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SMART MANUFACTURING: NATIONAL IMPLEMENTATION FRAMEWORK

Smart Manufacturing
National Implementation Framework

Dr. Meng Hua Li served as the volume editor.

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FOREWORD

Smart manufacturing (SM), the advanced technology-driven approach that integrates intensive applications of ICT and internet-connected machines in the production process, is a key element of the Fourth Industrial Revolution, also known as Industry 4.0. Even though it is typically led by highly industrialized economies and technology giants, APO member economies in different stages of development are embracing SM applications in key industries in various ways.

A need assessment study completed in 2020 by the APO Center of Excellence (COE) on SM found that the industrial structures of most APO member economies posed challenges for the transition to cyberphysical Industry 4.0 systems. The majority of firms in APO member countries are micro, small, and medium enterprises that are struggling to define the starting point for this journey. Nevertheless, the SM journey requires concerted efforts from the government to enterprise level to achieve digital transformation.

Based on those findings and to support member countries in gearing up for Industry 4.0, frameworks for SM implementation were drawn from the expertise of the APO COE on SM in this publication. Optimal strategies in national contexts to enable the adoption of smart production technologies are suggested. Recommendations on SM implementation at all levels, from national policies, to industry standards, to enterprise strategies, are given with the roles of each stakeholder delineated. The frameworks support efforts by member countries to initiate the SM journey and build up ecosystems for manufacturing to transform and thrive.

The APO hopes that the SM implementation plans developed in this study are useful for policy analysts and government officials in member countries in drawing up their own clear roadmaps for SM strategic planning. The valuable contributions and commitment of the APO COE on SM and all the experts who participated in the research are very much appreciated.

Dr. AKP Mochtan
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Without the contribution of the APO COE on SM, this publication would not have been completed.

BACKGROUND

Smart manufacturing is a concept or an idea to equip the manufacturing industry with state-of-the-art technologies, coupled with improved and relevant management guidelines and approaches to operations. The end goal is to improve efficiency while maximizing productivity with the use of digitalization and new technologies. By employing state-of-the-art technologies, along with integrated data-driven systems, smart manufacturing optimizes the entire manufacturing process to improve the efficiency and flexibility of the existing manufacturing environments [1]. The approach is always associated with the fourth industrial revolution, known as Industry 4.0 (I4.0). Smart manufacturing is also one of the initiatives to turn I4.0 into a reality.

APO member countries are gearing up for I4.0 with various policy initiatives. However, the recent pandemic situation has hit the developing countries hard. As most of the developing economies are lacking in resilience, it is an immense challenge for these countries and their enterprises to put focus on industrial transformation as they combat the pandemic. In future too, these countries will require longer periods to recover from their losses due to the pandemic.

In this report, insights on the development of smart manufacturing in five APO member countries, namely, India, Malaysia, Pakistan, the Philippines, and Vietnam are presented. The manufacturing industries of these five APO member countries share some common features. A majority of the enterprises in the aforementioned countries are small and medium enterprises (SMEs). Apart from that, the manufacturing industries of these countries are still moving from Industry 2.0 to Industry 3.0. This corroborates that information and communication technologies (ICT) are yet to be fully used in the production processes. As a result, the manufacturing processes are only partially automated and the demand for labor is sufficiently intense. As the host country for the Center of Excellence on Smart Manufacturing, insights on smart manufacturing from the Republic of China (ROC) are shared as best practices for other participating countries.

[1] Ku C.C., Chien C.F., Ma K.T. (2020). Digital transformation to empower smart production for Industry 3.5 and an empirical study for textile dyeing. *Computers & Industrial Engineering*, 142, 106297. <https://doi.org/10.1016/j.cie.2020.106297>.

OVERVIEW OF SMART MANUFACTURING IN FIVE APO MEMBER COUNTRIES

The demand for manpower has become dreadfully high due to the COVID-19 pandemic. Many factories were forced to shut down as governments began to lock the nations down to control the pandemic. Production lines were unable to function properly, and orders could not be completed on time, which caused huge losses for companies. Many countries were greatly affected, as business activities were halted and workers were urged to stay at home. Challenges were faced by both governments and companies in the implementation of smart manufacturing amidst tough global and local economic situations.

To handle the economic crisis resulting from the COVID-19 pandemic, governments have introduced various policies and economic stimulus programs to strengthen and rebound local economies. The Government of India has launched programs such as ‘Make in India’ and *Atmanirbhar Bharat* (self-reliant India) to help the economy rebound strongly in the next couple of years. Malaysia has initiated the National Economic Recovery Plan and subsidized MYR260 billion for SMEs to support their businesses. The Government of the Philippines has introduced programs such as Recharge PH, *The Bayanihan to Heal as One Act*, and other financial programs, to ensure business continuity in the country. It has also encouraged local manufactures to repurpose their products by producing COVID-19-related products, to reduce the dependence of the country on imports. In Pakistan, the government has countered the adverse impact of the pandemic by introducing programs such as Prime Minister’s Emergency Relief Package of PKR1,200 billion, provincial relief packages, Temporary Economic Refinance Facility (TERF), zero-rated industries, and more. The government has also cut down the interest rates for enterprises to lessen their financial burden. The Government of Vietnam has also issued policies to support SMEs (68% of the 783 surveyed enterprises) related to tax; finance and credit; labor; and insurance. The government support offered in the form of policies or financial packages is a necessity to assist people in their lives and the businesses to overcome their financial difficulties.

The majority of enterprises in the aforementioned countries are SMEs. A common challenge faced by SMEs when adopting smart manufacturing pertains to scarcity of resources. Financial resources are essential to realize intelligent manufacturing in the present production system of factories, e.g., in adapting and integrating basic devices such as sensors as well as advanced technologies such as industrial internet of things (IIoT), cyber–physical systems, big data analytics, artificial intelligence (AI), and more. However, the revenues made by the SMEs hardly leave room for them to invest in smart manufacturing. Also, given that it is considered to be a long-term investment, SMEs can barely attract financial investments. In most of the developing countries, the current digital ecosystem is also not fully mature to sustain smart manufacturing. Therefore, SMEs are somewhat challenged to adopt smart manufacturing in their respective businesses.

Lack of talent in the industry threatens to put the industry at high risk, as only a few will be able to sustain the systems in smart factories. Implementation of new technologies may also hasten job losses in future since less-competent workers will be replaced by autonomous machines that aim to reduce labor cost.

Many efforts were made by government agencies and authorities to draw the attention of players towards industrial revolution and assist those who are participating in the journey towards digitalized transformation. Countries have come up with blueprints and policies to initiate digital revolution in industries.

In India, manufacturing has traditionally played a key role in the economic growth and development of the world's sixth-largest economy. However, the importance of manufacturing had diminished towards the end of last century. The share of manufacturing in India's GDP had stagnated at 15–16% since 1980, though it has increased to 18.32% in the last 10 years. Given the large domestic market with high levels of consumption, it was recognized that industrialization with an increased share of manufacturing in GDP would be a key feature of economic growth.

India has been undergoing a challenging period due to the COVID-19 pandemic. Smart manufacturing underpins the realization of the government's Make in India and *Atmanirbhar Bharat* programs. Along with other measures needed for the revival of the manufacturing sector, widespread adoption of smart manufacturing is likely to be a silver bullet to propel competitiveness of the sector and pave the way for India's economic leadership. The government is working at every level to promote the manufacturing sector by taking early steps and spearheading activities to launch smart manufacturing. Many government programs were launched toward that end. These include *Smart Advanced Manufacturing and Rapid Transformation Hub (SAMARTH) Udyog Bharat 4.0*, Startup India, and Digital India initiatives on interdisciplinary cyber-physical systems; Impacting Research, Innovation and Technology (IMPRINT); Centers of Excellence for IoT and AI; and APO Center of Excellence on Industry 4.0.

Various other industry bodies such as Confederation of Indian Industry Smart Manufacturing Platform, and Federation of Indian Chamber of Commerce and Industry, in conjunction with academic institutions, are involved in promoting smart manufacturing. At the firm level, organizations take up readiness assessments as part of their plans to adopt smart manufacturing. India is gearing up to leverage smart manufacturing for achieving economic leadership. Although the Indian manufacturing industry is fast embracing technologies, it needs to confront the impediments that can impact the adoption of smart manufacturing. The adoption of new technology-based solutions is expected to bring the much-needed transformation in the manufacturing sector, thus making the sector a bigger participant in the development of the Indian economy.

In Malaysia, I4.0 has become a trendsetter. The Ministry of International Trade and Industry (MITI) had launched Industry4WRD: National Policy on the basis of I4.0, which has acted as a spur to digitalize the manufacturing and service sectors. The policy aims to increase productivity in the manufacturing sector, nurture high-skill-equipped employees to deal with the problems arising from digitalization, and raise innovation capabilities and competitiveness in the industry. The ministry and its collaborating organizations plan to bring about awareness among enterprises. Awareness campaigns and seminars will aim to help unaware enterprises move to the stage of smart manufacturing, followed by implementation of intelligent production.

Enterprises are required to do a ‘readiness assessment,’ conducted by the Malaysian Productivity Corporation (MPC), to assess their readiness for smart manufacturing. After the assessment, enterprises gain more clarity on how to implement smart manufacturing in their existing production systems and come out with a strategy and plan for the purpose. Further, there is involvement of experienced consultants for their guidance and suggestions. A similar program, Business Virtual Advisory Mentoring (BVAM), is also led by the MPC.

In terms of financing, government agencies are likely to support enterprises by providing loans to them or through other monetarily schemes, so that enterprises have enough funds to set up the emerging technologies in their manufacturing systems. Moreover, with support from the Ministry of Education, science, technology, engineering, and mathematics (STEM) education was implemented in the academic curriculum, including courses and subjects related to advanced technologies and manufacturing to prepare future talents that are ready for the era of smart manufacturing. Meanwhile, training programs were designed to upskill existing workforces so that they could carry out the implementation of smart manufacturing in their workplaces. Various government agencies have collaborated to gather resources for ensuring that the required technologies and infrastructures are in place. These include increasing broadband speeds and engaging tertiary education institutes to collaborate with ventures. The ultimate goal of the policy is to transform the manufacturing industry in the country, so that it is systematic, resilient, smart, and at par with other countries.

The Philippines faces several major issues, such as weak technology base, weak human capital, and poor infrastructure to support future production. To solve these hindrances, the Government of the Philippines introduced an industrial policy, namely, the Inclusive Innovation Industrial Strategy (i³S). Through this policy, it expects to improve the current situation of the industrial sector and reduce poverty by reviving GDP of the manufacturing sector. In future, the policy may also be implemented in agricultural and service sectors. The triple-helix relationship between the government, the academia, and the industry greatly influences the connectedness in the country because each of them has the duty to support the development of the country.

Although the government has not dedicated a framework for the application of smart manufacturing in the industry, the national experts of Philippines had suggested a framework for the implementation of smart manufacturing, referred to as I4.0, representing inculcate, improve, integrate, and institutionalize. The proposed framework is drafted on the foundation of some important policies such as i³S, Philippines Development Plan (PDP) 2017–22, and the *AmBisyon Natin 2040* (Our Vision 2040). Its goal is to strengthen the country’s manufacturing sector by employing smart manufacturing systems and solutions in local factories. By applying new technologies, it enables ventures to operate efficiently and improve productivity. In the meantime, it helps enterprises reduce their production costs, so that they are able to increase their competitiveness. To assess the readiness of enterprises, especially the SMEs, which are in majority, the Philippines plans to adopt SIRI as a potential international standard tool for Industry 4.0. The core elements for evaluation are process, technology, and organization of an enterprise. Due to the COVID-19 pandemic, the training for the assessor was put on a halt. This framework could further contribute towards the realization of the Philippines’ existing plans and long-term vision of reducing poverty in the country.

The Government of Pakistan has initiated many policies, with majority of them being focused on information and communication technology (ICT), to improve the technology and communication infrastructure in the country. Some of the policies, such as Vision 2030, Digital Pakistan Policy,

and Industrial Technology Acquisition Policy of Pakistan (2020–23), are meant to ensure the availability of accessible, affordable, reliable, and high-quality ICT services; create a digital ecosystem within the country; expand knowledge-based economy; and stimulate the socioeconomic growth, in order to improve the quality of life and economy in the country.

Like the Philippines, Pakistan is yet to have an actual framework for the implementation of smart manufacturing in the industrial sector. Major efforts need to be put towards enhanced usage of ICT technologies in manufacturing sectors; development of machine technologies; availability of skilled human resources; and implementation of smart manufacturing standards. An assessment mechanism to evaluate the readiness of enterprises for smart manufacturing also needs to be in place. It should bring awareness to SMEs about the existing digital revolution happening in the manufacturing industry and assess their current readiness for the implementation of smart manufacturing. The inclusion of cyber security as a component of the readiness assessment is extremely necessary and crucial, so that the information of an enterprise is secured and protected. Nurturing high-skill talents for the intelligent era and generating awareness among the manufacturing ventures are also necessary measures. Government agencies supporting the implementation by initiating industrial policies, smart manufacturing policies, or recognizing a smart manufacturing standard, should serve as references for enterprises.

Vietnam has been recognized as one of the most dynamic emerging countries in Asia. One factor that contributes to its fast-growing socioeconomic status is its initiation in digital transformation. ICT has been applied in Vietnamese enterprises for productivity growth and competitiveness. The government has also put in efforts for facilitating the application and development of ICT by building telecommunications infrastructure, fostering talents equipped with high-tech knowledge and skills, and focusing on the development of databases. Several policies promote the restructuring of the industrial sector towards intelligent and high-value-added production and provide guidelines for enterprises to participate in I4.0.

For the evaluation of enterprises on their readiness for smart manufacturing, Vietnam found the necessity to adopt its own assessment tools for smart manufacturing so that they are more relevant to local SMEs. Therefore, Vietnam National Productivity Institute (VNPI) has developed the Vietnam Innovation Productivity Assessment (ViPA) toolkits to benchmark local SMEs and assess their readiness for smart manufacturing. There is a significant difference in the levels of readiness. SMEs, which contribute 40% of the country's GDP, face major barriers that refrain them from undergoing digital transformation. Issues such as lack of financial resources, limited participation in domestic and international value chains, and bounded business capacity, discourage SMEs from undertaking digital transformation. It is necessary to form a smart manufacturing ecosystem involving different agencies to support the SMEs. Government organizations have their vital roles in promoting the implementation of smart manufacturing by raising awareness and training on smart manufacturing implementation; assessing the digital manufacturing capacity; and publishing a smart manufacturing standards framework for enterprises.

Overall, the proposed framework for the implementation of smart manufacturing focuses on the following elements: (1) awareness of enterprises, especially SMEs, on the industrial revolution; (2) maturity of ICTs, in terms of infrastructure and digital platforms, in the country; (3) assessment of enterprises on the readiness for smart manufacturing; (4) planning and roadmap of an enterprise to implement smart manufacturing; (5) financing resources of an enterprise to participate in digital transformation; and (6) cultivation of talents and upskilling of current workforce through education and training.

Governments need to provide support by way of initiating policies or allocating resources towards the industrial revolution. This would encourage ventures to participate in digital transformation. Readiness assessment is used to evaluate the strengths and weaknesses of enterprises before they adopt intelligent manufacturing. It could help them understand smart manufacturing better and outline a clear strategy for its implementation. Collaboration between government agencies, enterprises, and academia is crucial to make the implementation a success. Each party has a role to play, and their relationship needs to be strengthened. In future, the adoption of automated systems in industrial process will keep growing. As digitalization has become a demand globally, leaders of all nations should keep pace with the trend, recognizing it as the key to increase productivity, efficiency, and economic growth of a country.

In the subsequent chapters, detailed reports for all the selected countries will be presented. Situations and challenges to realize smart manufacturing in the countries, the impact of recent COVID-19 pandemic towards the implement of smart manufacturing, and policies and frameworks introduced by the government agencies will be discussed.

SMART MANUFACTURING IN THE ROC

Background of Manufacturing Industry in the ROC

The manufacturing industry contributes 35% to the overall GDP in the Republic of China (ROC). Industrialization in the ROC began with light industries, such as textiles and small devices, and began to spread rapidly in the 1960s, when more labor- and capital-intensive industries were developed focused on information and communication technologies. The rise of the manufacturing industry has transformed the ROC into a developed country. However, the declining birth rates and the aging of population have created a labor-force crisis. Therefore, the government has been working to cultivate a workforce that is knowledgeable, innovative, and equipped with the skills needed to sustain the industry and further contribute to breakthrough innovations in the industry.

Impact of COVID-19 on Manufacturing Industry and Countermeasures

Since 2020, the COVID-19 pandemic has changed the world economy, as many countries have been forced to take lockdown measures to tackle the infectious virus. Companies and citizens have struggled to make a living due to the impact of the lockdown. At a time when the global economy is facing its deepest recession, the ROC has outperformed many countries, having successfully controlled the spread of the pandemic by mid-May of 2021. It had clocked an overall annual GDP growth rate of 3.11% in 2020.

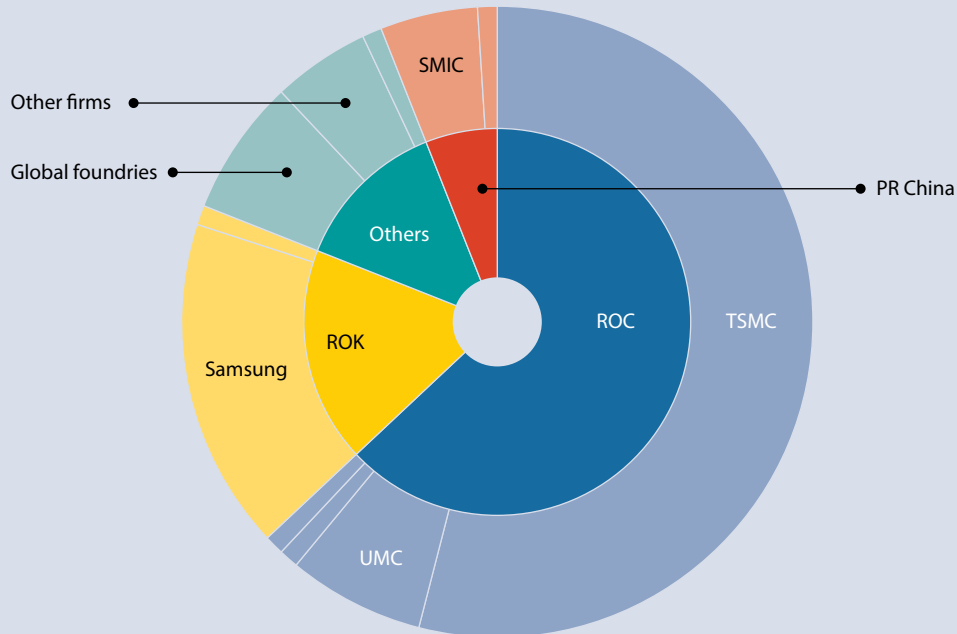
The ROC is also recognized for its domination in the production of semiconductors. Although the industry faced difficulties in managing production capacities and the supply chain, due to factors such as dropped orders, rescheduling of deliveries, temporary addition of niche microchip orders, or emergency changes in the manufacturing lines, it accounted for 60% of the total global foundry revenues in 2020, as shown in Figure 1. This was due to the global demand for microchips, which put the industry in spotlight. The most challenging aspects to resolve were collaboration with the customers and supply chain.

To counter the impact of the pandemic, enterprises set up situation rooms to integrate production indices and real-time distribution situations through intelligent technologies and platforms, to better adapt to the changes in manufacturing. On the other hand, in traditional manufacturing, the outbreak of the pandemic gradually struck an impact. Exports of products were limited due to import restrictions imposed by other countries, thereby threatening the revenues in the traditional manufacturing industry. In the meantime, enterprises were forced to reduce the working hours to mitigate the risk of COVID-19 infection. This jeopardized situation, however, prompted a rapid development of industrial transformation. Nowadays, the government is making efforts to promote high-level manufacturing, while aiming to transform the ROC into a high-end production hub for Asia. Along with the development of advanced technologies and production quality, the government is trying to accelerate the development of intelligent warehousing through a value-added-services system. The overall impact of the COVID-19 epidemic is shown in Figure 2.

FIGURE 1

HOW MUCH THE WORLD DEPENDS ON THE ROC FOR SEMICONDUCTORS.

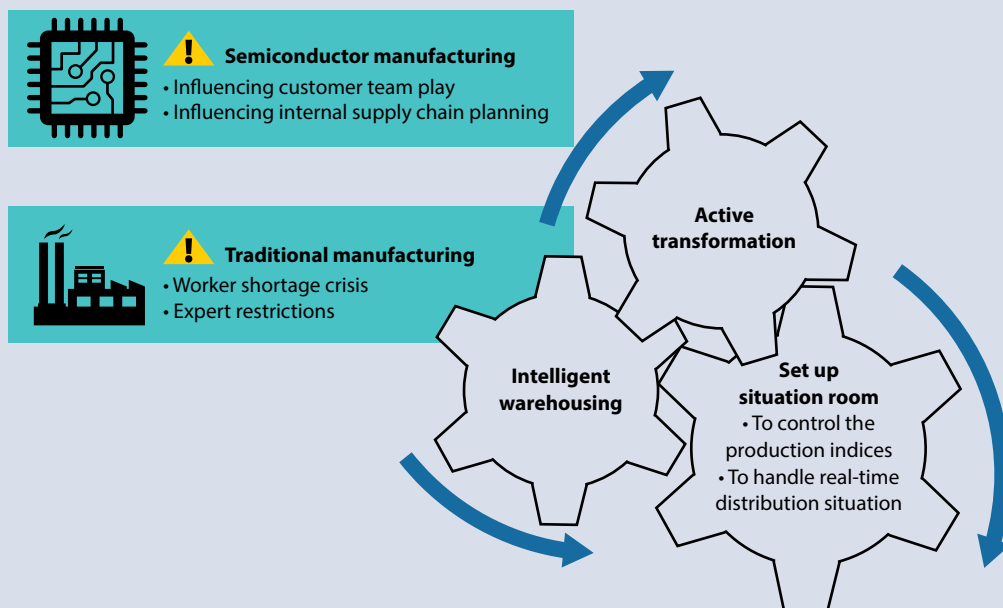
Semiconductor contract manufacturers by market share
Total foundry revenues stood at USD85.13 billion in 2020



Source: [1].

FIGURE 2

IMPACT OF COVID-19 ON THE MANUFACTURING INDUSTRY IN THE ROC.

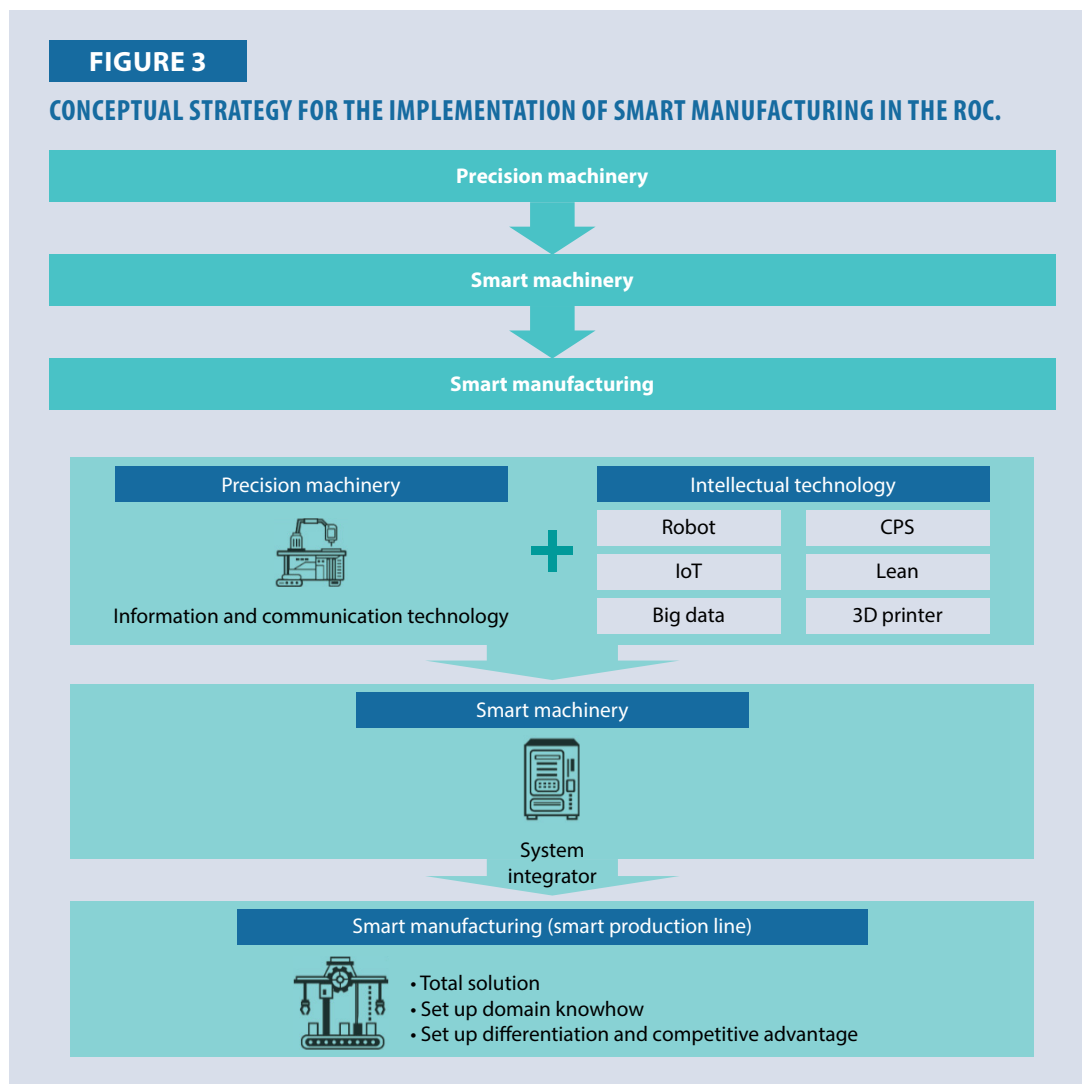


Policies for Smart Manufacturing in the ROC

As Industrial Revolution 4.0 started emerging globally, in 2016, the ROC government initiated the ‘Smart Machinery Development Program’ to accelerate adoption of intelligent technologies in production systems across the manufacturing industry. This was to comply with the global trends of intelligent manufacturing supporting small-volume and large-variety production and real-time big data analysis. The plan also aimed to promote the development of smart machinery, in order to create job opportunities and expand production plants, so that the machinery and equipment industries of the ROC could have the ability to provide total solutions and establish differentiated competitive advantages. Figure 3 shows the general plan for implementation of smart manufacturing in the industry. The ‘Statute for Industrial Innovation’ was amended in 2019, so that the enterprises that had invested more than TWD1 million on smart machinery between 2019 and 2020 were entitled for either (1) up to 5% of the annual spend to be credited against the profit-seeking enterprise’s income tax payable by it in the current year, or (2) up to 3% of the annual spend to be credited against the profit-seeking enterprise’s income tax payable by it in each of the three years from the then-current year. This legal provision was created to promote industrial innovation and optimize the industrial structure for further achieving smart transformation. By increasing the willingness of ventures to invest in intelligent manufacturing, the manufacturing industry in the ROC has been able to accelerate the pace of smart manufacturing.

