necessary knowledge does not imply an immediate response to technology

Table 5. The level of SM adoption among MSMEs by business scale (n = 496).

Business scale	**Frequency (n)**	**Adoption level**				**Overall weighted index**	**Overall awareness level**
		Poor	Below average	Average	High		
Micro	321	290	28	3	0	0.111	Poor
Small	140	126	14	0	0	0.110	Poor
Medium	35	27	7	1	0	0.126	Poor
MSMEs	496	443	49	4	0	0.115	Poor

Table 6. Relationship of SM awareness to adoption among MSMEs (n = 496).

Business scale	Sample size (n)	Awareness	Adoption	Coefficient (r)	*p*-value
Micro	321	0.231	0.111	0.123	0.028*
Small	140	0.251	0.110	0.099	0.247
Medium	35	0.263	0.126	0.038	0.828
MSMEs	496	0.248	0.115	0.113	0.012*

*Significant at 5% level of significance

acquisition. This suggests that other internal and external factors are affecting an enterprise's behavior towards adoption (Taherdoost 2018), which are not addressed in this study, and need further expansion of related variables.

The key results were validated through KII of Enterprise A (micro enterprise engaged in auto parts production), Enterprise B (small enterprise engaged in agro-industrial business), and Enterprise C (medium enterprise engaged in brown sugar milling). The selection was based on the quantitative results, and the inclusion criteria considered one representative per business scale. During the interview, Enterprise C was observed to be highly involved in the discussion and familiar with most SM technologies as they have already implemented some of them. However, compared to Enterprises A and B, they are relatively uncertain with the terms introduced to them. In fact, they frequently asked more questions about SM rather than answer them. Three out of four proven hypotheses (H1, H2, and H3) are observed in Enterprise C (see Appendix).

CONCLUSION

This study developed a modified conceptual framework focusing on the level of awareness and adoption of SM technologies among MSMEs. Using the framework, the study confirms that medium-sized companies are more adaptive and aware of emerging technologies than micro and small enterprises. However, the overall knowledge and acquisition of these technologies are poor among MSMEs. Surprisingly, the study further showed that awareness has a weak correlation towards adoption, which indicates that knowledge does not ensure the likelihood of businesses acquiring technological innovation. Among the nine SM technologies, cloud computing and 3D printing were the most important technologies among MSMEs that can explain the variability of technology awareness and adoption.

In general, the MSME sector – particularly medium-sized companies – can drive the future growth and prosperity of the Philippine manufacturing industry. Medium-sized businesses can help micro and small companies scale up knowledge and implementation of technologies because they can act as economic benchmarks that leverage campaigns to increase return on investment of newer technologies, including cloud computing and 3D printing. This study puts into discussion the importance of the government, industry, academe, and other non-profit sectors to address the lack of SM knowledge to create opportunities for growth and development. If these campaigns are established, MSMEs will become more aware and adaptive to the full capabilities and benefits of investing in such technologies.

RECOMMENDATIONS

This study offered a series of recommendations for multiple stakeholders in the business ecosystem, including local government and non-government units, to address the challenges and increase technology adoption among MSMEs. Government institutions should strengthen technological awareness through scaling up FIRe and SM knowledge-building activities – such as facilitating national awareness programs and developing informational materials to improve MSMEs' awareness, value perception, and financial access to adopt new technologies. In collaboration with the Asian Productivity Organization (APO), the authors of this study have designed a specific framework for SM in the Philippines that the policymakers can utilize to drive SM transformation in the country. The DOST SETUP 4.0 program may prioritize medium-sized companies, as they are more willing to provide more investments in adopting SM technologies – especially cloud computing and 3D printing. Hence, the findings of this research may serve as a guide to the DOST to develop efficient strategies for SETUP 4.0 implementation. This study used a non-probabilistic sampling with a limited number of MSMEs with DOST SETUP assistance. It is suggested for future studies to extend the scope and number of respondents and use a probabilistic sampling approach to minimize risks of systematic bias. Moreover, future works can determine the specific challenges to uncover the barriers to technology adoption.

ACKNOWLEDGMENT

This research is part of the DOST XI's efforts to foster an inclusive innovation ecosystem for emerging technologies, emanating from a project with APO and Development Academy of the Philippines. The authors would like to thank the DOST Central and Regional Offices for assisting with the deployment of the survey. In addition, financial and related support from the DOST XI Local Grants-in-Aid program is gratefully acknowledged.

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