FIGURE 3

CONCEPTUAL STRATEGY FOR THE IMPLEMENTATION OF SMART MANUFACTURING IN THE ROC.



The ROC's Industry 3.5 Strategy for Industrial Revolution 4.0

Today, Industry 4.0 (I4.0) has become the ideal standard for global manufacturing. Many solution providers are providing a variety of solutions, and some are even providing customized services, to assist companies in their digital transformation journey. However, these services are often expensive and hardly affordable for SMEs due to their limited budgets for such solutions. Considering that most of the enterprises in the ROC belong to the SME category, Chair Professor of National Tsing Hua University, Prof. Chen-Fu Chien has initiated the ideology of Industry 3.5. Based on his long-term observation and rich collaboration experience with the industry, Prof. Chien has stated that when it comes to smart manufacturing, I4.0 will be the first thing that comes to mind. However, I4.0 will disrupt the present business model of the ROC's manufacturing industry. Moreover, the manufacturing industry will require a long period to achieve digital transformation completely. Therefore, he came up with the hybrid strategy of Industry 3.5, which is a fusion of Industry 3.0 and I4.0 and uses disruptive innovation technologies such as artificial intelligence (AI), big data, and more. The strategy is based on the foundation of management practices used in the ROC's manufacturing industry. It enhances the capabilities of flexible decision-making and resource scheduling within a system, to maintain the ROC's niche positioning between advanced and emerging countries due to a lower production cost. Thus, enterprises are able to benefit from transformation and upgrading. As they accumulate sufficient experience, and the technologies are more mature, they are able to achieve the phase of I4.0 easily.

With the application of Industry 3.5, along with disruptive innovation as the core strategy, companies require to first establish operational core competence, such as comprehensive resource management, smart production, digitalization strategy, smart supply chain, and smart factory. There are four key factors driving the development of industrial ecosystem. These are: (1) systemization and digitization of production strength and knowledge management; (2) product lifecycle and revenue management; (3) vertical integration of hardware and software with analytic capability; and (4) sustainable development and green supply chain management. The underlying environment, taking the advanced technologies, including internet of things (IoT), big data, cyber-physical systems, and others into account, enhances the flexibility of current manufacturing processes and the overall management of the enterprise, to establish a new-era business model.

Reference

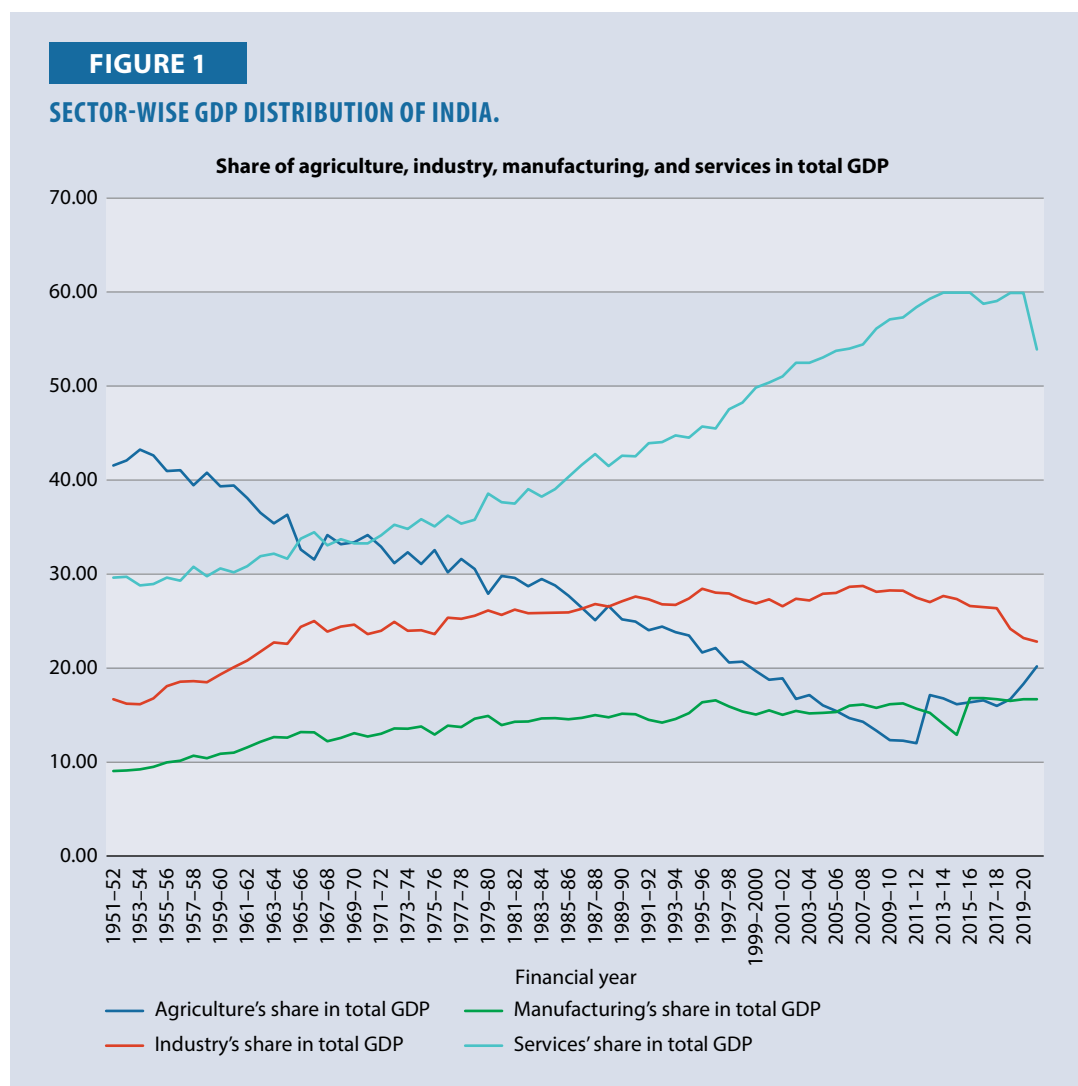
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INDIA

Introduction

India: The Fastest-growing Economy

India is world's sixth-largest economy by nominal GDP and the third largest by purchasing power parity. The government aims to grow the Indian economy to USD5 trillion by 2024 and to USD10 trillion by 2030 [1]. The GDP per capita in India is 16% of the world's average. It averaged USD693.96 for the period of 1960 to 2017, reaching an all-time high of USD1,967 in 2017 [2]. In 2021–22, India's real GDP was expected to record a growth of 11% and nominal GDP of 15.4%, which would be the highest since India's independence. As seen in Figure 1, the service sector contributes 54.13% to the GDP, followed by the manufacturing sector (18.32%) and the agriculture sector (14.39%) [3].



Indian Manufacturing Sector

Manufacturing has traditionally played a key role in the economic growth and development of India. The sector has evolved through several phases of transformation, including the *license raj* initially to liberalization later and the global competitiveness now [4]. The importance of manufacturing, however, diminished toward the end of the last century. The share of manufacturing in India's GDP had stagnated at 15–16% since 1980 while its share in comparable economies in Asia stood much higher at 25–34% [5]. In the fast-developing Asian countries such as Thailand, Indonesia, Malaysia, the ROC, the Philippines, the Republic of Korea (ROK), and PR China, manufacturing contributes 30–50% of GDP. Given the large domestic market with high levels of consumption, lower contribution of manufacturing is not a healthy sign. Therefore, it was recognized that industrialization with an increased share of manufacturing in GDP should be a key feature of modern economic growth. In the last 10 years, India's manufacturing sector's contribution to GDP has increased to 18.32% [3].

Revitalizing the Manufacturing Sector with Make in India Program

The Make in India initiative aims to make India an integral part of the global supply chain. Targets were identified along with policy initiatives. The three major objectives were (1) to increase the manufacturing sector's growth rate to 12–14% per annum in order to increase the sector's share in the economy; (2) to create 100 million additional manufacturing jobs in the economy by 2022; and (3) to ensure that the manufacturing sector's contribution to GDP increases to 25% by 2025 [6]. The program focused on 25 sectors including automobiles, aviation, biotechnology, chemicals, construction, textile and garments, thermal power, tourism and hospitality, and wellness, among others. The program involves many initiatives across several sectors and needs policy focus with more inbuilt consistencies [7].

With Make in India 2.0, the Government of India is making continuous efforts under investment facilitation to identify potential investors. India recorded its highest-ever annual FDI inflow of USD74.39 billion during the financial year 2019–20. In the six financial years up to 2020, India had received FDI inflows worth USD358 billion, which amounted to 53% of the total FDI of USD682 billion reported in the last 20 years [8]. Multinational companies have transformed the Indian market from a low-cost production ground to a global and important production base of strategic significance. Innovative products designed and manufactured by India are not only sold in the domestic market but can also compete in the international markets. Investment outreach activities are being carried out for enhancing international cooperation for promoting FDI; and India has improved its position from 142 in 2014 to 63 in 2019 on Ease of Doing Business [9].

COVID-centered Program, *Atmanirbhar Bharat*

The COVID-19 pandemic was a heavy blow for India. For India, the fall in real GDP in the April–June quarter of 2020 was the record lowest at 23.9%, with the Reserve Bank of India calling it a 'historic technical recession.' The contraction of the economy continued in the subsequent quarter at 7.5% [10]. The pandemic impacted the industrial-and-manufacturing sector through strict safety protocols, reduced workforce, and forced lockdowns. The challenges have highlighted the need for heightened automation, increased efficiencies, optimized performance and agility, and data-driven decision making.

The pandemic has turned India's focus towards becoming self-reliant by emphasizing on local manufacturing as the key to the country's survival, thus giving a major boost to the manufacturing sector. The government launched a new program called *Atmanirbhar Bharat* (self-reliant India).

Under this program, a production-linked incentive (PLI) scheme was introduced to benefit 10 key sectors for enhancing India's manufacturing capabilities and exports with an outlay of INR2,000 billion. This PLI scheme is expected to lead to an output worth USD520 billion in the next five years. Unlike the earlier schemes, which focused on incentives to be open-ended input-based subsidies, PLI espouses targeted and performance-based incentives through a competitive process. The government is working at every level to promote the manufacturing sector through measures such as ease of doing business, reducing the compliance burden, creating multimodal infrastructure to reduce logistics costs, and constructing district-level export hubs.

Smart manufacturing has been one of the most talked about trends in India in the recent past. With the support of programs like Make in India and *Atmanirbhar Bharat*, adoption of smart technologies is likely to assume greater importance. The adoption of newer technology-based solutions is expected to bring the much-needed transformation in the manufacturing sector, thus making the sector a bigger participant in the development of the Indian economy.

Status of Smart Manufacturing Promotion and Implementation

According to the Office of the Principal Scientific Adviser to the Government of India, smart manufacturing, which is synonymously used with Industry 4.0 (I4.0), is a technology-driven approach that encompasses fully integrated, collaborative manufacturing systems that employ internet-integrated machinery to monitor manufacturing processes in real time via an open infrastructure. Smart manufacturing involves interoperable systems, intelligent automation, and multi-scale dynamic simulation. It includes 3D printing, big data processing, advanced industrial robotics with networked sensors, industrial internet of things (IIoT), and distributed manufacturing technologies with strong cyber security mechanisms. These cyber-physical systems entail synergy of production and digital technologies to enable rapid adaptability and design changes, using data analytics that enable newer areas of innovation to optimize manufacturing by creating enhanced quality products, accelerating productivity, increasing energy efficiency, and sustaining safety. They enhance production processes and optimize supply chains by finding solutions to existing and future problems at the speed of business.

Smart manufacturing underpins the realization of Make in India and *Atmanirbhar Bharat* programs of the government. The Government of India is working with technology providers, user industries, consulting and audit agencies, educational and research institutions, industry bodies, and international organizations to promote and develop excellence in smart manufacturing. Complemented with several other government initiatives to foster best-in-class manufacturing infrastructure in India, the dawn of I4.0 and smart manufacturing has arrived. Experts say that for India, year 2021 is a tipping point to indicate that advanced digital capabilities are essential to create new products and services and to identify new markets. The need for implementation of smart manufacturing has two important dimensions as explained below.

First, the manufacturing sector was sluggish for two consecutive years for various reasons manifested through low productivity, inefficient supply chains, talent and skills shortage, and lower levels of supplier competence, among others. Many manufacturers depend on obsolete and complex systems to capture data, are reluctant to adopt newer skills and technologies, and have issues with machines' interoperability and tracking information during the production cycle. India's manufacturing sector was in need of a revolution that has smart manufacturing at its core, with new-age solutions across the value chain and a paradigm shift that transforms the manufacturing processes. India realized the

need to get onto the smart manufacturing bandwagon to restore the growth of its manufacturing sector and to meet the target of the sector contributing 25% to GDP by 2025.

Second, since early 2020, the industrial and manufacturing sectors in India have been reeling from the effects of the COVID-19 pandemic. Factories have struggled to manage production due to forced lockdowns, strict safety protocols, etc. While normal activities have resumed despite the pandemic, the impacts of COVID-19 have highlighted the need for automation, optimized performance, process visualization, and data-driven decision making. In such a scenario, smart manufacturing technologies are increasingly gaining traction in the manufacturing sector. These technologies help organizations reduce risks associated with non-availability of human workforce, improve the overall efficiency, and overcome the challenges posed by uncertainties and unprecedented events. Major programs of the government, especially the partnerships with industry bodies and research and academic institutions are presented in the following sections.

Smart Advanced Manufacturing and Rapid Transformation Hub

The Indian government took early steps and spearheaded several activities to launch smart manufacturing in the country. Many new government programs were launched by the government, including Smart Advanced Manufacturing and Rapid Transformation Hub (SAMARTH), Startup India, Digital India, and other initiatives through the Department of Science and Technology. *SAMARTH Udyog Bharat 4.0* is an I4.0 initiative of the Ministry of Heavy Industry and Public Enterprises under its scheme for enhancement of competitiveness in the Indian Capital goods sector. *SAMARTH Udyog* encompasses manufacturers, vendors, and customers as the main stakeholders. Experiential and demonstration centers have been proposed to spread awareness about I4.0 among the Indian manufacturing industries. It is emphasized that these centers would have resource sharing, common platforms of I4.0, and collaborate with each other so that the utilization of resources is maximized. The scope, objectives, partners, activities, and achievements of the five centers of excellence set up under SAMARTH are highlighted in the following sections [11].

The Centre for Industry 4.0 (C4i4): The C4i4 plans to develop an ecosystem that nurtures innovation and drives growth in smart manufacturing through collaboration among the government, the industry, and technology companies [12]. The center, established in 2017 in partnership with Kirloskar, provides I4.0 solutions on demonstration sets and equipment. C4i4 Lab helps in upskilling the existing workforce and accelerating training of the new workforce to keep up with new digital challenges and opportunities. In addition to I4.0 readiness assessment, C4i4 has also developed Industry 4.0 Maturity Model (I4MM) as a tool to assist manufacturing organizations across all industries to identify their current state of I4.0 maturity and readiness. The model helps enterprises in formulating a comprehensive and sustainable digital transformation roadmap. C4i4's SMART 50 tool uses a menu-based approach to assist SMEs in correctly selecting I4.0 solutions that help address specific value-chain challenges for swift and impactful solutions.

IITD-AIA Foundation for Smart Manufacturing (IAFSM): Indian Institute of Technology (IIT) Delhi and Automation Industry Association (AIA) have jointly set up a fully integrated smart manufacturing and learning facility for discrete and hybrid manufacturing segments such as automotive, consumer durables, and processed foods [13]. A demo-cum-experience facility supported by extensive skill building, SME consultancy, multi-academia partnerships, and research has been set up. Users have access to common engineering facilities and a full-fledged cyber-physical factory situated at IAFSM. Promotion efforts include awareness building, prototyping,

simulation and testing services, consulting services, site integration services, education and training, and skill certification. The foundation is collaborating with many leading industries such as Mitsubishi Electric, Rockwell Automation, Deloitte, KUKA, Hexagon, Mathworks, and Siemens. The initial focus will be on discrete and hybrid manufacturing segments such as automotive, consumer durables, and processed foods.

I4.0 India at Indian Institute of Science (IISc): Centre for Product Design and Manufacturing, Indian Institute of Science, Bengaluru had developed India's first indigenous smart factory platform *I4.0forIndia@IISc* comprising two components: (1) a labor-intensive tool room with a connected set of legacy machines that represents the SMEs of India; and (2) an automation-intensive factory that integrates 3D printers, metal laser routers, 5-axis CNCs using industrial robots, collaborative robots, and automated guided vehicles. The center is to focus on awareness campaigns around I4.0; training of master trainers; enabling startups and incubators; handholding SMEs to plan and implement relevant I4.0 projects; collaborating with neighborhood universities for training and internship programs for students; supporting development of indigenous I4.0 standards, protocols, and middleware; and participating in a government-formed platform for I4.0 on common agenda [14]. The center is partnering with Tata Consultancy Services, Toyota, Ashok Leyland, Yaskawa, Robert Bosch Center for Cyber-Physical Systems (RBCCPS), and Common Engineering Facility Centre (CEFC) of IISc.

Smart Manufacturing Demo and Development Cell at CMTI: The aim is to create a smart manufacturing platform at Central Manufacturing Technology Institute (CMTI), Bengaluru, for Indian manufacturing industries encompassing machinery OEMs, subsystem developers, users, component manufacturers, solution developers, startups, and so on. The smart manufacturing demo-cum-development center showcases I4.0 concepts, tools, and solutions, along with capabilities, advantages, and limitations. It supports the industry for rolling out smart production systems by way of consultation (configuration, selection, and viability analysis), as well as customized solutions (development and deployment, technology transfer, and handholding) [15]. Partnering with Siemens, the cell focuses on research and development in areas including IIoT solutions for machine tools, I4.0 dashboard for smart-machine health trending and analytics modules, smart-motor current signature analysis module, and intelligent module to predict the remaining useful life (RUL) of machine tools, subsystems, and digital twins for feed drive systems.

COE on Advanced Manufacturing Technology, IIT Kharagpur: The COE has been established at IIT Kharagpur with the support of a consortium of top industry members in the country. The center focuses on innovative and top-quality research focused on industries in design and automation, additive manufacturing, digital manufacturing, and IIoT. Recent innovations include real-time monitoring and control of friction stir welding process using multiple sensors and algorithm developed to boost profits in India's manufacturing sector and low-cost real-time machine vision-based quality inspection system. These innovations were possible through industry partners including Tata Motors, Tata Consultancy Services, Tata Steel, Tata Sons, BHEL, and HEC. The center also houses an innovation lab to facilitate the culture of innovation and open engineering among SMEs and startups; and enables end-to-end support from experts including access to various state-of-the-art facilities for early prototyping of products.

National Mission on Interdisciplinary Cyber-physical Systems

Cyber-physical systems (CPSs) are a new class of engineered systems that integrate computation and physical processes in a dynamic environment. A CPS encompasses technology areas of

embedded systems, IoT, big data, AI, and more. CPS systems are intelligent, autonomous, and efficient; and are expected to drive innovation in many sectors including manufacturing [16]. With seamless integration of the real and the virtual worlds with decentralizing control, the focus is on leading-edge smart manufacturing development and implementation. To harness the potential of this new wave of technology, Department of Science and Technology had launched National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS) with a total outlay of INR36,600 million for a period of five years [16, 17]. The mission aims to create a strong foundation and a seamless ecosystem for CPS technologies by coordinating and integrating nationwide efforts. The mission will be implemented through a network of 15 technology innovation hubs (TIHs), six sectoral application hubs (SAHs) and four technology translation research parks (TTRPs). Each hub and technology park will follow a technology life cycle approach, i.e., will be addressing all four stages of knowledge, development, translation, and commercialization [16]. Host institutes will be reputed academic and R&D institutions.

The first phase of NM-ICPS focuses on establishing six TIHs in the areas of

1. artificial intelligence and machine learning;
2. internet of things, sensors, activators, and control;
3. databanks, data services, and data analytics;
4. advanced communication systems;
5. robotics and autonomous systems; and
6. cyber security and cyber security for physical infrastructure.

The first phase of NM-ICPS is implemented in reputed academic and R&D institutions, with an impressive track record of scientific excellence, depth of experience in the proposed field, and a strategic vision, to establish and sustain dynamic technology innovation hubs in CPSs [16]. Each TIH focuses on knowledge generation, technology/product development and commercialization, skill development, innovation, entrepreneurship and startup ecosystem, and international collaboration. TIHs can support projects at academic and R&D institutions, industries, and other funding agencies. Support for projects must be based on requirement and due scientific diligence and processes. TIHs can provide support to student startups and support incubatees in the form of investments or debts. TIHs are allowed to initiate international collaborative projects on 50:50 cost sharing basis between India and participating international institutions from other countries [17].

IMPRINT IIC: A Unique Collaborative Initiative

Impacting Research, Innovation and Technology (IMPRINT) is a unique technology development initiative of the Ministry of Education (MoE) and the Department of Science and Technology (DST) [18]. This consortium approach was proposed in 2018 in the IMPRINT Institute Innovation Council (IIC) Program to include strong and complementary expertise from different disciplines and organizations in India to address major technological challenges for breakthrough in selected areas of industrial importance. The salient aspects of the program are following:

- The principal objective is to translate knowledge into a viable technology.

- Normally, the average cost of the approved projects will be around INR20 million.
- MoE and DST are equal partners to steer the scheme.
- IMPRINT IIC is open to all MoE-funded higher education institutions (HEIs) and centrally funded technical institutions (CFTIs).
- Industry support and partnership is mandatory.

It is required to specify the technology readiness level (TRL) of the proposal with suitable evidence and justification at the time of applying and to note the target TRL to be reached. All IMPRINT IIC proposals attempt to identify and involve industry partners or potential user groups or agencies that will offer financial support of a maximum 50% of the budget and undertake field trials of the prototype developed by the concerned project. At least 25% of the overall project cost should be supported by the industry, out of which at least 10% of the project cost should be in cash. The university will develop a sustainability plan and incorporate it into the proposal and run the consortium for at least another five years after the completion of project tenure towards long-term impact of the consortium. As of 2020, a large number of projects were funded in the areas of advanced manufacturing areas including I4.0 and smart manufacturing [19].

COE by Ministry of Electronics and IT on Smart Manufacturing Technologies

The Center of Excellence for IoT and AI was announced in 2015 as part of Digital India initiative to jumpstart the IoT and AI ecosystem by taking advantage of India's IT strengths. As part of the program, centers of excellence (COE) were set up in four locations, namely, Bengaluru, Gandhinagar, Gurugram, and Visakhapatnam. Out of them, the COE located in Bengaluru and Gandhinagar focus on robotics and I4.0, respectively. These COE act as platforms for the best minds from industry, academia, startups, and government to drive a culture of cocreation and research to find solutions for complex business problems and highlight India's innovation quotient and workforce development. The main objective of the COE is to create innovative applications and domain capability by harnessing the innovative nature of the startup community and leveraging the experience of corporate players [20]. These COE have been focusing on I4.0 and AI for enterprises in collaboration with TCS, Microsoft, Siemens, Schneider Electric, LG, Mitsubishi Electric, and BEML, among others. In addition, Ministry of Electronics and Information Technology (MeitY) has set up three COE in blockchain technology in collaboration with the government and private entities to help innovations and startups.

APO–NPC Center of Excellence on Industry 4.0

The Asian Productivity Organization (APO), in association the National Productivity Council (NPC), had established a COE on IT for Industry 4.0 in 2017 with the vision to be a knowledge center to provide support to the Asia-Pacific region on I4.0 [21]. The objectives of the COE are to act as a knowledge center for I4.0 and its applications through display of latest technologies and demonstration projects to help the SMEs and startups; and coordinate with the APO for experts to disseminate knowledge on I4.0 in other countries.

The NPC has signed a memorandum of understanding with National Small Industries Corporation, under the Ministry of MSME, Government of India. An analysis of capacity development needs for I4.0 was taken up to identify the gaps in the integration of I4.0 with national industrial policies. The gap analysis highlighted the critical needs for capacity development for embracing I4.0 at the national level to achieve inclusive and sustainable economic growth. In addition to a few e-learning

modules on I4.0, webinars were organized to disseminate various technology components of I4.0 and case studies of successful I4.0 implementations. More than 5,000 SMEs have benefited from these modules and webinars. Through a systematic process, Directory I4.0 of empaneled consultants, consulting companies, and solution providers was created and made available through the NPC portal.

To showcase the utilization of IT solutions for successful applications of I4.0 technologies in processes (to improve productivity), five demonstration companies, mostly SMEs, were selected and supported under the umbrella of the APO COE on IT for I4.0. In addition, a toolkit on I4.0 for SMEs has been developed to guide SMEs in identifying their own definitions, and approaches, to I4.0 and supporting them in adopting new and disruptive business models. An experience zone on I4.0 has been set up in the form of a studio for digital display of operational prototypes of IoT, AI, augmented/virtual reality (AR/VR), and simulation, along with storyboards, use cases, etc.

A study on ‘SME Readiness for I4.0 Adoption,’ conducted by Indian Institute of Information Technology, Sri City, Chittoor, has attempted to assess the readiness of the SME sector for adoption of I4.0 in five key sectors, namely, agriculture, automotive, food processing, pharmaceutical, and textile and garments. The study started with fact-finding workshops followed by a survey of SMEs and interviews of other stakeholders. In addition to sector-specific analysis and recommendations, the report covered cross-sector recommendations with specific action items for stakeholders.

Roles of Industry Bodies and Academic Institutions in Promoting Smart Manufacturing

The Confederation of Indian Industry (CII) Smart Manufacturing Platform is designed to make India an I4.0-enabled country, by working with government agencies, technology providers, user industries, consulting and audit agencies, education and research institutions, and international organizations to promote and develop excellence in I4.0 across the Indian industry. The platform is a one-stop shop to spearhead multidisciplinary I4.0 initiatives and services like assessment models, training programs, case studies, advisory services, state-level intervention centers, demonstration facilities, standardization, policy research, studies, and publications [22]. CII has set up five smart manufacturing demonstration centers to create awareness on I4.0 across the manufacturing industry. CII has also developed a set of 55 detailed case studies plotted on the map of India to represent the regional spread of deployment and implementation of smart manufacturing. Moreover, CII has conducted detailed primary and secondary research, including a study of various international programs and discussions with various stakeholders involving domestic and international consultations. It has also arrived at the ‘Action Plan for Fostering Adoption of Smart Manufacturing in India,’ and organized six smart manufacturing summits and more than 10 workshops in different parts of the country.

The Federation of Indian Chamber of Commerce and Industry (FICCI) has constituted a committee on I4.0. This committee aims to focus on creating awareness about this new technology across the industry and also support the government in developing a roadmap for the industry [23]. As part of the efforts, FICCI is capturing the major developments in smart manufacturing and disseminating them through newsletters. Along with Tata Strategic Management Group, FICCI has also carried out a survey on advanced manufacturing where over 90% of the respondents considered at least one of the advanced manufacturing trends relevant for their businesses. The committee has top industry leaders as members and the group will primarily focus on strategizing Digital India 2.0 with focus on smart manufacturing. FICCI has also instituted the country’s first-of-its-kind FICCI I4.0 Awards for Manufacturing to recognize organizations that are ahead on the path of digital transformation and would like to showcase their achievements as models for others to follow.

I4.0 offers a more comprehensive, interconnected approach to manufacturing. It ensures connection of the physical with the digital; and enhances the quality of collaboration across departments. It benefits industry owners to optimize their operations efficiently. Hence, it can easily be understood that educational institutes and universities should include new courses such as IoT, cyber security, robotics, and 3D printing in their curriculum, so that trained graduates are available for industries.

Tools and Techniques for Readiness Assessment at Enterprise Level

In the first phase, there is a need to create a critical mass of companies adopting smart manufacturing, which would lead to widespread adoption later. However, organizations want to ascertain their technical and operational capabilities and ensure that there is a potential for realizing significant benefits before they actually adopt smart manufacturing. Many companies are keen to check the viability of integrating smart manufacturing features with their existing manufacturing infrastructures. Organizations take up readiness assessments as part of their plan to adopt smart manufacturing. In addition, they also need smart manufacturing maturity models to assess the current state and accordingly pursue further plans. Some of the tools and techniques used by Indian companies for readiness assessment at the enterprise level are presented ahead.

APO–COE Digital Readiness Assessment Tool, called *Bharat 4.0*, can be used by organizations, especially SMEs, to assess their current level of digital readiness on five maturity levels, namely, starter, managed, adaptive, realizer, and top-notch (SMART). It also provides an overall assessment indicating the requirements and strategies to be adopted to transform to the next level. The tool is applicable to all companies, regardless of their industry, size, profile, and I4.0 maturity. It uses a digital questionnaire, which the company is required to answer. This is followed by an instant *Bharat B4.0 (B4.0)* evaluation report through e-mail. The B4.0 tool assesses three main drivers, namely organization strategy, manufacturing strategy, and digitalization strategy, which are covered through nine sub-pillars for gauging the readiness of I4.0.

ATS Smart Industry Readiness Index is developed by an independent solution provider to help manufacturers assess and raise their manufacturing maturity levels in the form of a Smart Industry Readiness Index (SIRI). It also takes a questionnaire-based approach to evaluate the relative readiness of various operational aspects of the plants by simplifying them along three building blocks of process, technology, and organization; eight pillars such as operations, supply chain, automation, connectivity, and intelligence; and 16 dimensions such as vertical/horizontal integration, shop-floor automation, and workforce learning. A SMART framework comprising five distinct elements, namely standardize, measure, architect, realize, and transform, is specially designed to help manufacturers improve their maturity levels for smart manufacturing by following a practical approach to digital transformation. While the first two elements help organizations develop an approach towards the whole assessment process and a detailed readiness assessment in line with SIRI, the other three elements (architect, realize, and transform) focus on designing and implementing a digital transformation strategy.

The Smart Manufacturing Assessment Model, developed by CII, uses criteria spanning the key aspects of the organization in its journey toward world-class smart manufacturing using digital technologies through the following five perspectives:

1. Leadership strategy: This requires the organization to determine its current state with respect to the level of smart manufacturing adoption and to set a goal state (e.g., from

level 1.0 to level 4.0) through management of resources, financial planning, and effective communication.

2. **People and organizational culture:** This aspect probes the level of understanding and knowledge of people on the core concepts of smart manufacturing and emphasizes the importance of collaboration across industry verticals.
3. **Infrastructure:** It focuses on core elements of digital manufacturing to determine the level of deployment of various technologies, including data security.
4. **Operations:** This component evaluates the extent of adoption of smart manufacturing tools in operations such as plant layout, design for manufacturability, and design for quality.
5. **Supply chain and logistics:** This component identifies linkages through alignment of information flow and seamless integration of supply chain partners, thereby enabling real-time decision making through use of collaborative tools for creating traceability chains up to component or part level. The outcome of self-assessment is presented in the form of criteria scores and visual charts.

Industry 4.0 Maturity Model (I4MM) was developed by C4i4, based on a joint industry survey conducted by the Department of Heavy Industries and Tata Strategy Management Group. I4MM is designed as a simple and effective model to understand the current state of I4.0 maturity and readiness for manufacturing organizations across all industries and helps them to plan a comprehensive and sustainable digital transformation roadmap. The model uses data collected from specific companies on various aspects. Based on in-depth assessments, tailor-made roadmaps and training sessions are provided to enable organizational teams to reach their full potential for smart manufacturing. Organizations are placed on one of the five levels of maturity, namely, beginner, explorer, investor, accelerator, and visionary. As part of the assessment, C4i4 has created a 90-day training-and-mentorship program to develop ‘digital champions’ who can spearhead, coach, and lead digital transformation within an organization.

The Enterprise Maturity Model for Excellence in Manufacturing has been developed by IIT Delhi-AIA Foundation for Smart Manufacturing. The model measures best practices necessary to ensure effective changes in both technologies and organizational cultures for smart manufacturing. In stage 1 (assessment), the model evaluates all facets of an organization’s existing IT network by examining the people and the processes that manage the network and the operations, while laying the foundation for more advanced technologies such as business intelligence software and cloud computing. Stage 2 (secure and upgraded network and controls) focuses on workshops with cross-functional teams to assess new technology options, establish vendor roadmaps and plot out future-ready scalable design for smart manufacturing. Stage 3, which pertains to defined and organized working data capital (WDC), defines and organizes the company’s WDC and determines how to leverage it for optimum gains. It helps organizations establish systems that allow them to identify how to turn data into tangible triggers for change and evaluate how CXO-level decisions benefit the bottom line. In stage 4 (analytics), the focus shifts from technologies to how to best leverage the new-found IT capabilities through real-time information and ability to act on the information with standardized protocols. Finally, in stage 5 (collaboration), organizations build predictive capabilities that make timely and leveled order execution, along with improved quality, streamlined plant-to-plant performances, and the ability to sense and manipulate plant processes on the fly.

The Evolving National Framework for Smart Manufacturing

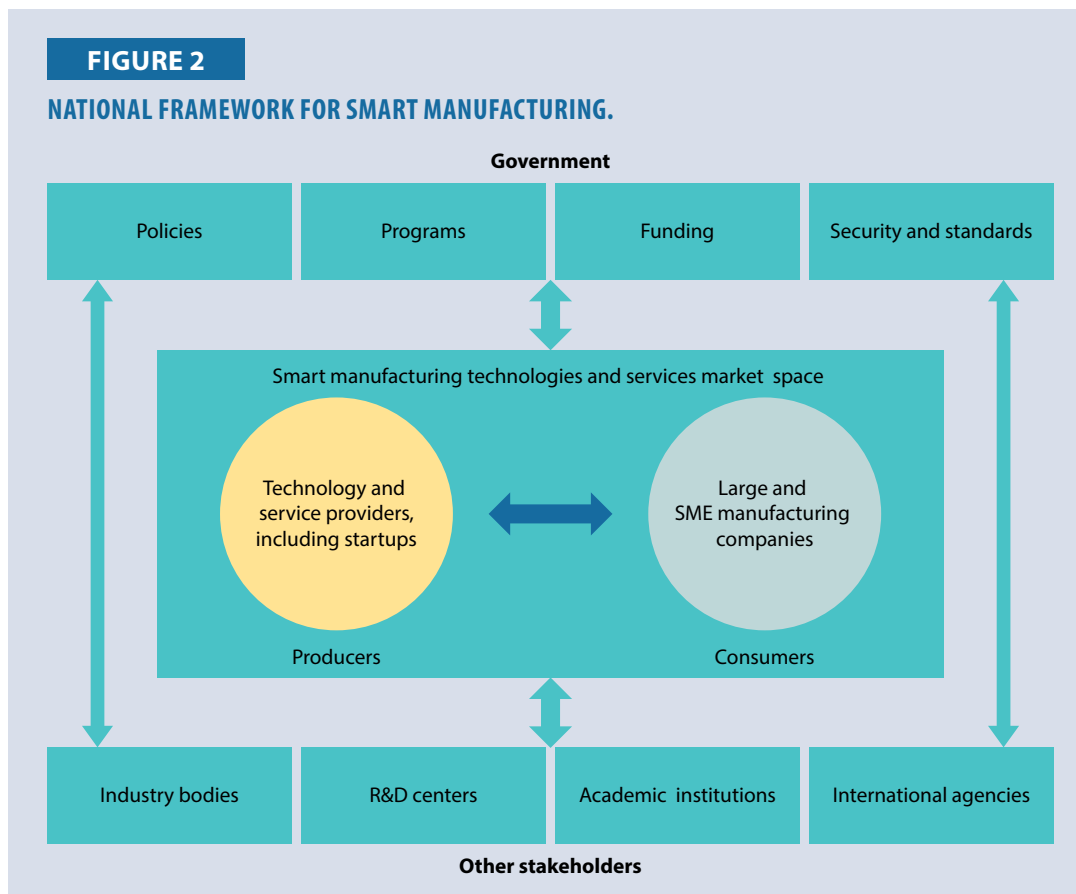
According to Gartner, with 50% of factory work expected to be done remotely by 2024, COVID-19 has only increased the investments made by manufacturers into smart manufacturing capabilities [24]. India is gearing up to leverage smart manufacturing for achieving economic leadership. Although the Indian manufacturing industry is fast embracing technology, it needs to confront the impediments that can impact the adoption of smart manufacturing. With manufacturing and conversion costs expected to reduce by 20% and 40%, respectively, with the deployment of emerging technologies in manufacturing, the smart manufacturing techniques are likely to be the new industry normal for manufacturers across sectors [25]. India's manufacturing industry is already moving in the direction of I4.0 where everything will be connected, and every data point will be analyzed.

The economic outlook of India and the underlying importance of the manufacturing sector highlight the importance of smart manufacturing. Given India's aspirations to become one of the top three economies of the world by 2035, driven by manufacturing competitiveness, and the near-term goal of achieving 25% of GDP from manufacturing by 2025, the government has to stimulate adoption of smart manufacturing at different levels. India's focus on smart manufacturing is significantly noticeable at the global level. The country has announced the Centre for the Fourth Industrial Revolution in India at the World Economic Forum [26]. The center has been developed in partnership with the Government of India through the National Institution for Transforming India (NITI) Aayog. According to a study by United Nations Industrial Development Organization (UNIDO) [27], India is the only lower-middle-income country that made it to the second group "followers in production," along with countries like Australia, Canada, Italy, Singapore, and Spain. Besides manufacturing capabilities, India also has a strong position in knowledge-intensive and ICT service businesses that control and connect the shop floor, supply chain partners, and markets. Although the financial impact of COVID-19 may currently be hampering investments in smart manufacturing technologies, obvious benefits of smart manufacturing would accentuate its adoption in the coming years. These technologies would better equip industries to face similar challenges in future and ensure improvement in overall efficiency and business continuity [28].

The successful implementation of smart manufacturing roadmap in the next five years will be of paramount importance for transitioning the manufacturing sector in India to be globally competitive. Participation and support of stakeholders ranging from the government, multilateral agencies, academia, and associations would be critical to establish an enabling ecosystem for faster adoption of smart manufacturing in India. It is imperative to have a national framework for smart manufacturing to achieve the targeted level of adoption and realization of benefits. Such a framework essentially needs to capture the role of the government and the underlying roles of other stakeholders. A national framework for smart manufacturing implementation is proposed, as presented in Figure 2.

The emerging smart manufacturing context is progressive and dynamic as per the technology options, nature of applications, implementation partners, investments, etc. The smart manufacturing technologies and services market comprising producers and consumers is at the centerstage of transformation. However, other stakeholders in the ecosystem play an equally important role in various forms. The smart manufacturing implementation has the following three primary constituents:

1. the smart manufacturing technologies and services market consisting of technology vendors and service providers including startups (producers) and large and SMEs manufacturing companies (consumers);



2. the government, which focuses on policies, programs, funding, and standards; and
3. other stakeholders including industry bodies, R&D centers, academic institutions, and international agencies.

India's smart manufacturing market is projected to witness considerable growth due to growing government focus and initiatives such as 'Make in India.' Moreover, the ease of foreign direct investment (FDI) is further attracting the attention of market players in the country. The market space has four types of entities comprising large technology providers and startups/mid-size niche companies as producers, and large manufacturing companies and SMEs as consumers of technologies. The smart manufacturing market is also classified on the basis of components, technologies, and end-use industries. Among these end-use industries, the automobile industry is contributing significantly to the market's growth. The key players of the smart manufacturing market include ABB Ltd., Emerson Electric Co., SAP SE, Schneider Electric SE, Siemens AG, Honeywell International, Inc., General Electric Co., and Intel Corp. These companies are playing a significant role in the growth of the smart manufacturing market by providing various products and adopting several strategies such as partnerships and collaboration, and technological development, among others.

A great opportunity exists for tech startups to disrupt the traditional manufacturing, logistics, and supply-chain sectors. For example, according to The National Association of Software and Service Companies (NASSCOM), more than 5,000 IoT patents were filed in 2014–19 while India was home to more than 480 Indian IoT startups in 2020 [29]. Startups offer increased flexibility and

customization to manufacturers at a significantly lower cost than that offered by more established technology companies. Moreover, startups have multidisciplinary teams of entrepreneurs who have worked on developing the technology and implementing it, which enables them to provide end-to-end solutions. Given their smaller sizes, they are more agile and responsive to changes in the ecosystem and are able to adapt to larger platforms as well as individualized needs of customers.

National Mission for Smart Manufacturing

Almost all the ministries and their departments related to the manufacturing sector have launched programs to promote smart manufacturing. However, there seems to be lack of a comprehensive long-term policy for effectively leveraging the smart manufacturing technologies. Such a policy framework could drive programs in an integrated manner, provide funding, and aid development of standards. The framework could also define the roles of smart manufacturing technologies, services markets, and other stakeholders; and enable them as well. It would also enable effective linking of other national programs such as Startup India, Digital India, and Skill India, thereby leading to a synergistic contribution towards transformation. Programs are to be focused to support smart manufacturing technologies and services market space consisting of technology and service providers including startups (producers) on one hand and large enterprises and SMEs as users of smart manufacturing (consumers) on the other hand. The policy framework needs to address how to create a win-win partnership between the providers and consumers, with the help of other stakeholders. There is a need to create a national mission with a mandate to drive a smart manufacturing-focused manufacturing transformation.

The national mission may adopt an ecosystem approach to help all market entities to achieve a win-win opportunity. This requires bringing them together and aligning them with industry bodies and others through a policy framework. The large technology providers such as ABB, Honeywell, Bosch, and Siemens are helping organizations in developing and implementing smart manufacturing technologies. However, the high costs of technologies and long implementation times deter mutual opportunities. Thanks to the Startup India program, the country is witnessing a large number of startups in this market space. They have made inroads into many industries within the manufacturing sector with innovative technologies and solutions. Their price points are very competitive as compared to large players, coupled with the advantage of a faster implementation cycle. However, many startups face huge challenges due to lack of supportive policies and are looking for markets outside India for growth.

There are also possibilities of large manufacturing companies helping their SME partners in the adoption of smart manufacturing technologies. For example, TAFE, a large tractor manufacturer in south India, has helped its 70-plus suppliers, mostly SMEs, through standard I4.0 technologies, resulting in benefits for both the entities. Such efforts have to be supported through direct financial incentives or reduced taxes. The governments may have policies to support SMEs through subsidies and other financial incentives for smart manufacturing implementation. Technological development may be funded by the government so that the solutions are made available at affordable prices.

The Government of India has launched major programs through Ministry of Heavy Industries, Ministry of Electronics and IT, and Department of Science and Technology, among others, to promote smart manufacturing. In 2015, the government launched an IoT policy that aimed at skills development, technological upgrades, and building IoT products specific to Indian demands, thereby occupying a considerable share in the global IoT market. In addition to the establishment of five COE under *SAMARTH Udyog Bharat 4.0*, the government has implemented a mission on

cyber–physical systems and allotted initial corpus to about 25 centers [30]. However, a continued funding to current programs and the need for additional programs is important, and therefore a long-term funding scheme has to be proposed specifically for smart manufacturing promotion.

Proliferation of smart manufacturing in all manufacturing industries is inevitable in a near future. The adoption of technical standards facilitates the expansion of both domestic and international markets. The Indian industry cannot shy away from adopting I4.0 standards and practices. It is important for organizations to participate in the development of standards that will shape the future of smart manufacturing technological development. Besides benefitting the industry, it will enhance the reputation of organizations that take a leading part in the development of impactful standards. In 2019, Bureau of Indian Standards (BIS) established a new technical committee dedicated to standardizations for smart manufacturing. However, it will be a long way to achieve certain levels of standardization maturity, which again, needs to be addressed by the government through appropriate policy initiatives. Moreover, India needs to develop adequate cyber security norms to safeguard the interests of ecosystem partners.

One of the key strengths in favor of India's foray into I4.0 is the IT services industry. India is one of the most sought-after IT outsourcing destinations in the world and houses some of the world's largest IT companies. India's IT expertise, along with the right infrastructure, can now be leveraged locally to catalyze I4.0 adoption in the country [31]. Indian IT companies are already on the lookout to bolster their I4.0 capabilities through R&D in order to seize the hidden opportunity. Apart from this, the IT majors have started exploring organizational tie-ups and collaborations to develop their I4.0 capabilities and offerings. IT services companies have also started increasing their focus on partnering with manufacturing companies from other countries to develop new solutions relevant to smart manufacturing.

Industry bodies such as NASSCOM, CII, and FICCI have been playing their roles in promoting smart manufacturing in India. These bodies have memberships from companies of different sizes, R&D centers, and academic institutions. At present, their focus is mainly on creating awareness, training, and demonstration facilities. However, NASSCOM has moved one step further to establish COE in collaboration with MeitY to link the technology developers and consumers. Such COE are yet to make a meaningful impact due to lack of integration with the entire ecosystem. For example, the major government programs launched through leading academic institutions have limited linkages with other important initiatives. Active participation of these bodies in the national mission will largely improve the effectiveness of the ecosystem.

R&D activity is vital because economies that have consistent levels of innovation tend to achieve high levels of manufacturing growth. The smart manufacturing landscape is vast in terms of technologies and applications, and requires R&D for faster development and implementation. Almost all the ministries related to manufacturing, science and technology (S&T), electronics, and IT have their own research centers. In addition, large technology companies have their own specialized research centers. These centers are required to collaborate on specific technology areas for the benefit of the industry. They also require collaboration with countries like Germany and the UK that have made significant progress towards successful implementation of smart manufacturing.

The role of academic institutions is pivotal for promotion of smart manufacturing in India. It has the primary responsibility of developing highly talented graduates who are industry ready. More and more industries and professionals undertake skill enhancement programs, not only for

immediate use, but also to make the employees future ready. Institutions also have to participate in reskilling and upskilling of the workforces to make them ready to take up emerging job roles. Top technology institutions such as IITs are at the centerstage for garnering government funds to set up R&D facilities and rope in industry partnerships for developing new technologies. R&D facilities are also used to promote innovation and startups in smart manufacturing technologies. More Indian institutions have to play a larger role in smart manufacturing-related R&D and skills development in the immediate future. Collaboration with leading universities in Germany, the UK, and PR China is essential for faster and better results in this domain.

Communication and sharing of best practices among industries and countries is important for achieving development and implementation of smart manufacturing technologies. International development and intergovernmental agencies such as the APO, UNIDO, World Economic Forum, the World Bank, and Asian Development Bank have key roles in supporting major programs and missions. India has to systematically move up the efforts to engage with these agencies for establishing relationships with industries and R&D centers of world's leading countries and channelizing funds required for the smart manufacturing mission.

Potential Collaborations and Dialogs in Smart Manufacturing with other Countries

Global supply chains are a common way of managing investments, production, and trade in the global economy. Effective supply chain gives companies a competitive advantage over others through increased efficiency, more sourcing options, elimination of wastes, increased output, and better customer service. Smart manufacturing has a significant role in improving the efficiency and effectiveness of global supply chains. Therefore, there is a greater need for collaboration among countries, both at global and regional levels, on smart manufacturing adoption. Such collaborations have to involve large as well as small providers of smart manufacturing technologies and services.

First, the collaboration among large companies happens through MNCs that have manufacturing locations in multiple countries. Local companies in different countries are able to gather insights from such MNCs and explore opportunities for smart manufacturing. Further, large smart manufacturing technology and solution providers such as ABB Ltd., Emerson Electric Co., SAP SE, Schneider Electric SE, Siemens AG, Honeywell International, Inc., and General Electric Co. have presence in multiple countries. Best practices are being shared by these companies with manufacturing industries across multiple countries. International agencies such as the World Bank, UNIDO, and others have to launch programs that will connect the manufacturing industries across many countries.

Second, collaboration among SMEs is enabled through many development agencies. German Agency for International Cooperation (GIZ), an international enterprise owned by the German Federal Government, is helping transfer of smart-manufacturing knowledge from Germany to other countries. The APO is spearheading collaboration through various approaches. The COE on Smart Manufacturing in the ROC and the COE on Industry 4.0 in India are significantly contributing towards collaboration across Asian countries, especially among SMEs. There are many smart manufacturing startups with innovative products and solutions present in these countries. A well-structured global or regional industrial policy is likely to provide a win-win opportunity for the startups and other manufacturing companies.

According to McKinsey, companies should build deep relationships with global players and technology providers to ensure access to latest technologies. In exchange, ASEAN companies can offer global players access to local markets for their products. Germany's SAP, for example, complements its

existing capabilities in IoT and machine learning by inviting other leading players to join it on a platform called the Co-Innovation Lab. The effort allows SAP to communicate with other players along its value chain to ensure a proper development of its own products and services.

Smart Manufacturing Adoption among Indian SMEs

SMEs occupy an important and strategic place in the economic growth and equitable development of India. They employ around 40% of the country's workforce, which equals an estimated 80 million people earning their livelihood through employment in low-skilled jobs. Around 1.3 million SMEs contribute 45% to India's manufacturing output and 40% to India's total export [32]. SMEs are the second-largest employment generators after the agriculture sector in India. The manufacturing SMEs, also known as the 'engine of growth' for India, have scaled significantly. They form 95% of total industrial units in the country and manufacture around 8,000 quality products for local as well as international markets [33]. To support its massive growth, India will need an ecosystem of suppliers across various tiers, with a higher level of automation flexibility achieved through digitization. If the local manufacturers including SMEs do not gear up, the opportunities will be lost to foreign players. Some key facts about the SMEs in India are given in Figure 3.



In spite of their contribution to the socioeconomic growth of India, SMEs face a number of challenges, including lack of capital due to inadequate access to finance and credit, inability to attract talented and tech-savvy manpower, and poor infrastructure and utilities resulting in low production capacity. Despite the challenges in the form of infrastructural constraints and lack of access to formal credit, they are thriving and standing tall to shoulder their responsibility towards India's economic and social development. It has been envisioned to increase SMEs' contribution to India's GDP to over 50% from the current 29%. For the Indian economy to scale the USD5 trillion mark, the role of SMEs will be crucial. Their export contribution, which currently stands at 50%, should be increased to 75% [34].

Indian SMEs could learn many lessons from leading economies such as Germany, Japan, and PR China. Bringing economies of scale into production is difficult for SMEs. Collaboration among SME units is the best way to find innovative solutions. Using a united approach to production and marketing for a cluster can help in standardization. Online marketplaces play an important role in helping SMEs expand their market reach. Such a collaboration is a win-win opportunity for both

the market parties, as it allows consumers to have more choices and SMEs to have new opportunities. Offering one-time support through different schemes is difficult as the needs of the SMEs are different. Very few SME players in India have the required visibility of global competitiveness.

There is a clear distinction between large and SME manufacturing companies. While the large manufacturing companies are supported by leading MNCs and startups for smart manufacturing implementation, SMEs really suffer due to many factors. The Indian SME sector is somewhere between Industry 2.0 and Industry 3.0 and India's unique challenge is to get the SMEs to automate their machines, refine their processes, and develop their skills and talents so that they can actually begin to understand the potential of I4.0. The pervasive use of IT is a prerequisite for successful adoption of smart manufacturing. The integration of the data generated in the value creation process requires networking of various IT systems, both within and beyond a company. The integration of physical systems on cyber platforms, which is an essential premise of I4.0, is still in its infancy. Due to a lack of resources and the inability to assess the technological maturity of potential solutions, it is not easy for SMEs to go for smart manufacturing. Lack of general standards makes it difficult for them to join value creation networks with different standards and norms, thereby constraining their ability to transform. It has been found that awareness and knowledge, technical competencies, and affordability are the key determinants of smart manufacturing adoption among SMEs. The findings related to these variables across five sectors, namely, automotive, agriculture implements, textiles, pharma, and food processing are presented in the sections ahead.

Smart Manufacturing Awareness and Knowledge

Programs of the Government of India such as Make in India and Digital India have made a significant impact on SMEs. Initiatives such as *Aadhaar* and Unified Payment Interface (UPI), among others, have created a foundational infrastructure for SMEs across all sectors. However, the level of I4.0 awareness ranges from 'very low' to 'very high' across the five sectors mentioned earlier. Industry associations have made efforts to push smart manufacturing-related information to their members through social media. However, given the small nature of their businesses, SME owners and managers tend to adopt a policy of 'nice to know' rather than 'need to know' when it comes to smart manufacturing. Creating awareness on smart manufacturing in terms of technologies, benefits, and basic information is an important milestone in making SMEs adopt smart manufacturing. Close linkages with OEMs enable automotive SMEs to acquire a high level of I4.0 knowledge. Further, sessions offered by technology providers, including startups, provide detailed presentations at the technology summits and other events that have helped the SMEs.

Smart Manufacturing Technical Competencies

Technical competencies required for smart manufacturing among SMEs are based on the size of the firms and the level of IT adoption in their administration and manufacturing functions. Given their financial conditions, it is not possible for SMEs to acquire additional IT manpower to fulfill the needed I4.0 competencies. It is observed that most automotive SMEs located in industrial estates are serviced by a set of local consultants and vendors. Specialized institutes set up in the respective sector may be provided support to conduct technical training. For example, COE set up by Automotive Components Manufacturers Association (ACMA) in two locations, Sonipat and Gandhinagar, help SMEs to develop technical competencies. Machinery suppliers may take up the responsibilities for providing training to their SME customers. Similarly, OEMs may focus on their tier 2 and tier 3 suppliers for imparting technical skills. Research and technical institutions may play an important role in developing technical competencies through short-term technical training, including live demonstrations and certification programs, as per the requirements.

Affordability of Smart Manufacturing Technologies

Affordability is one of the major concerns of SMEs across sectors. First, the overall economic situation, especially over the last couple of years, has not been favorable for making any investments in smart manufacturing. Many in the SME sector are hard pressed for capital expansions and working capital requirements due to thin margins. Moreover, such technologies take longer lead times to realize the benefits of investments, thus discouraging SMEs to commit upfront investments. It is understood that government support is very important for all sectors and may be in the form of capital subsidy and interest subvention through various existing schemes for different industry sectors. It was also proposed that higher depreciation may be allowed wherever capital subsidy is not relevant or possible. It was also proposed that academic institutions are best placed for developing cost-effective solutions and democratizing the solutions, along with implementation support with funding through DST, MeitY, and other departments.

Potential Actions by Stakeholders

Based on the learning from workshops and the preliminary discussion with industry associations, SMEs typically go through a lifecycle once they decide to adopt smart manufacturing. It starts with being aware of high-level details of I4.0, followed by acquiring detailed knowledge, gaining technical competencies, and getting funding support to adopt smart manufacturing. Given the global scenario, cutting-edge competition, and changing business environment, it is expected that SMEs have to adopt advanced manufacturing technologies, including I4.0. The role of key stakeholders to address the top three determinants for smart manufacturing adoption by SMEs is summarized and presented in Table 1.

TABLE 1

ROLES OF KEY STAKEHOLDERS IN ADDRESSING TOP THREE SMART MANUFACTURING DETERMINANTS.

Stakeholder	Knowledge and awareness	Technical competence	Affordability
Academic institutions	<ul style="list-style-type: none"> Conduct seminars for cross-sector SMEs located in the region. Organize exhibitions and lecture sessions in IEE, CSI Chapters. I4.0 COE of NPC to design awareness programs. 	<ul style="list-style-type: none"> Conduct basic- and advanced-level training for specific sectors. Develop self-learning material for various sectors. Develop online platform to provide training to various sectors. 	<ul style="list-style-type: none"> Develop cost-effective solutions and democratize the solutions. Provide cost-effective implementation support to SMEs.
Technology providers	<ul style="list-style-type: none"> Share case studies of successful implementations. Conduct technical training for SMEs. Machinery suppliers to organize sessions for SMEs. 	<ul style="list-style-type: none"> Launch training programs in industry estates. Certify technically competent professionals. 	<ul style="list-style-type: none"> Work on cost-effective solutions to make them affordable. Offer standard and advanced solutions for SMEs to choose from.

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Stakeholder	Knowledge and awareness	Technical competence	Affordability
Industry associations	<ul style="list-style-type: none"> Conduct dedicated sessions at the annual national-level events. Conduct technical workshops by technology at annual conferences for owners. Organize regional seminar sessions. OEMs to sponsor and share case studies. 	<ul style="list-style-type: none"> Conduct training need assessments and share with agencies. Facilitate SMEs in attending the training sessions and workshops. Augment Industry 4.0 skill components in degree/diploma programs. 	<ul style="list-style-type: none"> Provide inputs to the government for designing various schemes. Facilitate SMEs in availing the benefits of the schemes. Provide feedback to the government and funding agencies.
Government	<ul style="list-style-type: none"> Expose association office-bearers to international trends in I4.0 adoption. Sponsor sessions and seminars at national/regional levels. Fund institutions to organize seminars. Recognize successful I4.0 implementations. Launch a scheme for demonstration companies in each sector at strategic locations. 	<ul style="list-style-type: none"> Sectoral skill councils to focus on technical training. Certify technically competent professionals. Provide special funds for specialized institutes for organizing training programs. Empanel consultants for each sector to assist SMEs. 	<ul style="list-style-type: none"> Promote incubation centers for startups in I4.0. Provide capital subsidy for those sectors that cannot afford initial investments. Provide interest subventions, subsidies on depreciation, etc. Allow OEMs to support their SMEs with cost-sharing arrangements and claim subsidies or tax exemptions. Machinery suppliers may be provided subsidies for I4.0 features. Enable standardization of I4.0 technologies.
Legend: Relative importance	High	Medium	Low

Conclusion

India is rapidly emerging as a preferred country for foreign investments in the manufacturing sector. Several mobile phone brands as well as luxury and automobile brands, among others, are already here or have plans to establish their manufacturing bases in the country. The manufacturing sector in India has the potential to reach USD1 trillion by 2025. According to a Cushman & Wakefield Report 2021, India has emerged as a global manufacturing hub and effectively surpassed the USA to become the world's second-most desired manufacturing destination. This indicates the growing interest in India by manufacturers as a preferred manufacturing hub over other countries. Widespread adoption of smart manufacturing would be a game changer in leveraging the global opportunities. While large enterprises are likely to accentuate the smart manufacturing adoption efforts in the next few years, SMEs require significant thrust through policies and funding from the government and other stakeholders. The national framework proposed in this study, along with the establishment of a national mission for smart manufacturing, would enable and support the country.

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MALAYSIA

Introduction: Manufacturing Sector in Malaysia

The manufacturing sector is an important economic sector of Malaysia. It has contributed an average 23% to the overall GDP of Malaysia in the last five years [1]. As of date, the growth of the manufacturing industry has brought about the effect of stimulating job growth, attracting foreign investments, and creating business and work opportunities throughout Malaysia. The manufacturing sector is estimated to remain a strong pillar on track to achieve a targeted annual GDP growth rate of 5.1% under the 11th Malaysia Plan (11MP). The manufacturing industry has also played a significant part in providing job opportunities for the local population, with an estimated 2.28 million workers in the manufacturing industry making up for 14.55% of the total employed personnel in the country. It is crucial to note that the manufacturing sector is made up of a large number of SMEs, which account for an estimated 97.1% of the total establishments in the sector. Although most of the existing SMEs do not have a strong global presence, a large number of them have the potential to be global exporters.

In July 2020, Malaysia's manufacturing sales stood at MYR119.3 billion, having grown 1.9% compared with July 2019. The rise in sales value was driven by food, beverages, and tobacco products (24.9%); transport equipment and other manufactured products (14.3%); and electrical and electronics products (8.4%). Based on the Monthly Manufacturing Survey, the total number of employees engaged in July 2020 were 2.19 million, after a decrease of 2.4% as compared with 2.25 million in July 2019. The decline was mainly attributed to transport equipment and other manufactured products (-5.6%); wood, furniture, paper products, and printing (-5.1%); and electrical and electronics products (-2.4%). Salaries and wages paid amounted to MYR7.1 billion in July 2020, after a drop of 3.2% or MYR236.7 million, compared with the same month of the preceding year. All these declines were mainly due to the COVID-19 pandemic. However, the sales value per employee grew 4.5% to MYR54,403 as compared with MYR52,072 in July 2019. Meanwhile, the average wage per employee was MYR3,235 versus MYR3,262 in July 2019 [2].

By the year 2018, Malaysia's internet penetration had risen to 85.7%, compared with 70.0% in 2015 [3]. A considerable number of SMEs in Malaysia are still at a stage where computerization can be done with minimal effort, though this is beginning to change, especially in the e-commerce sector. However, the manufacturing sector is still slow and is currently stuck between Industry 2.0 and 3.0, according to the Ministry of International Trade and Industry (MITI).

Definition of SMEs in Malaysia

A definition of SME was officially endorsed in the 14th National SME Development Council (NSDC) meeting in July 2013 [4]. It covers a wide range of sectors, namely manufacturing, services, agriculture, construction, mining, and quarrying. Under this new definition, SMEs are defined as

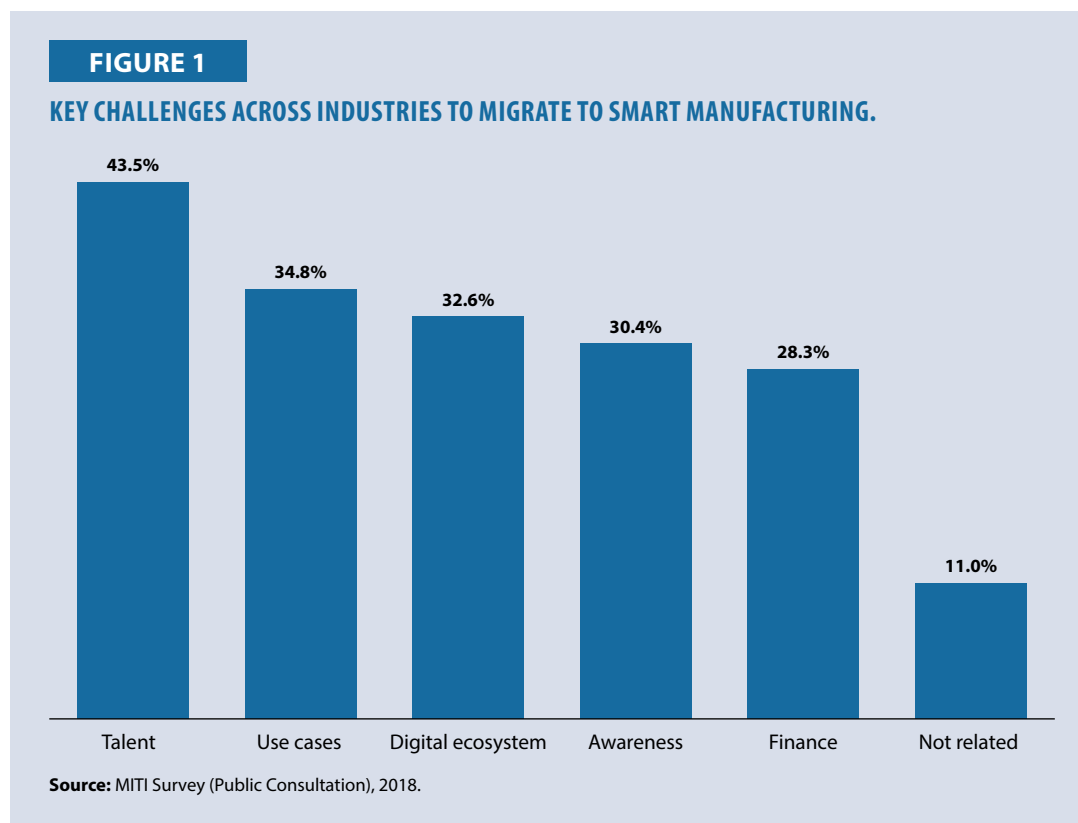
- those companies in the manufacturing sector having sales turnover of less than MYR50 million or full-time employees less than 200; and

- those companies in services and other sectors having sales turnover of less than MYR20 million or full-time employees less than 75.

Additionally, to be qualified as an SME, the said entity must be registered with the Companies Commission of Malaysia (CCM), more commonly known as *Suruhanjaya Syarikat Malaysia (SSM)*. However, this requirement excludes entities that are publicly listed on the main board; subsidiaries of publicly listed entities on the main board; multinational corporations (MNC); government-linked companies (GLCs); Minister of Finance Incorporated entities; and state-owned enterprises [3].

Challenges of Smart Manufacturing Implementation

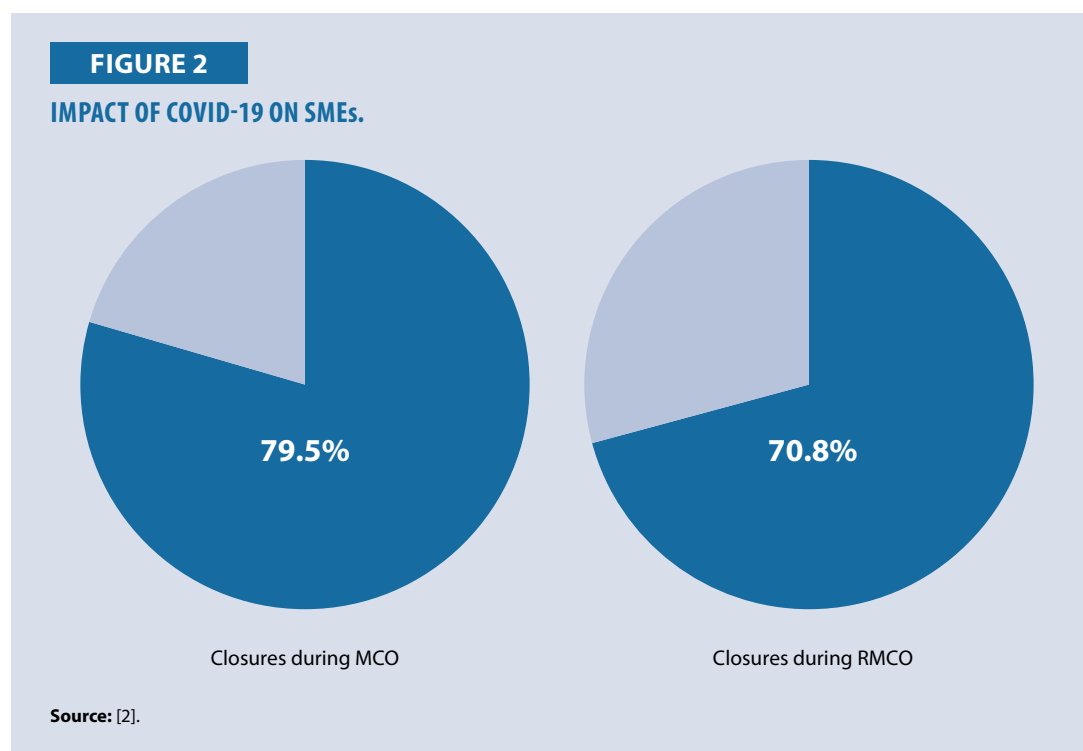
The SME Association of Malaysia (SME Malaysia) conducted an online survey titled SME Industry 4.0 Quick Survey in the month of September 2019. The survey was distributed mainly through e-mails to over 10,000 business communities, to gauge the general interest of the industry toward I4.0, and subsequently, toward smart manufacturing. The results revealed that the adoption of smart manufacturing technologies was rather low due to various obstacles. According to the survey results compiled by SME Malaysia, only 2.7% of SMEs were implementing smart manufacturing initiatives in certain processes of their production while 75% had not taken any actions despite attempts made in trying to understand more about smart manufacturing. The survey had further drilled down to the reasons that were preventing SMEs from embracing smart manufacturing and had identified three main reasons based on the responses: (1) smart manufacturing requires a massive financial investment backing, which SMEs cannot afford (54% of the respondents); (2) SMEs have no clear idea of where to start implementing smart manufacturing and who to look for to help them kickstart this journey (32% of the respondents); and (3) SMEs are unsure if they are ready for smart manufacturing (29% of the respondents).



Across the board, there also existed another set of key challenges in migrating current technologies to smart manufacturing. One, 43.5% of the industries agreed that it was a challenge to obtain, source, or upskill talents that were ready for smart manufacturing. Next, there was also a lack of relevant use cases as reference points, as indicated by 34.8% of the industry players. Besides that, industry players were concerned that the existing digital ecosystem was not fully developed to sustain smart manufacturing. Lack of awareness was also agreed upon as a challenge in migrating to smart manufacturing by 30.4% of the respondents. Further, financial issues also formed a key challenge in migrating to smart manufacturing. Since most industry players were SMEs, they needed a sturdy financial backing, apart from meeting their current business operating needs, when migrating to smart manufacturing.

Impact of COVID-19 and the Countermeasures

Along with the unfortunate circumstances that led to a ravage across the globe, the pandemic has left a dent on Malaysia's manufacturing industry like it has for the rest of the world. According to the survey conducted by the Malaysian Investment Development Authority (MIDA) and the Department of Statistics Malaysia (DOSM), the manufacturing sector had suffered a potential loss of MYR12.9 billion during the 14 days of Movement Control Order (MCO) [5], i.e., the *cordon sanitaire* implemented by the federal government of Malaysia in response to the pandemic. The manufacturing sector's total exports were MYR834 billion, i.e., 84.6% of the total national export of MYR986 billion. The exports of the manufacturing sector had a potential loss of MYR32.0 billion during the 14 days of the MCO [6].



In response to the outbreak of COVID-19, the Malaysia Productivity Corporation (MPC) is carrying out a survey to have a clear understanding of the current business status and needs of Malaysian-owned businesses effectively and immediately. The data collected will be analyzed, in order to build relevant and useful assistance schemes or programs to help SMEs that are affected by COVID-19. The impact of COVID-19 on SMEs in Malaysia is that 79.5% of the companies had

suspended their operations during the MCO. During Recovery MCO (RMCO), an estimated 70.8% of companies had ceased their operations. It may be noted that RMCO was a loosened control order issued by the Prime Minister with reduced limitations on travel and gathering for Malaysian citizens, in order to improve and revitalize the economy [7].

Along with the MCO announcement, the Federal Government of Malaysia had implemented the Wage Subsidy Programme to address the impact of COVID-19 on the economy. As of 19 June 2020, MYR4.89 billion had been approved for a total of 303,596 employers, benefiting an estimated 2.4 million workers [8]. As compared to 19 April 2020, when the approved amount was MYR1.2 billion for 159,000 employers, increasing the number of persons benefiting from the Wage Subsidy Programme meant that more jobs were saved [6]. The People-centric Economic Stimulus Package or *Pelaksanaan Pakej Rangsangan Ekonomi Prihatin Rakyat (PRIHATIN)* and the National Economic Recovery Plan or *Pelan Jana Semula Ekonomi Negara (PENJANA)* had also been launched to ensure that as much as possible, the unemployment rate be controlled and possibly reduced. At the same time, the plans aimed at protecting and cushioning the financial burden of the people, supporting local businesses that were affected, and strengthening the local economy. The *PRIHATIN* scheme was worth MYR250 billion while *PENJANA* was worth MYR35 billion [6]. The Central Bank of Malaysia, Bank Negara Malaysia (BNM) had indicated that the packages were estimated to add 2.8% to GDP growth in 2020 [9].

Upon various requests from multiple interest groups to provide better support for SMEs, which are the backbone of Malaysia's economy, on 6 April 2020, an additional MYR10 billion was allocated to further strengthen the support for SMEs [10]. Thus, together with the previously announced economic stimulus packages, the total amount pledged by the government for the *PRIHATIN* economic stimulus package became MYR260 billion.

In Malaysia, there is an ongoing call for the manufacturing industry to shift toward higher value-added processes, digitization, advanced manufacturing technologies, and resource utilization to drive competitiveness. To ease the transition of industry members toward implementation of smart manufacturing and automation technologies and concepts, Malaysia has earnestly been investing in the development and growth of this sector. The Ministry of International Trade and Industry (MITI) has been leading the integration and adoption of smart manufacturing and I4.0 and preparing industry players in Malaysia for growth and innovation, while aligning with the 2050 National Transformation or *Transformasi Nasional 50 (TN50)*. *TN50* is a 30-year transformation plan that was launched by the sixth prime minister of Malaysia, with the intention of building the foundation for Malaysia for the next thirty years, starting from the year 2020 [6]. MITI had taken the initiative by tabling the National Policy on I4.0. The policy is to assist Malaysia in advancing the local businesses and factories toward smart manufacturing, and subsequently, achieving I4.0. It intends to serve as a guide to provide useful insights by defining parameters and definitions of smart manufacturing; assist in increasing efficiency, productivity, and quality of industry players; and develop the skills needed by the local talent pool.

Smart Manufacturing Context in Malaysia

There are some important technologies that enable smart manufacturing. These technologies include but are not limited to autonomous robots, simulation, system integration, internet of things (IoT), cyber security, cloud computing, additive manufacturing, augmented reality (AR), and big data. These are the smart manufacturing technologies that are going to be in trend for the next foreseeable years.

The integration of smart manufacturing is still a very foreign concept for most of the SMEs in Malaysia. To assess the digital capabilities of smart manufacturing, another common denominator is that the technologies require a stable and high-speed connection for them to work. The average connection speed in Malaysia is 23.86 Mbps, which ranks 30th in the world. In comparison, the neighboring Singapore has a staggering speed of 70.86 Mbps, which amounts to the second-fastest internet connection speed in the Asia region as well as the entire world [11]. This shows that Malaysia still has plenty of room for improvement to catch up to be digitally ready to accept and integrate smart manufacturing. Apart from speed, the stability and coverage of the internet also need to be addressed as there are still some parts in Malaysia where the internet is not accessible.

From a geographical standpoint, it should be noted that Penang, one of the states in western Malaysia's northern region, was aptly named as the Silicon Valley of the East due to its technological advances [12]. The Industrial Zone of Bayan Lepas in Penang is a famed semiconductor hub in Malaysia. Bayan Lepas, which is a major smart manufacturing location booming with its free industrial trade zones and strategic location near transportation and shipping hubs, is undoubtedly a leader in the country's smart manufacturing activities. In the central part of western Malaysia, the economic activities are more focused on the rubber industry. The vast stretches of rubber plantation in the region have helped it become an active site for the production and manufacturing of rubber-based products. The central region of Malaysia oversees smaller scales of smart manufacturing activities and implementation. However, the east coast of western Malaysia and the two states of eastern Malaysia, namely Sabah and Sarawak, are having less smart manufacturing activities.

Smart Manufacturing Policies

SME Corporation Malaysia (SME Corp) is the central coordinating agency (CCA) under the Ministry of Entrepreneur Development and Cooperatives (MEDAC) that coordinates the implementation of development programs for SMEs across all related ministries and agencies. SME Corp acts as the central point of reference for research and data dissemination on SMEs and entrepreneurs and provides business advisory services for SMEs and entrepreneurs throughout the country. SME Corp had launched the SME Masterplan, a policy that focuses on productivity and innovation-led growth for SMEs in Malaysia [13]. One of the goals of the SME Masterplan is to align SMEs with the new, growing trends in Malaysia's industry. One of such trends is Industrial Revolution 4.0, which is closely linked with smart manufacturing.

In response to Industrial Revolution 4.0, Industry4WRD: National Policy on Industry 4.0 was launched on 31 October 2018 by the Ministry of International Trade and Industry (MITI) to drive digital transformation of manufacturing and related services sectors in Malaysia. This policy focuses on achieving four goals: (1) drive growth in the manufacturing sector; (2) increase national productivity; (3) create higher-skilled employment opportunities; and (4) raise innovation capabilities and competitiveness. It is believed that the Industry4WRD Policy will enable and allow the manufacturing sector to take the first few steps toward transitioning to smart manufacturing and subsequently to I4.0, and will also be able to contribute toward fulfilling Malaysia's commitment to the United Nation's Sustainable Development Goals (SDGs).

The decision to develop this national policy on I4.0 stems from the intention to transform the manufacturing industry in Malaysia and enable its related services to be systematic, resilient, and smart. Countless discussions have been opened to discuss the impact of I4.0 on the local businesses, the society, and the industrial and economical scene at large.

The main agencies that are responsible for the implementation of smart manufacturing are the MPC, MIDA, and Human Resources Development Fund (HRDF), to name a few. The MPC is primarily in charge of the productivity of the nation. Having multiple productivity nexuses under its care, the MPC would be one of the core government agencies to lead the transformation of the manufacturing industry with smart manufacturing. It has an assessment program called the Readiness Assessment, which is a tool used to gauge the preparedness of an enterprise for smart manufacturing integration and provide the means and methods for the enterprise to integrate smart manufacturing into its operating space. COE will be involved as treasurers in this scenario, as they will primarily be focusing on financing for the enterprises that wish to integrate smart manufacturing and transition to I4.0. The funding assistance would be in the form of matching grants or program schemes so that enterprises would be able to secure enough finances to bolster themselves against the changes. Next, HRDF would be responsible for providing and preparing talent pool and workforce. They will be in charge of supplying training courses for trainers and trainees alike, while also allowing the current workforce in the industry to avail the training programs to upskill and prepare themselves to be able to navigate the new technological industrial wave.

Smart Manufacturing Priority Industries

The industries that have a higher priority for the development of smart manufacturing are electricals and electronics, machinery and equipment, chemicals, medical devices, and aerospace, as compared with other sectors such as automotive, transport, textiles, pharmaceutical, metal, food processing, and services. These six sectors are the sectors that are considered to be the sectors with high potential. The electricals and electronics industry spearheads Malaysia's manufacturing sector, playing a big role in contributing to the country's employment and exports status. The subsectors of the electrical and electronics industry are: electronic components, consumer electronics, industrial electronics, and electrical products. Machinery and equipment industry is the next in line that has key potential areas for growth and further development. By having high-value and high-technology machinery and equipment, this industry can contribute to the development and integration of smart manufacturing. Particularly, subsectors such as specialized machinery and equipment for specific industries would be contributing to smart manufacturing. Included here are subsectors such as general industrial machinery and equipment, along with parts and components, power-generating machinery, and machine tools.

The chemicals industry is a catalyst industry within Malaysia that also has a high potential for the integration of smart manufacturing alongside its rapid growth. The industry will act as a catalyst for the development of other industries. There is also an abundant availability of oil and gas as a primary commodity, which acts as a base for usage by other industries. Medical devices also form an ever-expanding industry, spanning across an enormous range of supplying industries ranging from rubber, latex, plastics, machinery, as well as engineering and electronics support.

The aerospace industry is also one of the industries in Malaysia that has the potential to be a high-value sector from the implementation viewpoint of smart manufacturing. It is a strategic sector with a promising potential and scope for growth. Aerospace is widely involved in Malaysia's industrialization as well as technological development programs. The potential for industrial growth lies in its subsectors such as engineering and design; aero-manufacturing; system integration; and maintenance, repair and operations (MRO). The aerospace industry and its subsectors will be able to provide opportunities to the manufacturing industry by stimulating and generating the need for the suitable technology to be implemented. To bring these priority industries to a conclusion, there also are a number of industries that have high potential for development. These include automotive,

transport, textiles, pharmaceutical, metal, food processing, and service industries. They are heavily involved in the provisioning of essential services, which makes them very desirable candidates for smart manufacturing-related adoption and transformation. They could be the priority sectors that would be adapting themselves for smart manufacturing technologies and be frontliners in leading Malaysia's manufacturing industry's transformation to smart manufacturing [14].

Tools and Techniques for Readiness Assessment at Enterprise Level

To fully integrate and enable smart manufacturing in Malaysian enterprises, there currently exists a program by the Federal Government of Malaysia called the Readiness Assessment.

Readiness Assessment is a program conducted by the MPC, as part of the Budget 2019 measures taken to accelerate the adoption of smart manufacturing. An amount of MYR210 million has been allocated for the period 2019–21 in order to support the Readiness Assessment program. The guidelines for Readiness Assessment were created based on an initial study conducted with 22 companies. Guidelines on manufacturing-related sectors were estimated to be finalized for proper implementation in the second quarter of 2019 [15].

The MPC is responsible for spearheading the Readiness Assessment program to facilitate up to 500 SMEs to upgrade to smart manufacturing. Readiness Assessment is a comprehensive tool to help companies and firms in assessing their readiness and capabilities in adopting the technologies and processes of smart manufacturing. The Readiness Assessment utilizes predetermined guidelines and criterion to understand and analyze a company's current capability and identify any gaps in reaching smart manufacturing standards. This enables the company to prepare and execute feasible strategies and plans for moving toward smart manufacturing. Readiness Assessment is able to determine the company's readiness in adopting smart manufacturing along with opportunities for productivity improvement and growth.

Besides Readiness Assessment, a new tool, Productivity 1010, was launched on 29 August 2020. This program is led by the Machinery and Equipment Productivity Nexus (MEPN), an initiative consisting of four main machinery-and-equipment sectoral initiatives that were identified by the Malaysia Productivity Blueprint (MPB), with the intention of improving productivity across enterprises. The four initiatives of MEPN are to (1) set up partnerships between government and industry associations to upskill existing employees; (2) set up COE for skilled professionals to share industry expertise and develop new technologies; (3) update domestic product standards to be at par with international standards to enforce compliance; and (4) set up more product testing facilities to ensure that the standards are met.

Productivity 1010 has two main activities as its core. These are: 'Digitization Self-diagnostic and Prioritization Matrix' and 'Business Virtual Advisory Mentoring.' Both these are efficient tools to help businesses start their digitization journeys. MEPN is targeting an estimated 1,000 companies from the manufacturing sector to kickstart Productivity 1010 with the intention to improve their productivity for long-term competitiveness. Not just improving an individual enterprise's ability to remain competitive, this program also intends to train and produce more than 20 industry experts to initiate the transfer of knowledge and technology to the industry. Digitization Self-diagnostic is an online self-assessment tool that offers enterprises a series of questions, allowing them to self-diagnose their own businesses in the field of digitization. Upon completion of assessment, enterprise could opt for participation in the Business Virtual Advisory Mentoring (BVAM) Program

conducted by the MPC. The BVAM Program offers a virtual mentoring session of 10 hours of duration, under the guidance of a board of 20 system integrators from The Malaysia Industrial 4.0 System Integrator (MISI4.0) and Malaysia Automation Technology Association (MATA), certified as mentors by the MPC. Meanwhile the ‘Prioritization Matrix’ tool is a management planning tool, encompassing 4Rs of reality check, ROI calculation, review KPIs, and reference global best practice. The intention of this tool is to assist companies in quantitatively identifying the high-priority index dimensions where improvements will bring the maximum benefits [16].

While Readiness Assessment is conducted by the MPC, Productivity 1010 is fully endorsed by the MPC. With the involvement of the MPC in conducting Readiness Assessment, enterprises that are able to pass the Readiness Assessment not only have a clear overview of their readiness on I4.0 and smart manufacturing, but are also able to benefit in the form of more open doors to a wide range of projects and grants that are under the care of either the MPC or other government agencies.

Readiness Assessment

The assessment criteria for Readiness Assessment are based on three shift factors, namely people, processes, and technology (see Figure 3).

People: By focusing on the people and the whole organization, the emphasis is on implementing feasible strategies towards building a suitable workforce. This is achieved by developing the human capital that is needed as well as creating a sustainable transformation process with suitable activities for smooth transition with regard to an organization’s business and growth strategies, governance, and collaboration.

Processes: The focus is on the management system that is in charge of business operations, product lifecycle, and supply chain. The process of transformation involves an emphasis on strategic, smart, and suitable business partnerships; process security; economic sustainability; and innovative cocreation of products.

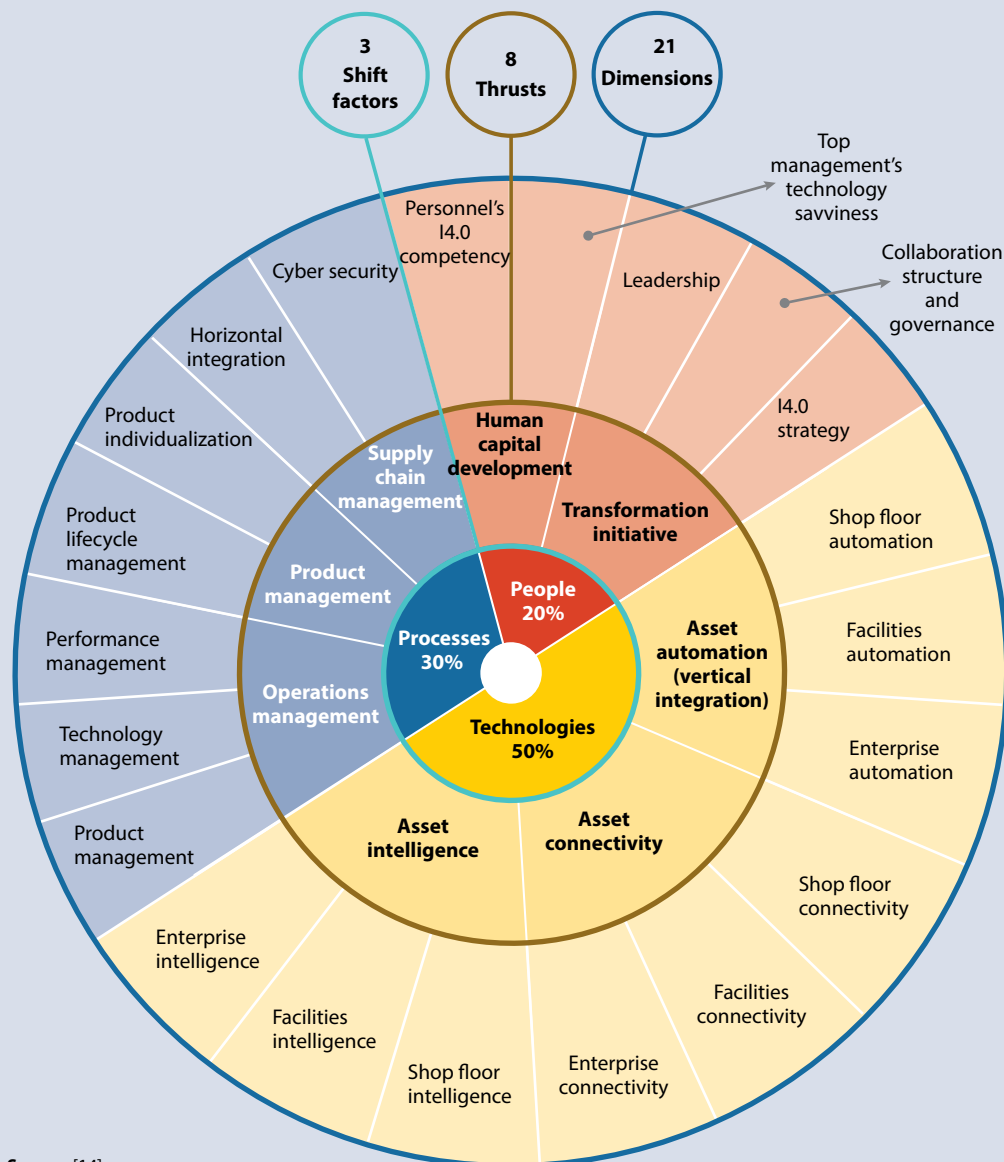
Technology: This is about giving attention to the application of automated, connected, and intelligent technologies. The technological criteria are measured by three different layers of the business, namely, enterprise, shop floor, and facilities.

Each shift factor is a core that branches out into smaller, more specific branches known as thrusts. Thrusts are activities that would speed up or facilitate the development of that specific core. Within thrusts are dimensions, i.e., clusters of different sectors that are responsible in working together to assist their respective thrusts in accelerating the core development.

Within the people core, the respective thrust activities are human capital development and transformation initiative. The dimensions that made up human capital development are personnel’s I4.0 competency, as well as top management’s technology savviness. The dimensions for transformation initiative are leadership, collaboration structure and governance, and I4.0 strategy.

The three thrust activities that make up the process core are supply chain management, product management, and operations management. Supply chain management contains dimensions such as cybersecurity and horizontal integration. Product management works with the dimensions of product individualization and product lifecycle management. Operations management has three dimensions, which are performance management, technology management, and product management.

FIGURE 3
READINESS ASSESSMENT CRITERIA MODEL.



Source: [14].

Of all the three cores of the Readiness Assessment criteria, technology is considered to be the biggest core. The thrusts that make up the technology core are asset automation (vertical integration), asset connectivity, and asset intelligence. Asset automation connects with shop floor automation, facilities automation, and enterprise automation. Asset connectivity is made up of dimensions such as shop floor connectivity, facilities connectivity and enterprise connectivity. Asset intelligence deals with dimensions of shop floor intelligence, facilities intelligence, and enterprise intelligence.

The pros of using Readiness Assessment are that it is a comprehensive tool and a well-rounded program that has been designed with the similarities of various industries in mind. This means that it allows enterprises to utilize Readiness Assessment for their smart manufacturing journey, without raising the concern whether the guidelines stipulated in the Readiness Assessment are of appropriate

relevance or not. The program is a one-size-fits-all, ensuring that sectors across all industries will have an equal opportunity to improve themselves and stand a chance to upgrade to smart manufacturing to be more competitive.

The only con is that the assessors for Readiness Assessment must also be adequately equipped and prepared to guide and advise various types of enterprises in the industry. Readiness Assessment's assessors will have to be enriched with the appropriate manufacturing knowledge. It would be even better if they come from the relevant industries so that they can utilize their experience to guide enterprises hailing from the same industry. This is because there would be different sets of criteria and requirements to assess the readiness of companies for smart manufacturing. The variety of assessment criteria will better assist the assessors and their respective agencies to facilitate smooth communication between them and the companies being assessed, thereby allowing for a better chance to encourage and assist more companies from each industry in implementing smart manufacturing. Therefore, the assessors themselves must first be prepared with the arsenal of knowledge needed, in order to guide the enterprises in smart manufacturing implementation.

Productivity 1010

There are two major process flows of Productivity 1010, namely the Digitization Self-diagnostic Tool and Business Virtual Mentoring Services (BVAM), as shown in Figure 4.

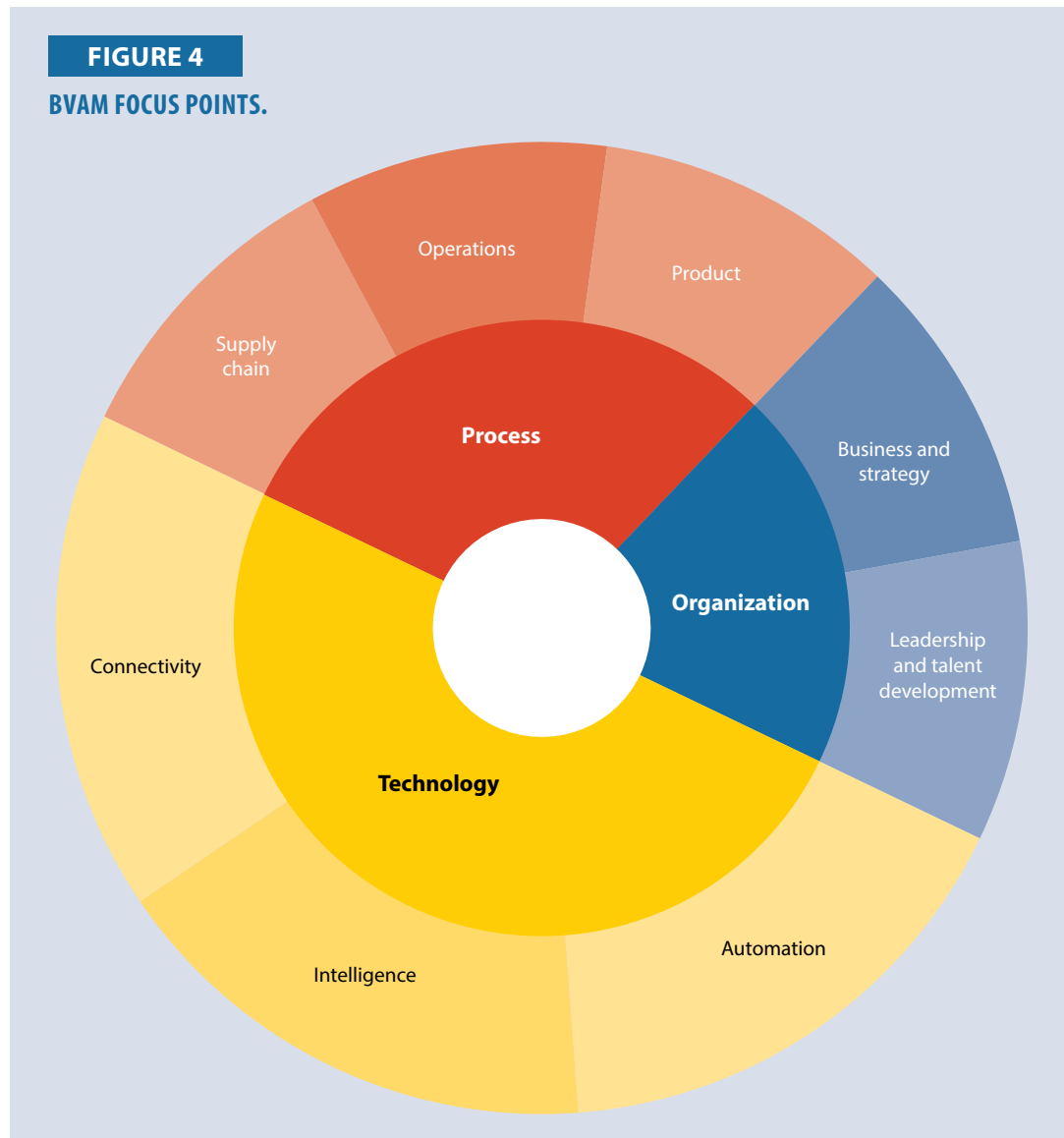
Enterprises that chose to participate in Productivity 1010 as their steppingstone to I4.0 will have to undergo a self-check with the use of the Digitization Self-diagnostic Tool, answering 15 questions that are related to their current business and operating environment. Upon completing the assessment, the companies' readiness for I4.0 and smart manufacturing is graded based on their answers. Each enterprise gets its own Readiness Profile, which is a standard grading scale that shows where the enterprise stands on readiness for I4.0 and smart manufacturing. The Readiness Profile has five categories, naming observer, beginner, learner, leader, and master.

The observer profile is for enterprises that get a score of 0–20% with the Digitization Self-diagnostic Tool. The beginner profile has a score of 21–40%; the learner profile has a score of 41–60%; and the leader profile has a score of 61–90%. The master profile is graded the highest, with a score in the range of 91–100%.

An observer enterprise is one that has operations remaining 'as is,' with no intention or initiative to venture into the adoption of digitization. Beginner enterprises show a clear interest in undertaking digitization but with minimal initiatives and efforts to do so. Learner enterprises show the interest and intention to go for digitization adoption in their operating environments, have the plans and strategies in place, and exhibit observable efforts and initiatives being carried out and implemented in the workplace. These enterprises are also ready for system adoption. Leader enterprises are enterprises that have pursued small- to medium-sized digitization adoption initiatives and are currently carrying them out. They are also carrying out horizontal integration and are ready for large-scale system adoption. Master enterprises have already implemented large-scale, company-wide digitization adoption initiatives; and have already integrated a new system in favor of the existing one.

After knowing their Readiness Profile scores and where they are currently placed on I4.0 and smart manufacturing readiness, enterprises could go for BVAM, which is a management planning tool that enterprises could make use of to understand in detail and find out more about the current standing of their smart manufacturing journey.

The coaching focuses on three points, namely, process, technology, and organization. Within these focus points lie different focus areas. For process, the focus areas are operations, supply chain, and products. For technology, the focus areas are connectivity, intelligence, and automation. For organization, the focus areas are business and strategy, and leadership and talent development.



In the 'process' focus point, coaching is done to improve the equipment readiness for smart manufacturing implementation as well as the degree of digitization of an enterprise's vertical value chain. This means that there is focus on integration of processes and systems across all hierarchical levels of the automation pyramid, from product development to production. The degree of customization of an enterprise's available products is also assessed. The adaptation of product lifecycle is also determined, to find out the degree of automation within the production line. It may be noted here that an integrated product cycle is the integration of multiple parties such as people, processes, and systems along the entire product lifecycle. This lifecycle is inclusive of the research, design, and development stages as well as the engineering, production, customer use, service, and disposal stages. Lastly, it is assessed if the enterprise's supply chain system links up with its customers and suppliers, and how much automation technology is being integrated at the moment.

For the technology focus point, the most forefront requirement that is assessed is the automation adaption level of an enterprise. Technology intelligence is essential for processing and analyzing data in order to optimize and improve existing processes, so that the enterprise is able to introduce new products, services, and application methods to the operating environment. Assessment is also done of the collection of data generated during operational activities, and the enterprise is coached to further utilize and improve upon making the best out of the collected data. It is also important to note that manufacturing equipment must be intelligent enough to be able to self-optimize the processes. The connectivity between different equipment, machinery, and systems must also be established to enable seamless data exchange within different departments of the organization. The degree of interconnection is important to allow interaction and exchange of information. Aside from that, the security and integrity of the enterprise must also be weighed thoroughly, for it contains the working recipes of the said enterprise. Therefore, the degree to which IT and cyber security have been implemented in an enterprise must also be assessed.

Coming to the 'organization' focus point, the two focus areas are business and strategy, and leadership and talent development. An established digitalization strategy and designated roles for design and execution of long-term smart manufacturing goals are important to provide a roadmap as well as a plan of action for the enterprise's smart manufacturing journey. The roadmap could include items such as a system of rules, practices, and processes, to translate a vision into business value, and the presence or absence of an urgency to see it to fruition. Besides that, the top management of an organization should also be adequately prepared to drive the implementation of smart manufacturing. The competency of the top management mostly refers to the readiness of the senior management team to leverage the latest and upcoming trends and technologies, to allow the enterprise to remain highly competitive while being incredibly relevant and related to the latest technological practices and values.

The benefit of using Productivity 1010 is that it is an easily and readily available tool for enterprises of all sizes. The assessment test is available online, so enterprises could access it at any time they desire. The beneficial aspect of virtual business mentoring is that enterprises could enjoy the guidance of industry experts without having to arrange for a venue for those experts. Besides, the guidance can be personalized to fit an enterprise's needs, so there need not be any concern about irrelevant content. The downside of Productivity 1010 is that it may not be as comprehensive as Readiness Assessment in terms of implementation, as Productivity 1010 is more of a self-assessment tool for an enterprise's self-enrichment purpose. Nevertheless, it is still a relevant tool for enterprises that wish to determine where they belong on the smart manufacturing readiness scale.

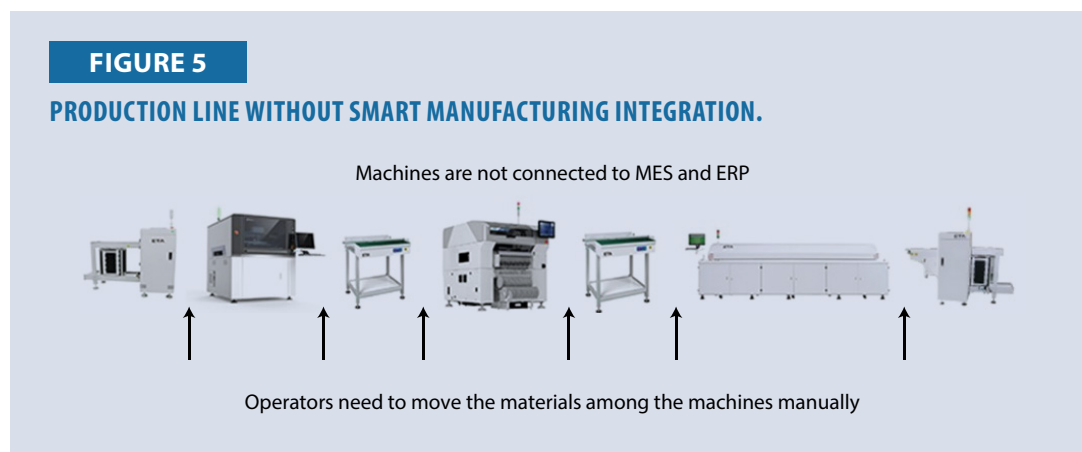
Smart Manufacturing Structure

The priority sectors chosen for smart manufacturing structure are Malaysia's two major subsectors in the electrical and electronics sector. These are electronic manufacturing service (EMS) and semiconductor industries. Based on these two subsectors, a model will be developed to form the basis of a national-level framework to be widely implemented across Malaysia's manufacturing industry.

EMS refers to a sector that provides a wide range of value-added engineering and manufacturing services. EMS is also often used interchangeably with the more generic term 'electronics contract manufacturing.' In short, EMS allows manufacturers to improve operational efficiencies and focus on core activities.

Semiconductor industry engages in the design and fabrication of semiconductors. The industry is the main driving force behind the electrical and electronics industry. As semiconductors have become more heavily embedded in an ever-increasing number of products, from cars to coffee makers, and with the rise of nascent technologies like artificial intelligence (AI), virtual reality, and internet of things (IoT), the global demand for semiconductors has increased [17].

Currently, enterprises rely on manpower such as operators or engineers in order to oversee the smooth operation of the entire manufacturing process. Operators are mostly tasked with physically moving the components from one machine to another, or from the machine to the conveyor in order for it to be able to transport over to the next machine (see Figure 5). Engineers mostly oversee the entire process flow, making sure that there are no unexpected discrepancies or errors that might arise, and act on them if there are any.

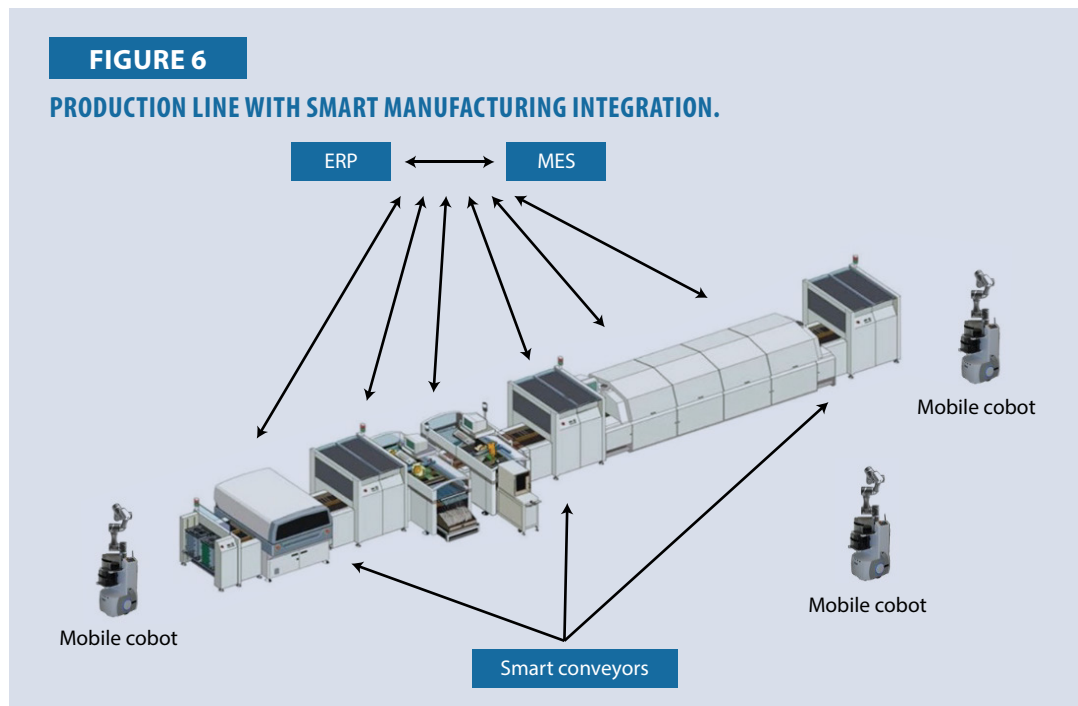


Most of the machines that are deployed in the factories are not connected horizontally with each other. Also, they are not connected vertically to a centralized server that hosts enterprise resource planning (ERP) and manufacturing execution system (MES) software. They are operating in the shared environment individually, aided by external help from the operators.

For the machines to be horizontally connected, the contribution of new technologies must be considered. The use of smart manufacturing technologies such as smart conveyors, automated guided vehicles, and robotic arms is essential in allowing the individual machines to be connected horizontally with each other. This would enable the reduction of labor and manpower across the production line, thus taking enterprises a step closer to automation, and consequently, to smart manufacturing.

For the manufacturing line to be vertically connected, each machine in the manufacturing line must be connected to a centralized local server, which would act as a hub that oversees the entire manufacturing process flow and also act as a controller for all the machines that are connected to it (see Figure 6).

With horizontal and vertical integration, we can define the combination of both the integrations as smart manufacturing. The intelligent automation technologies such as smart conveyors, robotic arms, and automated guided vehicles, when put together with the unconnected machines, would create a more complete integrated system that could be defined as smart manufacturing. The goal is to bring about the interconnection of machines and automate them; integrate them to the server as part of a bigger network; and enhance them with functionalities such as visualization, real-time



monitoring, remote control, predictive maintenance, overall equipment effectiveness (OEE), and utilization, among various other smart manufacturing capabilities. Some individual machines may have the potential to communicate with a centralized server. However, the ones that do not have the capability to do so could be upgraded with technologies such as smart sensors, IoT, big data, and cyber-physical production systems.

There exists an urgency for the establishment of a smart manufacturing framework. This framework is needed to help the establishments with a reference point and the enterprises with a blueprint to follow, in order to fully integrate smart manufacturing in the operating sites. Currently, the national policy on Industry 4.0 and Smart Manufacturing, Industry4WRD, highlights the achievable goals and milestones, which are high-level visions for the nation to set sight on. To penetrate further into the deliverables to achieve the said goals, a smart manufacturing implementation framework is needed. This will allow the manufacturing industry to have a better understanding of the tasks that they need to carry out, in order to fully embrace smart manufacturing.

The combination of high-level policy and mid-level deliverables will bring about an increased adoption of smart manufacturing among SMEs across various sectors and industries. In summary, the idea that is visualized in the policy, combined with the actions that can be taken in the framework, will result in a large number of smart manufacturing implementations. The smart manufacturing framework can also tackle the pain points of SMEs, such as lack of reliable operational data for business decisions, which is a key reason why SMEs are unable to grow fast enough despite a high level of expertise and product quality. This leads to an inability to strategize where the capability and capacity building is to be focused. The shortage and rising cost of labor can also be eliminated with the introduction of smart machinery and computerized processes. Unpredictable downtime will also be reduced, as smart manufacturing will be able to enable predictive maintenance across the entire production chain. Other suitable maintenance procedures can also be performed whenever needed, before the machine gets to the point of expiration or needs maintenance. Thus, the overall efficiency of the production line will be improved.

Proposed Framework for Smart Manufacturing Implementation

Enterprise Level

At the enterprise level, the three acting catalysts, namely, action, actor, and outcome will exist in each phase of the implementation roadmap. The aim of the enterprise-level implementation of smart manufacturing is to bring an enterprise from the stage of being unaware to the implementation stage.

Initially, the idea is to bring about the awareness and importance of smart manufacturing in an enterprise to decision makers. This can be initiated through a conversation started by dedicated personnel hailing from places of interests such as technology centers or lighthouses. In this scenario, the actors are the dedicated personnel, the action that they do is initiating the conversation, and the outcome is that they spark the awareness for the need of smart manufacturing within the enterprise.

In the next phase, the said enterprise will have to come up with a plan. Planning will be carried out in order to come up with a strategy or a blueprint, so that the enterprise has a clear idea of what is to be done to implement smart manufacturing. In this scenario, the actors are the enterprise's decision makers, the action taken is the planning and creation of the strategy or the blueprint, and the outcome is the existence of the plan or the blueprint.

Next, the enterprise will engage a consultant experienced in smart manufacturing, to oversee the implementation roadmap, provide feedback on any shortcomings, or give suggestions on the existing blueprint. In this scenario, the consultant is the actor, the providence of the consultancy service is the action taken, and the outcome is an enhanced and complete roadmap.

Thereafter, a technical team is to be assembled, be it an internal team within the enterprise, or an external team to which the tasks are outsourced. The team will carry out the solutions that are outlined in the roadmap, while performing installation tasks and jobs wherever necessary within the enterprise. In this scenario, the technical team is the actor, the installation jobs that it carries out as per the solutions depicted in the roadmap form the action, and the outcome is the upgraded operations base that is created for the enterprise.

In order to carry out the smart manufacturing implementation as a whole, the first and foremost need that comes to mind is financing. To carry out an implementation, the finance department, with or without the help of a government agency, will have to provide sufficient financing to supply the labor and workmanship of the technical team to implement smart manufacturing. In this scenario, the finance department, alongside the government agency, is the actor that will carry out the actions to provide financing to the technical team, leading to an outcome, i.e., a funded project.

In the final stage, the enterprise will also have to engage trainers who are experienced in educating in the area of smart manufacturing, in order to provide training to the enterprise's working personnel and upskill the said talents so that they are able to fully utilize the smart manufacturing environment and the enterprise truly achieves the smart manufacturing status. In this scenario, the trainers are the actors, and the training they provide to the personnel is the action that they carry out, followed by the outcome of upskilled talents who are well-prepared to navigate in a smart manufacturing environment.

National Level

At the national level, we are looking at a whole industry and any or all of its subsectors to implement smart manufacturing. The implementation framework is built with the idea that our target audience

will primarily be SMEs, as SMEs make up a large portion of Malaysia's manufacturing sector. However, this scheme is also available for the existing MNCs and LLCs in Malaysia for their perusal. Once again, the use of the three catalysts, namely, actor, action, and outcome will be utilized, with the hope of providing a clearer insight and a better comparison of the enterprise-level framework and the national-level framework.

The elements that make up the national-level framework are awareness, assessment, planning, financing, talent sourcing, and technology provisioning. The awareness element is needed to increase the number of SMEs that are aware of smart manufacturing. Planning is important for SMEs to have a clear idea of how to go about implementing smart manufacturing. Financing is also an important factor in order to monetarily fund the activities needed to carry out the implementation. Talent sourcing too is crucial because there exists the need for appropriate talents to do the smart manufacturing implementation and handle any subsequent innovative upgradation works. Finally, technology provisioning is a key element needed to realize smart manufacturing.

To bring about awareness, the huge percentage of SMEs that are yet to be fully aware of smart manufacturing in Malaysia, will need a bigger scale to kickstart and get the conversation going. Awareness campaigns will lead to the organization of activities such as technology exhibitions, industrial talks, and networking seminars, to name a few. These events will undoubtedly feature a huge group of SMEs from various sectors of the manufacturing industry, brought together by either the sheer interest of expanding their horizons, or under the influence of esteemed guests and/or organizations. These events will be hosted by government agencies such as the MPC, which is known for spearheading smart manufacturing activities; technology centers; universities; or associations such as the Federal of Malaysian Manufacturers (FMM) and the SME Association of Malaysia. The organization of such activities under the umbrella of awareness campaign will effectively spread awareness around the importance of smart manufacturing among SMEs. In this scenario, the actors will be the government agencies, technology centers, universities, and associations. They will organize or co-organize awareness campaigns, which will form the action undertaken, while the outcome will be the successful spread of awareness on smart manufacturing implementation and its benefits.

Next, to assess the readiness levels of SMEs, they will have to first undergo an assessment of their current standing on smart manufacturing readiness. This can be done either through on-site inspection or by undergoing a self-check assessment. (There are several dedicated government agencies providing such services, with the departments available in order to better assist and facilitate the assessment process.) This will allow more SMEs across various sectors to understand their current readiness on smart manufacturing, thereby allowing them to review their existing states and further review the recommended steps to achieve smart manufacturing. In this scenario, the actors will be the government agencies, which will be providing actions such as on-site or self-assessment, and allowing SMEs to reach their outcome, i.e., a better and clearer understanding of their smart manufacturing readiness.

The planning stage will also require SMEs to have a collective strategy and a concise roadmap to serve as a guideline, which will help them know how to kickstart their smart manufacturing journey. This stage usually requires a number of activities to be carried out, with training for top management being a core one. Top management training will be provided by government agencies, who will be assisted by industry experts, tech-center personnel, academic professors at universities, and such others. Proper guidance is needed and expected by the top management across SMEs in order to achieve the national implementation of smart manufacturing. Only when the top minds come

together bearing the same goals, the entire sector or industry of a country could start to take a new shape. The training for top management will not be a regular training. Instead, they will be educated on aspects such as coaching, mentoring, planning, and the like. This is because the top management's understanding will indirectly cause a ripple effect, spreading the use of smart manufacturing across SMEs. In this scenario, the actors are government agencies (e.g., the MPC), technology centers, industry experts, and universities. They carry out their actions of providing training for top-management persons in SMEs, and the outcome is the creation of a blueprint or a strategy to implement smart manufacturing.

For financing, government agencies such as MIDA and SME Corp have been consistently providing financial support for SMEs to improve and upgrade their working environments in line with the latest technological trends. In the new national implementation framework blueprint, these agencies will be in charge of provisioning of funds to SMEs in order to carry out the smart manufacturing upgradation activities. In this scenario, the actors will be the government agencies (e.g., MIDA and SME Corp); their actions will be to procure funds for the SMEs; and the outcome will be that smart-manufacturing upgradation activities get funded.

When it comes to providing talents, it is discovered that there are two separate paths that the country can undertake. The first path is to upskill existing talents and make sure that they are well-equipped for the new smart manufacturing technologies. The second path is to prepare the upcoming workforce to be ready for the era of smart manufacturing. For upskilling of current workforce, trainings could be conducted by the government agency in charge of talents and the workforce, i.e., the Human Resources Development Fund (HRDF). For the preparation of the next generation, science, technology, engineering, and mathematics (STEM) divisions of tertiary-education institutes could assist by preparing relevant course content and suitable hands-on activities to nurture interest and grow skills. The education scheme could be under the care of the Ministry of Education (MoE), which would be in charge of coming up with an appropriate syllabus to be implemented across STEM divisions, in order to fully prepare STEM graduates for smart manufacturing. In this scenario, the actors are the HRDF and the MoE, who will carry out the action of conducting training and preparing STEM courses and subjects relating to smart manufacturing. This will lead to the outcome of having a workforce, both existing and upcoming, which is fully prepared to navigate in the new era of smart manufacturing.

Regarding the provisioning of technology, be it machinery, software, components, or licensing, a joint effort will be required from various government agencies to come together and pool resources, to make sure that SMEs are well-supplied. This will involve agencies such as the Malaysia Digital Economy Corporation (MDEC), MIDA, Ministry of Science, Technology and Innovation (MOSTI), and even MoE and Collaborative Research in Engineering, Science and Technology (CREST). The involvement of MoE and CREST will be to engage tertiary education institutes to collaborate with industrial players. This will help prepare and produce talents that are well-versed and adequately equipped with smart manufacturing knowledge.

Conclusion

To conclude this report, the additional insights and inputs of equal importance are to draft the legalities surrounding smart manufacturing implementation. Appropriate court laws to prevent foul play or misuse of technology or power should be considered, to better secure the physical and financial safety of industry players with the newly integrated smart manufacturing technologies.

Discussions and collaborations with other neighboring countries should also be encouraged to stimulate different insights, while keeping proper safety methods in place in the wake of the COVID-19 outbreak. Issues that could draw more attention would relate to financial procurement, as global businesses have taken a hit due to the pandemic outbreak. So, a balance must be maintained between sustainability and development. The smart manufacturing framework will be implemented more effectively if there is more awareness around smart manufacturing, because the drive for constant planning and action will only come from a proper understanding of the concepts.

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PAKISTAN

Introduction to Smart Manufacturing

Manufacturing Sector of Pakistan

Pakistan is a developing country with a GDP growth rate of 3.29% and population of 212 million, according to Economic Survey of Pakistan 2018–19. The GDP was estimated at USD284 billion, which ranked it 42nd globally. Pakistan's economy has experienced frequent boom and bust cycles. Typically, each cycle comprised three to four years of relatively higher growth followed by a macroeconomic crisis that necessitated stabilization programs. The preceding five years have seen an average growth rate of 4.7% against a target of 5.4%. The fiscal year 2018–19 witnessed a muted growth of 3.29% against an ambitious target of 6.2%.

Three main pillars contributing to the country's GDP are industry (20.3%); agriculture (18.5%); and services (61.2%) [1]. Manufacturing is the largest among Pakistan's industrial sectors. The contribution of manufacturing to GDP had hovered in the range of 13.5–13.8% for almost a decade, while in the fiscal year 2018–19 it declined to 13.0% [2].

The manufacturing sector is further divided into three segments, i.e., large-scale manufacturing (LSM) with a share of 78% of the manufacturing sector; small-scale manufacturing (SSM) with a share of 15.2%; and slaughtering with a share of 6.9%. LSM's overall contribution to the GDP stands at 9.5%, while SSM contributes 2.04% and slaughtering contributes 0.94%. LSM mainly includes textile, cement, fertilizer, edible oil, sugar, iron and steel products, tobacco, chemicals, pharmaceuticals, machinery, food processing, automobile, telecom, electrical and electronics, non-metallic mineral products, and medical instruments, primarily surgical. SSM covers industrial and household units engaged in manufacturing activities, having less than ten employees. Slaughtering constitutes products such as meat, hides, skins, bones, and blood.

The manufacturing sector is the driver of economic growth due to its forward and backward linkages with other sectors of economy. This sector provides employment opportunities to around 16.1% of the total labor force.

Role of SMEs in Manufacturing Sector

Small and medium enterprises (SMEs) make a significant contribution to the total GDP of Pakistan, according to Small and Medium Enterprises Development Authority (SMEDA) working as an autonomous body under Federal Ministry of Industries and Production (MoIP), Government of Pakistan. Unfortunately, there is no single definition of SMEs in Pakistan. Different government departments categorize them according to their perspectives. Normally, SMEs are defined as per the definition of SMEDA and State Bank of Pakistan (SBP).

As per the definition by SMEDA, SMEs are enterprises having employee base of up to 250 persons with a paid-up capital of PKR25 million and annual sales turnover up to PKR250 million. This definition was an outcome of a consultative process spanning over two years, followed by scrutiny

and refinement at various levels of government before its finalization and approval by the Federal Cabinet in 2007.

SBP broadly defines SMEs as comprising (1) small enterprises (SEs) with employment size up to 20 persons and having sales turnover up to PKR75 million; and (2) medium enterprises (MEs) with employment size of 21–250 persons (for manufacturing and services sectors) and 21–50 persons (for the trading sector) and having annual sales turnover from PKR75 million to PKR400 million [3].

SMEs' share in the annual GDP is 40%, and they generate significant employment opportunities for skilled workers and entrepreneurs. Small- and medium-scale firms represent nearly 90% of all the enterprises in Pakistan and employ 80% of the nonagricultural labor force. These figures indicate the potential for further growth in this sector.

SMEs play a key role in shaping national growth strategies and employment generation and improving the standard of living of vulnerable segments of the society. They are the backbone of the economy but lack the resources to adopt new technologies and improve their production based on latest developments. To provide impetus to the SME sector and enhance its competitiveness, the present government is developing National SME Policy through SMEDA, which would serve as Government of Pakistan's master plan for providing support to catalyze growth of the sector. The focus of the policy is on job creation, export enhancement, and increased contribution of SMEs in the national economy. A cohesive strategic framework for business facilitation across the public-sector institutional infrastructure, both federal and provincial, will be developed for the implementation of policy under the principle of ease of doing business.

Impact of COVID-19

The economic fallout of coronavirus is visible not only in the countries most affected by the pandemic but also across the globe. Pakistan's economy, which was already in a low-growth phase due to macroeconomic imbalances and was undergoing a stabilization program, was hard hit by COVID-19 during the last quarter of 2019–20. The economic growth declined to a historical low of –0.4%. Activities in the manufacturing and services sectors, like for the rest of the world, were adversely affected. The decline in services sector was particularly substantial due to a larger impact of social-distancing norms. This adversely hit daily workers during the lockdown that was enforced to control the spread of the pandemic. Agriculture grew by 2.7%, but industry contracted to a negative 2.6% and services to a negative 0.6% against the growth targets of 3.5%, 2.3%, and 4.8%, respectively [4].

Impact of COVID-19 on Manufacturing

Industrial sector plays a significant role in the economic development of the country. It contributes almost 20% to GDP and employs 24% of the total employed labor force. The sector was envisaged to grow 2.3% on the back of manufacturing sector (2.5%), utilities (1.5%), and construction (1.5%). However, it faced a major brunt of the COVID-19-related shutdown and depicted an overall contraction of 2.3%. The LSM sector showed a decline of 5.40%. Major declines were observed in textile (2.6%); food, beverage, and tobacco (2.3%); coke and petroleum products (17.5%); pharmaceuticals (5.4%); chemicals (2.3%); automobiles (36.5%); iron and steel products (8%); electronics (13.5%); engineering products (7.1%); and wood products (22.1%). Increases were witnessed in fertilizer (5.8%); leather products (5%); rubber products (4.3%); paper and board (4.3%); and nonmetallic mineral products (1.8%) [4].

Pakistan has the ninth-largest labor force in the world. Almost 4 million youth are being added every year to the total civilian labor force, which stood at 65.50 million in FY2017–18. The existing labor force participation rate of 31.7% (crude) and female participation rate of 14.6% need to be enhanced. Due to the outbreak of the COVID-19 pandemic, most of the non-agriculture informal workers (27.3 million) and home-based workers are at risk of losing their jobs [4].

Relief to Industry by Government of Pakistan

The government is fully cognizant of the impact of COVID-19 and has taken certain emergency measures to lessen the adverse impact, especially for industry workers, daily wage earners, and street vendors. These programs include:

- Prime Minister’s Emergency Relief Package of PKR1,200 billion;
- provincial relief packages;
- SBP’s Refinancing (*Rozgar*) Scheme;
- reduction in policy rate;
- Prime Minister’s *Kamyab Jawan Programme*, a skill development initiative; and
- Prime Minister’s *Hunarmand Pakistan Programme* (Skills for All).

SBP has complemented the government efforts and announced various monetary measures to address challenges posed by COVID-19 to employment and growth. The key measures are being discussed in the next section.

Facilitating New Investment

SBP has announced Temporary Economic Refinance Facility (TERF) and its *Shariah*-compliant version to stimulate new investments in manufacturing. Under this scheme, the SBP will refinance banks to provide financing at a maximum end-user rate of 7% for 10 years for setting up of new industrial units. Total size of the scheme is PKR100 billion, with a maximum per-project loan size of PKR5 billion.

Reduction in Interest Rates

In March 2020, the policy rate was cut by 75 basis points. On 24 March 2020, 16 April 2020, and 15 May 2020, the policy rate was further reduced by 150, 200, and 100 basis points, respectively.

Relief Package for Businesses

SBP, in collaboration with Pakistan Banks Association (PBA), announced a comprehensive relief package for businesses, including microfinance companies, SMEs, and corporates across commercial, retail, and agriculture sectors/segments to ensure adequate liquidity amidst growing disruptions.

Incentivizing Businesses to Support Employment and Prevent Layoff of Workers

SBP introduced incentives for businesses under refinance scheme for payment of wages and salaries to workers and employees to prevent layoffs. To shoulder the scheme, Federal Government allocated PKR30 billion under a credit-risk-sharing facility for banks, spread over four years, to share the burden of losses due to any bad loans in future.

Prime Minister's *Kamyab Jawan* Program

To provide decent work and employment opportunities for youth joining the labor market, Prime Minister launched *Kamyab Jawan Youth Entrepreneurship Scheme (PMKJ-YES)* in October 2019. Under this scheme, PKR100 billion would be disbursed to 140,000 youth entrepreneurs over five years, which will create around 1 million employment opportunities for the youth in Pakistan.

Implications of COVID-19

Due to the spread of COVID-19 in Pakistan in February 2020 and rapid increase in cases on a daily basis, the country was put under a nationwide lockdown by the government from 1 April 2020. The lockdown was extended twice and lasted until 9 May 2020. The government also announced closure of all private-sector industries and technical/vocational institutes till 31 May 2020, resulting in suspension of all corporate trainings and technical/vocational trainings offered by Gujranwala Tools, Dies and Moulds Centre (GTDMC) under donor-funded projects. Similarly, due to the lockdown, mostly industrial units were closed and GTDMC technical services were also affected. Overall, revenue streams of organizations were severely disturbed.

However, as COVID-19 has resulted in high-level economic suffering for many other countries, its limited exposure in Pakistan may create substantial economic benefits for many export-oriented Pakistan's industries and may also result in import substitution. Such opportunities create room for enterprises like GTDMC, which facilitates local industries through latest technologies, skilled workforce, and expert consultancy services.

Definition of Smart Manufacturing in Pakistan

In this modern era of industrialization and increasing global competitiveness among countries, Pakistan is still lagging behind due to long-term socioeconomic challenges. There is no approved definition of smart manufacturing in Pakistan. The merging of virtual and physical worlds through cyber-physical systems and the resulting fusion of technical processes and business processes are leading the way to this new industrial age of smart manufacturing. Smart factory products, resources, and processes are characterized by cyber-physical systems, providing significant real-time quality, time, resource, and cost advantages in comparison with classical production systems. The smart factory is designed according to sustainable and service-oriented business practices. It insists on adaptability, flexibility, self-adaptability, and learning characteristics, along with fault tolerance and risk management.

In Pakistan, smart manufacturing tools need to be involved from 'design to prototype to assembly.' Pakistan's ICT industry, its innovative capability as well as its skills development industry are at a growing edge. IoT platforms, artificial intelligence (AI), and cloud computing can easily get adopted in Pakistan. Adoption of cyber-physical systems for advanced manufacturing processes is also required. Further, rapid prototyping can even make it possible for each customer to order one-of-a-kind product without significant cost increase. Collaborative virtual factory (VF) platforms can drastically reduce the cost and the time associated with new product designs and engineering of the production process, by exploiting complete simulation and virtual testing throughout the product lifecycle. 5G technology for cyber-physical systems can also be a revolutionary addition.

The major factors that will impact this transformation include infrastructure availability, stable economy, utilities, skilled labor, R&D supportive environment, structured production systems, industrial automation, etc. The Digital Pakistan Policy developed in 2018 can be helpful in industrial transformation [5].

Pakistan's industry has lack of management experience in the context of Industrial Revolution 4.0 and needs competitive management resources in the context of I4.0. Human resource management would play a vital role through training programs and could jointly work with engineering and business universities to overcome challenges more efficiently. Pakistan's infrastructure, economic condition, instability, utility crisis, unavailability of smart devices, and unavailability of latest machinery would also be possible barriers.

For smart manufacturing, knowledge and skillsets would be different as people with digital knowledge would be required in future. So, there is a need to prepare people for enhanced planning capabilities. Information flow would be rapid and require people with relevant skills to understand the signals fast and act quickly. Firms would need to become demand-driven adaptive enterprises and must adopt the demand-driven model to manage end-to-end supply chains. Parameters such as return on assets/cash equity, customer service level, and lead time to serve, in conjunction with other performance indicators would be used for measuring business success.

Status of Smart Manufacturing Promotion and Implementation

The initiatives taken at the national level to enhance productivity, competitiveness, and upgradation of manufacturing/industrial sectors are being discussed in detail in the following section.

National-level Initiatives for Smart Manufacturing Promotion

National Technology Fund (Ignite)

Ignite (formerly National ICT R&D Fund) is a non-profit company owned by the Government of Pakistan and administered by the Ministry of Information Technology and Telecommunication. It provides grants to startups and innovative projects that utilize the 'fourth industrial wave' technologies to solve local problems and target global opportunities in health, education, energy, agriculture, telecom, finance, and other verticals. It has a network of incubators across Pakistan to support startups and engage them with investors and corporations. Ignite has established national incubation centers (NICs) in five major cities across Pakistan and has launched Digiskills program to prepare 1 million people for future technologies.

Ignite outreach activities seek to inform professionals, media, students, corporations, and policy makers about the challenges and threats posed by the new economy and the importance of innovation. Prime Minister's National ICT Scholarship Program was a flagship human resource development (HRD) initiative of Ignite. Ignite has successfully completed more than 125 projects relevant to telecommunication, cyber security, IoT, software systems, networks, embedded systems, and AI, among others.

Taskforce on Technology-driven Knowledge-based Economy

This task force was developed by the government in 2019, focusing on an economic and institutional regime that stimulates the acquisition, creation, dissemination, and use of knowledge and information to improve economic growth and welfare. It also aims for effective systems of education and skills, information and communication technology (ICT), research and development (R&D), and innovation. The task force is working on the objectives of

- knowledge-based industrial development through technology innovation, dissemination, and commercialization;
- promoting cutting-edge research in academia and industry;

- intensifying cooperation among the relative stakeholders including government, private sector, and academia;
- taking steps to build human capital in critically important areas; and
- taking all measures necessary so that education, science, technology, and innovation can be effectively employed to develop a strong, inclusive, and sustainable knowledge economy

The task force recommends the innovative projects to Public Sector Development Programme (PSDP) of Government of Pakistan, with a focus on building a knowledge-based economy.

Industrial Designing and Automation Centers

Realizing the importance of digitization and automation in manufacturing sector, Technology Upgradation and Skill Development Company (TUSDEC), working under the administrative control of MoIP, has proposed Industrial Designing and Automation Centers (IDAC) in three major industrial cities of Pakistan, i.e., Lahore, Karachi, and Sialkot. The aim is to upgrade technology and skills of key and strategic industrial sectors. The centers will offer specialized services for automation and design-related issues in Pakistan's industry. They will focus on industry processes, product designing, and additive manufacturing. Following are the key features of IDAC:

- Dedicated labs will be established with an environment to encourage and carry out R&D activities, along with trainings on automation and additive manufacturing technologies, for industry professionals and students from relevant fields.
- In order to increase 'R&D productivity' and 'reduce the time to market,' external relationships will be built including partnerships with academia, industry, and equipment manufacturers/principals to foster this process.

Vision 2030 of Ministry of Planning, Development and Reform (MoPD&R)

MoPD&R has developed Vision 2030 for Pakistan with the objectives of

- establishing a developed, industrialized, just, and prosperous Pakistan through rapid and sustainable development in a resource-constrained economy by deploying knowledge inputs; and
- changing the share of the manufacturing industry sector from the current 13% of GDP to nearly 30% by employing latest ICT technologies and other cutting-edge I4.0 technologies;

Pakistan Industrial Vision by Pakistan Council of Science and Technology

Pakistan Council for Science and Technology (PCST) is mandated to advise the government on the development of science and technology (S&T) at the national level. The Council is involved in S&T policymaking, planning, implementation, and carrying out policy studies. PCST is also the secretariat of National Commission of Science and Technology (NCST), headed by the Prime Minister. It takes the major decisions for the development of S&T in the country.

'PCST Technology-based Industrial Vision and Strategy for Pakistan's Socioeconomic Development' lays down the framework for the future development of the country. There are three

technology policy instruments, namely, technology transfer, technology diffusion, and indigenous R&D. Technology techniques focus on latest ICT technologies and rapid manufacturing techniques (smart manufacturing).

National Industrial Policy (Draft)

Developed by the Core Group of the Ministry of Industries and Production, Government of Pakistan, the draft National Industrial Policy envisaged that in the next ten years, Pakistan would establish itself as a formidable manufacturing economy producing for an expanding domestic market as well as for the world market. Through value addition and diversification, this policy aims to increase the manufacturing output per worker by at least 100% in the next 10 years. This increase is expected to enhance manufacturing's share in GDP to at least 30% in the next 10 years, as envisioned in Vision 2030.

Digital Pakistan Policy

Pakistan introduced its first 'Digital Pakistan policy' in 2018. The policy was developed by Ministry of IT & Telecom, Government of Pakistan, with a focus to digitize the economy, tackle socioeconomic issues, and capitalize the digitization. It aims to bolster the IT industry by building a digital ecosystem. Taking a step forward, the current government launched the 'Digital Pakistan Vision' in December 2019 with an aim of enhancing connectivity, improving digital infrastructure, increasing investment in digital skills, promoting innovation, technology entrepreneurship, and adopting industrial revolution 4.0, i.e., IoT, AI, etc.

The policy is focused on advancing entrepreneurship and research and innovation (R&I) by implementing a paradigm shift toward the strategic exploitation of traditional as well as emerging technology sectors such as robotics, fintech, augmented/virtual reality, IoT, big data, and AI. It will also help promote the local manufacturing of IT hardware, e.g., desktop PCs, laptops, mobile handsets, network equipment, LEDs, and microprocessors, to augment the measures that are already in place to incentivize local manufacturing [5].

National Science, Technology and Innovation (ST&I) Policy 2012

The policy was drafted by Pakistan Council for Science and Technology (PCST), Ministry of Science and Technology, for promotion of ST&I in the society and development of an S&T management system. The new policy envisaged a paradigm shift, in which innovation was recognized as an integral part of the S&T system. The main focus of the policy remained on science, technology, and innovation planning; management structure; human resource development; indigenous technology development; technology transfer; and creation of absorptive capacity and international cooperation as well as R&D.

The thrust areas included metrology; standards; testing and quality (MSTQ); environment; health and pharmaceuticals; energy; biotechnology; and genetic engineering; agriculture and livestock; water; minerals; ocean resources; electronics; ICTs; space technology; materials science; nanoscience and nanotechnology; lasers and photonics; and engineering.

Science, Technology and Innovation Strategy 2014–18

The Government of Pakistan developed the Science, Technology and Innovation Strategy 2014–18 to shift toward a realistic and fast-moving S&T strategy. The strategy aims to address the key challenges faced by Pakistan in the fields of energy, water, food security, health, unemployment, and export enhancement through

- rapid human capital development to meet the country's current and future human resource demands;
- improving communication, coordination, and collaboration among S&T, ICT, and other sectors of socioeconomic development;
- supporting emerging technologies through research and development, commercialization of R&D results, exploring innovative solutions, and establishing new firms;
- ensuring acquisition of emerging technologies, i.e., biotechnology, nanotechnology, renewable energy technologies, and fuel cell technologies to gain world-class expertise and global competitiveness;
- promoting indigenous technology development, innovation and entrepreneurship through establishing network of innovation incubators, holistic technology clusters, and technology fund;
- establishing S&T think tanks to support policy research;
- enhancing R&D expenditure by up to 2.0% of GDP by 2018; and
- creating 1 million employment opportunities during five years to support economic growth.

Board of Investment Pakistan Policy 2013

Board of Investment (BOI) is mandated to promote, encourage, and facilitate both local and foreign investments. BOI works for enabling business environment through policy and strategic interventions. Guiding principles of Investment Policy 2013 include

- reducing the cost and processes of doing business in Pakistan;
- ease of doing business with creation of industrial clusters and special economic zones; and
- linkages of trade, industrial, and monetary policies for greater convergence.

According to the sector policy of BOI, one of the key points is “enabling digitization of key socioeconomic sectors” through ICTs. Major sectors include agriculture, cloud computing and big data, IoT, fintech, robotics, health, and energy.

Industrial Technology Acquisition Policy of Pakistan, 2020–23

TUSDEC has developed ‘Draft Industrial Technology Acquisition Policy to benchmark, acquire, assimilate, and improve the technology being used in various industrial sectors across all major clusters of Pakistan with the objectives of

- acquiring high-end technologies for potential industrial sectors;
- bridging the identified technology gaps (horizontal technology transfer) and enabling Pakistan to become a producer of technology (vertical technology transfer);
- enhancing technical capacity of labor market and skill development;
- creating, fostering, and supporting national technology climate in Pakistan;
- strengthening investment climate through joint ventures and incentivizing local industry; and
- promoting knowledge dissemination, stakeholder linkages, and engagement for sustainable industrial development.

At the time of writing this publication, the policy was at the approval stage with the Ministry of Industries and Production. The expected investment size of the policy was PKR118 billion.

Skilling Pakistan with the National Skills Strategy

The National Skills Strategy (NSS) is a key policy document prepared by the National Vocational and Technical Training Commission (NAVTTTC) to revamp Pakistan's TVET sector and make it a just, prosperous, and industrialized country by 2030. This strategy addresses the weakness in the current TVET delivery system through a number of actions. The major reforms that the strategy is focused on include

- introducing competency-based training;
- establishing industry-specific centers of excellence;
- increasing the role of the private sector;
- reforming the apprenticeship system; and
- encouraging entrepreneurship.

Draft National SME Policy 2019

Currently, the SME sector contributes 40% to the GDP of Pakistan and provides employment to 80% of the country's non-agriculture workforce. The current growth of the SME sector is 8% in manufacturing, 10% in exports, and 10% in services.

In order to enhance the share of the SME sector in Pakistan and develop a strong industrial base, the Small & Medium Enterprises Development Authority (SMEDA) has developed Draft National SME Policy 2019 in consultation with Ministry of Industries and Production. The policy involved detailed consultations with relevant stakeholders and inputs/feedbacks from chambers of commerce and industries. Various consultation sessions were organized that helped gain valuable inputs, recommendations, and engagement of stakeholders for SMEs' growth in Pakistan.

The basic aim of the policy is to develop a uniform definition of SMEs based on annual sales turnover of small industries, include all industries based on the definition, and give credit for working capital and promote SMEs through the introduction of a credit guarantee scheme. *Modaraba* should also be included for the financing of small and medium enterprises.

The policy has given high priority to SME development and creation of a conducive business and economic environment for SMEs across Pakistan, where SMEs can exploit emerging opportunities in the local and global markets. Other priority areas include ICT and e-commerce to promote productivity and growth. The policy focuses on job creation, export enhancement, and increased contribution of SMEs to Pakistan's economy.

Priority Industries for Smart Manufacturing

Various countries have developed their economies by adopting industrial revolutions through latest technological developments. Due to a low technological base, Pakistan's industrial sector's share is very low in GDP when compared with other developing countries. Consequently, it is having very limited share in global exports.

Pakistan needs to focus on its key and potential economic sectors that will positively support sustainable industrial development. The economy is still dependent on traditional industries and is far behind on the I4.0 revolution front due to limited research as well as technological and skill gaps. The present government is focused on transformation as is also evident from the latest Digital Pakistan Policy.

TABLE 1**PRIORITY INDUSTRIES FOR SMART MANUFACTURING.**

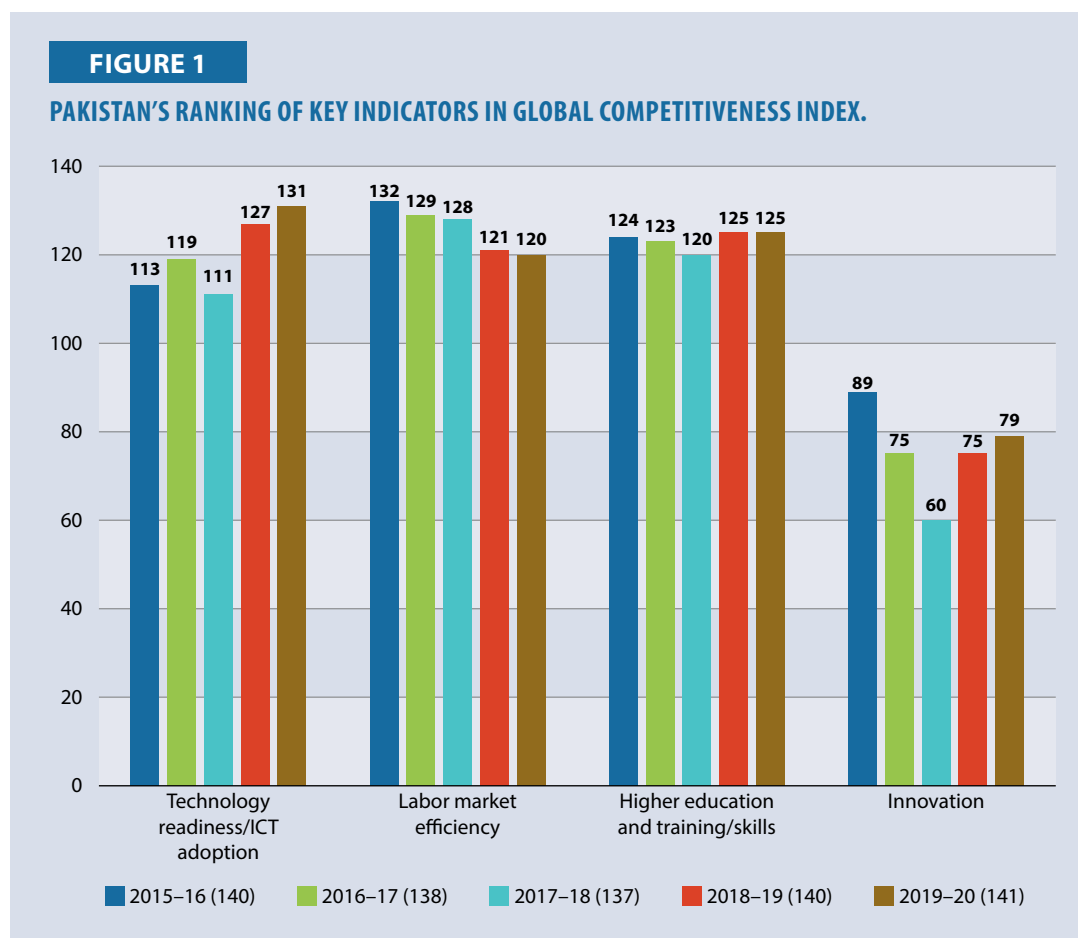
Priority industries	Rationale
Textile	It constitutes 58% of manufacturing exports. Smart manufacturing is imperative. Also, support is required for technical textile (sportswear, fire and safety, and health sector, etc.).
Automobile	Mostly dies and molds are being imported. Additive manufacturing is the key to manufacturing high-precision and complex contour parts. Key areas are reverse engineering, prototype development, 3D printing, metal injection molding, etc., in addition to smart manufacturing.
Surgical	There is high potential in manufacturing of implants and electro-medical devices using smart manufacturing technologies. Potential exists to create orthopedic implants, patient-specific tools, devices, and innovative ways of treatment. The surgical global market is worth USD247.4 billion, while Pakistan's share is USD0.356 billion.
Electronics/ICT	There is a need to promote local manufacturing of IT hardware (desktop PCs, laptops, mobile handsets, network equipment, LEDs, microprocessors, etc.). This has been prioritized in Digital Pakistan Policy.
Food processing	There is a potential for exports in processing of canned food, fruit pulp, potato chips and powder, fruits and vegetable dehydration, processed meat, and milk products such as cheese and butter. Smart manufacturing technologies are required for competitiveness in international markets.
Sports goods	Smart manufacturing, including additive manufacturing technique, is imperative in manufacturing of composites-based sports goods (e.g., skis, golf sticks, fishing tackles, hockey and ice hockey sticks) and mechanized balls. The estimated market size is USD7 billion.
Cutlery	For the tableware market, automation in continuous polishing and CAD design-ing is required. The global cutlery market is estimated at USD22.6 billion, while Pakistan's share stands at USD0.085 billion.
Leather	For footwear and leather goods, smart manufacturing techniques, including computerized pattern designing, compliance with REACH etc., are required. The global leather market's size is USD119 billion, with Pakistan's share being USD1.17 billion. The global footwear market's size is USD54.46 billion, with Pakistan's share being USD 0.092 billion. The leather goods market has a size of USD27.51 billion, while Pakistan's share in it is USD0.022 billion.
Marble, granite, and onyx	Smart manufacturing techniques are required for processing and finished products.
Marine fisheries	Growth opportunities exist in value fish/seafood processing using smart manu-facturing technologies.

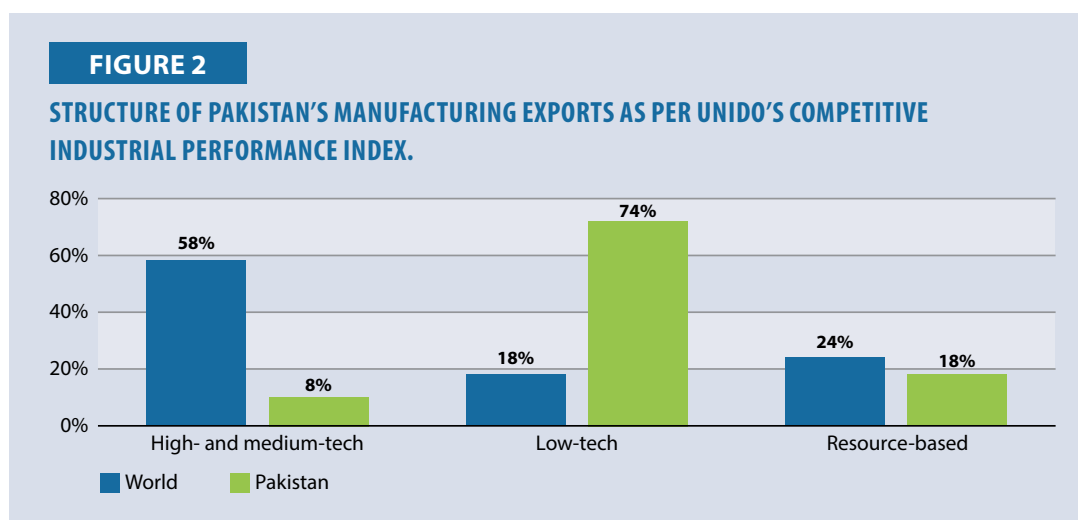
Tools and Techniques for Readiness Assessment at Enterprise Level

Readiness Assessment at National level

Smart manufacturing is necessary to cope with the economic, social, and environmental challenges being faced by the world. Some factors establishing the need for Pakistan to adopt smart manufacturing and gauging readiness are mentioned below:

- Smart farms are required to be introduced in the agriculture industry for food security.
- The textile sector, with its high growth rate, has a potential to use smart manufacturing technologies for further enhancement and transformation from conventional to technical textile manufacturing.
- Pakistan's overall ranking in Global Competitiveness Index has improved over the years. However, as can be observed in Figure 1, with a low ranking of 131 in technology readiness, 120 in labor market efficiency, and 125 in higher education in 2019–20, the country is facing slow growth rates of output and exports. However, with a comparatively better ranking of 79 in innovation, effective policymaking and its implementation could help Pakistan adopt the innovative technologies involved in smart manufacturing.
- The structure of Pakistan's manufactured exports as per UNIDO's Competitive Industrial Performance Index shown in Figure 2 depicts its low share in medium and high-tech categories and thus confirms the need for smart manufacturing adoption.





Smart Manufacturing Tools and Techniques for Local Industry

Smart manufacturing will help boost the production of Pakistan's industrial sectors, decrease production times, and increase quality and quantity by integrating IoT and cyber-physical systems. Smart manufacturing tools need to be involved from design to prototype to assembly. Pakistan's ICT industry and its innovative capability as well as skills development industry are at a growing edge. IoT platforms, AI, and cloud computing will easily get adopted in Pakistan. Smart manufacturing in advanced manufacturing processes and rapid prototyping can even make it possible for each customer to order one-of-a-kind product without significant cost increase. Collaborative virtual factory platforms can drastically reduce the cost and time associated with new product design and engineering of the production process, by exploiting complete simulation and virtual testing throughout the product lifecycle. 5G technology for cyber-physical systems can also be a revolutionary addition.

Pros and Cons of Smart Manufacturing Tools

Security Issues

A smart manufacturing system is one that makes use of an integrated network system in a manufacturing system for sharing information between manufacturing or machining units with end customers. This requires reliable network connectivity, especially access to the internet. Sharing information through the internet requires security of data and information throughout the system at various points with globally unique identification and end-to-end data encryption.

System Integration

Another challenge in the implementation of a smart manufacturing system is the integration of new technology equipment with the existing ones. The compatibility issues of existing devices with the new ones cause various problems in the implementation of smart manufacturing technologies. The old conventional machinery, which may be controlled by legacy communication protocols, might be outdated and new devices might use different protocols hindering system integration.

Interoperability

Without proper matching of the communication protocols and standards, interoperability may not be achieved efficiently. The dissimilarities between communication bandwidth, operational frequency, mode of communication, and hardware capabilities determine the limitations of the interoperability of the system.

Safety in Human–robot Collaboration

The main considerations should be made regarding occupational health and safety of personnel working on sites. Any hazardous environment should be avoided, and the necessary occupational health and safety should be maintained. Although the use of robotic systems in Pakistan is rare, while implementing any industrial robotic system, attention should be given to minimize any types of mechanical, electrical, thermal, noise, vibrational, radiational, and material or substance-related work environment hazards in a given industry.

Multilingualism

Smart manufacturing systems should be handling multilingual operations, to be able to interpret any instructions given in human language in machine language in order to instruct the machine on the desired operation. To make the concept of smart manufacturing realistic and to implement AI and advanced technologies in manufacturing systems, they should preferably be able to get the instructions directly from the operator either in voice or text format.

Return on Investment in New Technology

When shifting to another advanced technology in an existing manufacturing system, financial analysis is done and return on investment (RoI) is very carefully analyzed. The additional investment that should be done when adopting a new technology should be compared with the losses in production during the upgrade. The time required to recover the investment influences the adaption of the new technology.

Challenges to Human workforce

In the wake of smart-manufacturing tools and technologies, policy makers and government agencies need to consider very critically the probable layoffs/replacements of workforce with machines, especially in countries like Pakistan where abundant labor force is available. The implementation of smart manufacturing requires careful analysis and adoption of selected technologies to avoid layoffs.

Proposed Readiness Assessment Tools and Techniques at Enterprise level

In Pakistan, considering recent developments in terms of the industrial progression to smart factories, companies are overwhelmed and seem to be incapable of developing appropriate implementation strategies. SMEs have to analyze their situations and individual needs and then choose those smart-manufacturing concepts that can best help them achieve the output targets. There is a need to develop suitable models and instruments to assess the current status of technologies in industrial companies and to implement the concepts based on their appropriateness for the companies. SMEs are usually less informed about these concepts. Therefore, an assessment model should clearly describe the concepts and also show the different possibilities and technologies that can be adopted by the companies. Thus, the model's objective should be to

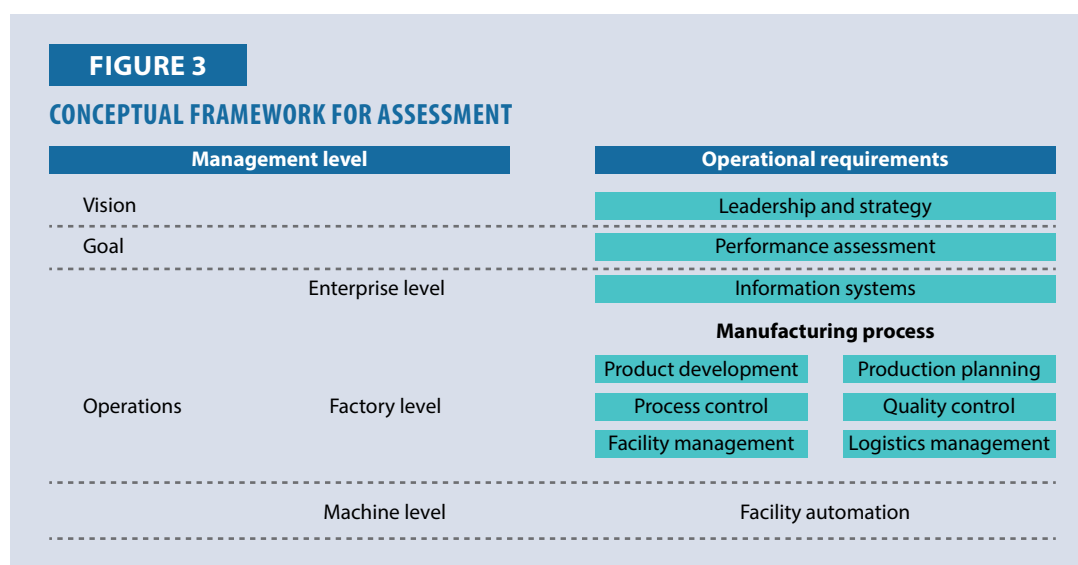
1. inform SMEs about the existing smart manufacturing concepts;
2. assess the current status for implementation and application of smart manufacturing concepts and readiness; and
3. signal the SMEs as to which smart manufacturing concepts are the most important ones for them.

There is no existing agreed assessment model available in Pakistan. Therefore, the country is in a dire need to have a framework for smart manufacturing implementation at the national as well as the enterprise level.

For readiness assessment, it is proposed to establish a conceptual framework as follows [6]:

- The objectives should include optimal management of production processes, zero waste, maximum efficiency, product customization, strengthening of manufacturing competitiveness, asset utilization, and innovation of supply chain and logistics.
- The directions to be pursued should include intellectualization and optimization, responding to changes in the external environment, ICT-led integration of processes, connection of functions, controlled improvement, and sensitiveness to contexts.
- The necessary technologies would include automation, IoT, big data, cyber-physical systems, etc.
- The applicable objects would be facilities, devices, workers, materials, parts, and products.
- The applied processes would be product design, production planning, process control, quality control, logistics, and sales from a product lifecycle view; and sensing, controlling, and actuating from a behavioral view.

The management activities can be divided into strategic planning, management control, and operational control. In order to make the management activities at the factory smarter, it is necessary to provide operational requirements for each activity. Therefore, the smart factory's operating system is divided into 'vision' based on high-level strategy; 'goal' based on performance evaluation for management control; and 'operations' at the lower level, subdivided into enterprise, factory, and machine levels. Enterprise-level requirements involve not only enterprise information systems such as product lifecycle management (PLM), enterprise resource planning (ERP), supply chain management (SCM), and manufacturing execution systems (MES), but also factory energy management systems (FEMS). In addition, security should be implemented.



Factory-level requirements mean that step-by-step manufacturing processes such as product development, production planning, process control, quality control, facility management, and logistics management should be intelligently implemented. Machine-level requirements mean that automation of factory facilities, such as production facility, logistics facility, inspection facility, and equipment information networking, should be implemented. The conceptual framework is depicted as shown in Figure 3. The list of criteria and sub-criteria specifying the detailed core activities of each criterion has been given in Table 2.

TABLE 2**CRITERIA, SUB-CRITERIA, AND READINESS ASSESSMENT ITEMS.**

Criteria	Sub-criteria	Assessment items
Leadership	Leadership and strategy	CEO leadership
		Strategy and plan for implementing smart factory
		Management of organization and capability of smart factory
		Management of key performance indicators (KPIs)
Process	Product development	Procedure of product development, product design and evaluation, and process design and evaluation.
		Management of product information
		Management of technical information
	Production planning	Management of information for production planning
		Demand and order planning
		Sales and operation planning
		Master production scheduling
	Process control	Development of a detailed job schedule and order
		Management of the production progress
		Management of abnormalities in the manufacturing process
	Quality control	Management of information for quality control
		Management of documents of standards for quality control
		Management of testing data
	Facility management	Management of machines and equipment for quality control
		Management of operation of facilities
		Maintenance of facilities
		Management of spare parts
	Logistics management	Management of molds, jigs, and tools
		Management of the demand of materials
		Management of orders and lead times
		Management of storing and releasing products in a warehouse
		Management of racking systems
		Management of peaking and delivering products
System and automation	Information system	Management of information about delivering and tracking
		Utilization of ERP and SCM
		Utilization of MES
		Utilization of PLM
		Utilization of FEMS
		Management of information security

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Criteria	Sub-criteria	Assessment items
System and automation	Facility automation	Automation of manufacturing facilities
		Automation of logistics facilities
		Automation of evaluation and testing facilities
		Automation of information network for facilities
		Management of energy, safety, and environment
Performance	Performance assessment	Productivity
		Quality
		Cost
		Lead time
		Safety
		Environment

Framework for Smart Manufacturing Implementation at National Level

Proposed Framework

Shifting Priority Industrial Sectors to Smart Manufacturing

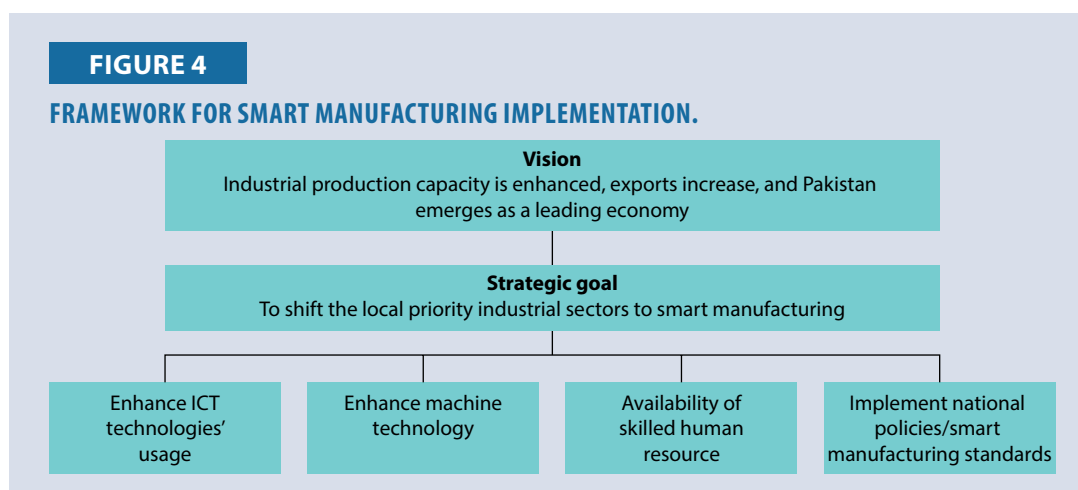


TABLE 3

SHIFTING INDUSTRIAL SECTOR TO SMART MANUFACTURING

	Thematic area	Implementation mechanism/ tasks	Major stakeholders/ implementation agencies	Timeline
Enhance use of ICT technologies				
1	Applicability of internet of things (IOT)	<ul style="list-style-type: none"> • Introduction of IOT in priority industries • Smart chip development • Design and development digital and analog circuits • Enhanced embedded systems 	<ul style="list-style-type: none"> • National Institute of Electronics (NIE) • Ministry of Science and Technology (MoST) • Ministry of IT and Telecommunication • Ministry of Industries and Production (MoIP) • Chambers of commerce and industry and industrial associations 	Short-to-medium term

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	Thematic area	Implementation mechanism/ tasks	Major stakeholders/ implementation agencies	Timeline
2	Enhanced internet security	<ul style="list-style-type: none"> • Network security • Application security • Information security • Operational security <p>To stop cyber crime, cyber attacks, and cyber terrorism</p>	<ul style="list-style-type: none"> • Pakistan Telecommunication Authority (PTA) • National Information Technology Board (NITB) • MoST 	Short term
3	Digitization and analysis	<ul style="list-style-type: none"> • Big data analysis • Artificial intelligence • Cloud computing • Digital designing • Cyber-physical systems (CPS) • Active design and manufacturing software 	<ul style="list-style-type: none"> • MoST • NITB • MoIP • TUSDEC • NIE • National University of Science and Technology (NUST) • Private/public universities • Chambers of commerce and industry and industrial associations 	Short-to-medium term
4	High-speed internet	<ul style="list-style-type: none"> • 5G technology • Optical fiber 	<ul style="list-style-type: none"> • PTA • NITB • Ministry of IT and Telecommunication 	Short term
5	Materials and nano technologies	<ul style="list-style-type: none"> • Sensors and actuators 	<ul style="list-style-type: none"> • MoST • NIE • MoIP 	Medium-to-long term
Enhance machine technology				
1	Development of platform to enhance smart manufacturing technologies	<ul style="list-style-type: none"> • Research and development centers to facilitate local industry • Induction of advanced robotics and cobots • Additive manufacturing • Facility for machine learning • Technology upgradation centers working on common facility center's concept 	<ul style="list-style-type: none"> • MoIP • TUSDEC • MoST • National University of Science and Technology (NUST) • Private/public universities • Higher Education Commission (HEC) 	Short-to-medium term
2	Readiness of firms and Individuals regarding adoption of smart manufacturing technologies	<ul style="list-style-type: none"> • Technical assistance • Consultancy services 	<ul style="list-style-type: none"> • TUSDEC • MoIP • MoST • Small and Medium Enterprises Development Authority (SMEDA) • Sector development companies 	Short-to-medium term

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	Thematic area	Implementation mechanism/ tasks	Major stakeholders/ implementation agencies	Timeline
3	Awareness	<ul style="list-style-type: none"> • Training and support centers • Roadshows • Workshops • Webinars 	<ul style="list-style-type: none"> • MoIP • MoST • TUSDEC • HEC • Chambers of commerce and industry and industrial associations 	Short term
4	Technology grants and joint ventures	<ul style="list-style-type: none"> • Challenge funds • Technology transfer fund • Government facilitation programs for joint ventures between MNCs and progressive local enterprises for technology transfer • Introduction of tax incentives and reforms 	<ul style="list-style-type: none"> • HEC • MoIP/TUSDEC • MoST • Ignite • Ministry of Commerce • Board of Investment • Ministry of Finance (MoF) 	Short-to-medium term
Availability of skilled human resource				
1	Educational reforms	<ul style="list-style-type: none"> • Introduction of degree-level programs in universities • Introduction of certificate-level courses in TEVT institutes • Short courses on smart manufacturing for company executives, mid-level managers and operators • Center of excellence (technology specific) 	<ul style="list-style-type: none"> • TUSDEC • MoST • Private/public universities • SMEDA • NAVTTC • Provincial TEVTAs • HEC 	Short to-medium term
2	Research assistance	<ul style="list-style-type: none"> • Digital library • E-research papers • Online sessions and presentations 	<ul style="list-style-type: none"> • MoST • MoIP • HEC 	Short term
3	Industry–academia linkages	<ul style="list-style-type: none"> • Support through Office of Research, Innovation and Commercialization (ORIC) 	<ul style="list-style-type: none"> • MoST • Provincial TEVTAs • Chambers of commerce and industry and industrial associations • HEC 	Short term
National policies/implementation of smart manufacturing standards				
1	Industrial policies	Finalization/approval of existing draft policies: <ul style="list-style-type: none"> • National Industrial Policy • National SME Policy • Industrial Technology Acquisition Policy 	<ul style="list-style-type: none"> • MoIP • MoST • SMEDA • TUSDEC • Chambers of commerce and industry and industrial associations 	Short term

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	Thematic area	Implementation mechanism/ tasks	Major stakeholders/ implementation agencies	Timeline
2	Smart Manufacturing Policy	<ul style="list-style-type: none"> Development and approval of National Smart Manufacturing Policy 	<ul style="list-style-type: none"> MoIP MoST TUSDEC Ministry of IT and Telecommunication Chambers of commerce and industry and industrial associations MoF NPO Pakistan 	Short term
3	Smart manufacturing standards	<ul style="list-style-type: none"> Awareness on international smart manufacturing standards Development of local standards and harmonization with international smart manufacturing standards 	<ul style="list-style-type: none"> Pakistan National Accreditation Council MoST MoIP NPO Pakistan 	Short-to-medium term

Conclusion

It is inevitable for Pakistan's industry to shift from conventional manufacturing processes to smart manufacturing. Pakistan's ICT industry is rapidly growing, which is a healthy sign for the easy absorption of IoT, cloud computing, and AI technologies in Pakistan's domestic market. As of May 2020, Pakistan had about 82 million internet users, making it the ninth-largest base of internet users in the world. The growth rate and employment trends had indicated that Pakistan's ICT industry would exceed the USD10-billion mark by 2020 [7]. The sector employs 12,000 employees and counts among top-five freelancing nations.

It is evident from research that Pakistan is far behind on technological readiness in the Asian region, so this is an opportunity for timely measures to be taken to introduce smart manufacturing in the country. Pakistan has got enormous potential in the textile industry as well as in the agricultural industry. If smart manufacturing tools are incorporated in these industries, they can boost manufacturing and exports, thereby resulting in a significant rise in GDP. The government should promote and support acquisition of latest technologies including AI, additive manufacturing, IoT, and related emerging technologies that can revive the key economic sectors of Pakistan.

The government could develop a forum to support coordination between the relevant federal ministries, divisions, or organizations and the provincial governments and stakeholders to streamline policies and programs relevant to a smart manufacturing implementation framework in Pakistan. The NPO in Pakistan may be tasked to act as a secretariat for this joint forum. The forum may propose recommendations in developing national policies, facilitate in getting the necessary approvals from the government, and oversee the implementation of the framework to encourage smart manufacturing in industrial sectors.

The government may also facilitate in acquiring technology and seeking foreign investments in high-technology manufacturing industries and joint ventures with foreign investors on smart manufacturing technologies. Through the Board of Investment (BOI), the government could seek foreign investment in priority industries for smart manufacturing and facilitate local and foreign investors for speedy materialization of their projects. These measures would ultimately result in enhancement of Pakistan's international competitiveness and contribute to its economic and social development.

It is recommended to support technical human resource development through ‘blended learning’ approach at the school, college, and university levels to promote smart manufacturing. The government should promote R&D through industry–academia linkages to identify latest skills, technologies, and innovative ideas for smart manufacturing implementation. A national R&D fund may also be established with support from federal and provincial governments. The fund should support continuous R&D activities.

The concept of sector-specific technology upgradation and skill development centers should be promoted to address the technology- and skill-development needs of each priority sector. The currently established training facilities may be relocated to local industrial clusters.

A national technology transfer fund may be created for priority industries to incentivize the SMEs that are ready to transform to smart manufacturing. Changes in taxes and duties may also be introduced to facilitate such SMEs.

The government should create an enabling environment to encourage local manufacturers and SMEs to shift to smart manufacturing technologies. Support of other APO member countries may be sought through the NPO to establish technology-specific centers of excellence. Visits of international experts to Pakistan may be arranged with dedicated trainings on smart manufacturing technologies. The experiences gained and lessons learnt by other member countries would help Pakistan in its transformation to smart manufacturing.

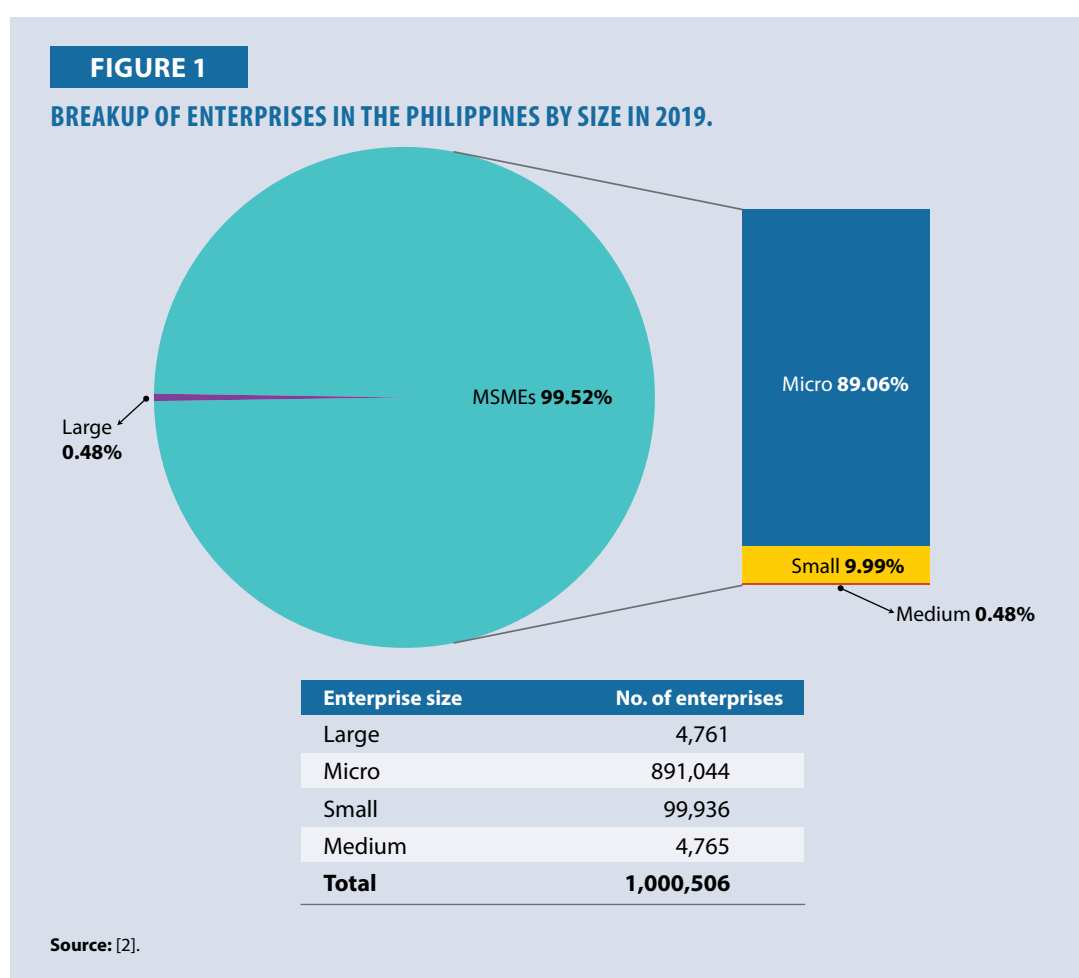
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THE PHILIPPINES

Introduction to Smart Manufacturing in the Philippines

Small and medium enterprises (SMEs) have been widely recognized as drivers of economic and industrial development, particularly in providing growth, investments, and employment in a country [1]. In the Philippines, a total of 1,000,506 enterprises were registered under the Philippine Statistics Authority's (PSA) List of Establishments in 2019. The majority of them were micro, small, and medium enterprises (MSMEs), accounting for 99.52% of the total enterprises, while 0.48% were large enterprises (see Figure 1). More than half of the workforce belonged to MSMEs, which created 5,510,760 jobs or 62.4% of the country's total employment in 2019 [2].



Enterprises are categorized according to their asset and employment sizes as defined in the Republic Act No. 9501 or the Magna Carta for MSMEs. As seen in Table 1, a micro enterprise employs less than 10 workers, small has 10–99 workers, medium has 100–199 workers, and a large enterprise employs 200 or more workers. These businesses are engaged in industry, agribusiness, or services, regardless of their

legal structures such as sole proprietorship, partnership, cooperative, and corporation [3]. Classification of enterprises is still subject to evaluation by the Micro, Small and Medium Enterprises Development Council (MSMEDC), considering the changes in inflation and other economic indicators [3].

TABLE 1**CLASSIFICATION OF ENTERPRISES IN THE PHILIPPINES.**

Size	By asset value	By employment
Micro	<PHP3,000,000 (<USD58,465)	1–9
Small	PHP3,000,000–15,000,000 (USD 58,465–292,323)	10–99
Medium	PHP15,000,001–100,000,000 (USD292,324–1,948,824)	100–199
Large	>PHP100,000,000 (>USD1,948,824)	>200

Source: [3].

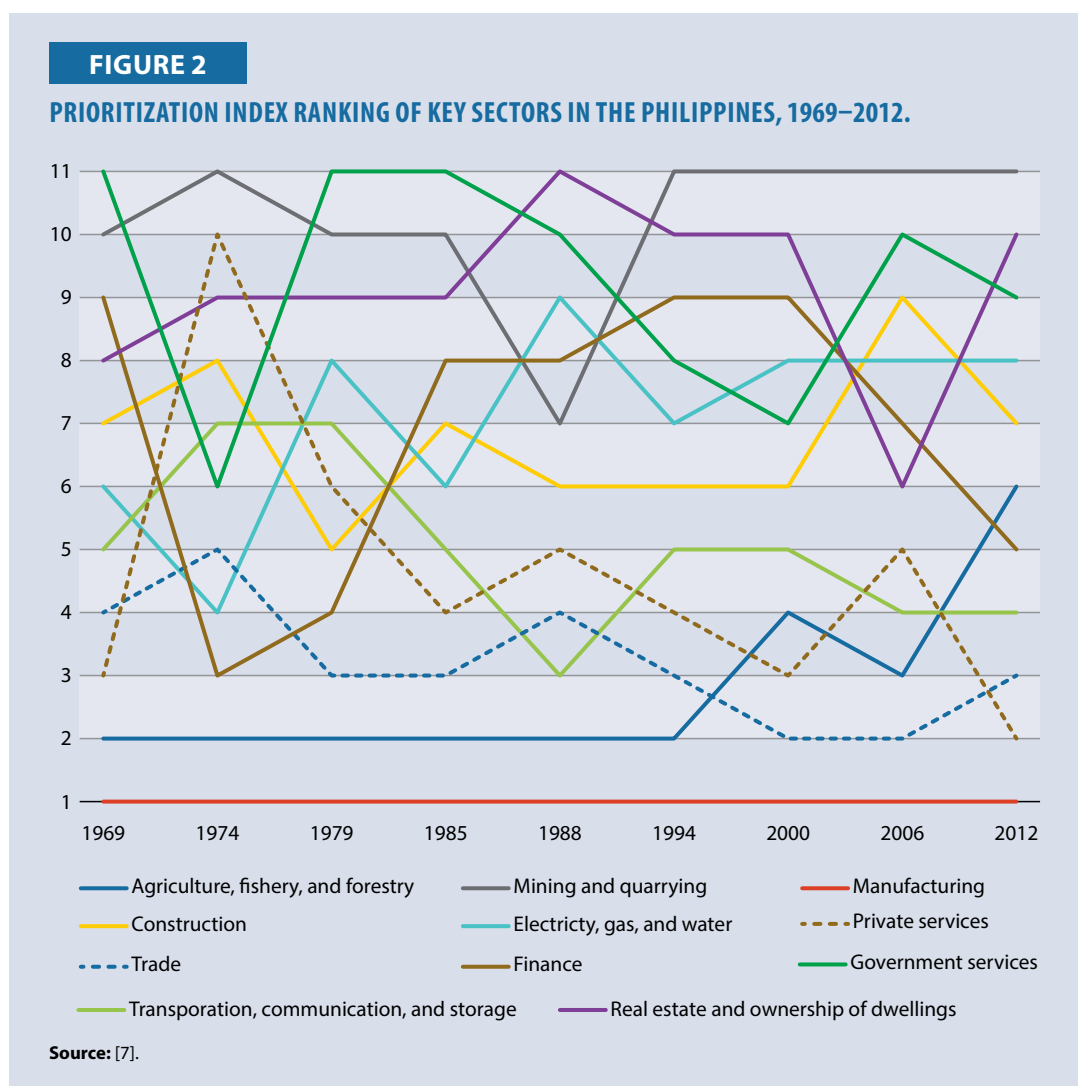
With the substantial contribution of MSMEs to the country, the government has made it a priority to promote inclusive and sustainable growth through improved and innovative strategies encapsulated in the MSME Development Plan 2017–22. One of its strategic goals has been to provide enhanced access to technology and innovation, especially as the Philippines started to revive its manufacturing industry [4]. According to the 2019 MSME Statistics of the PSA, manufacturing played a vital role in the MSME sector, where it ranked third with the maximum number of establishments engaged in manufacturing. Other top industry sectors included wholesale and trade, accommodation and food service, financial and insurance, and other services [2].

Historically, from the 1980s up to the early 2000s, manufacturing had a low performance in terms of its contribution to the country's growth and employment [5]. The share of manufacturing in the total GDP declined from 22.5% to 22.1%, in contrast with the rising trend of industrialization in the neighboring countries, including PR China, Indonesia, Malaysia, and Thailand [6]. This was due to the series of financial and political declines in the country, coupled with SMEs' difficulty in competing and entering the market, and weak linkages in both domestic and global supply chains [5, 6]. Aldaba [5] observed a decline in the manufacturing industry brought by the absence of structural transformation of the Philippine economy from agriculture to manufacturing.

The Philippines' drive towards industrialization and its policies, programs, and innovative interventions are being continuously developed to understand the country's scope of activities as it envisions to have a globally competitive manufacturing industry. In the prioritization index of key sectors in the Philippines developed by Go, et al. [7], the manufacturing sector (see red line in Figure 2) had consistently received the highest priority ranking from the government among the key sectors. It is followed by the sector comprising agriculture, fishery, and forestry, for which the Philippine economy was largely known. Manufacturing retained its top position in terms of resource allocation because of its interconnection with other sectors. Simply put, parts of the operations of most sectors are linked with manufacturing in terms of production and value addition that signify the sectors' shares in economic growth.

In addition, the vulnerability of agriculture to disaster-related impacts has resulted in unstable output share, thus leading to the country's shift toward an industry-driven economy. Hence, most of the government's efforts were reallocated to the manufacturing industry [7].

Having a large play in the manufacturing industry, MSMEs are part of the government's priority in coping with the increasing demand for industrialization. Various policies and interventions have



been formulated to address the significant issues faced by MSMEs. With these, innovative incentives and mechanisms have been provided, such as R&D facilities and financial assistance to improve enterprises' products and services and to promote their production efficiencies. There are also technology upgradation and access-to-market activities for linking MSMEs with multinational companies and production networks. Overall, SME-related policies concentrate on technology transfer, financing, market improvement, and domestic linkages to support SME ventures in manufacturing and other industry sectors [4–6].

Evidently, the manufacturing industry has been gaining more relevance in the Philippine economy. It was labeled as the country's rising source of growth in the 2018 Philippine Economic Forum [8]. Rafael Garchitorea, Managing Director and Chief Strategist at Deutsche Pegis Partners, Inc. had declared the Philippine manufacturing industry as the country's 'new growth driver' in his speech at the 2018 Economic Forum [8]. According to the PSA [9], manufacturing has consistently remained the top contributor to GDP since 1998 at an average of 19.7%. In 2019, it dominated the industrial sector (19.2%), which accounted for almost or near a quarter of the total GDP (see Table 2). It may be noted here that the PSA defines GDP as comprising three major sectors, namely agriculture and fisheries, industry, and services. Each sector has sub-components indicated in Table 2, with manufacturing belonging to the industry sector [9].

TABLE 2

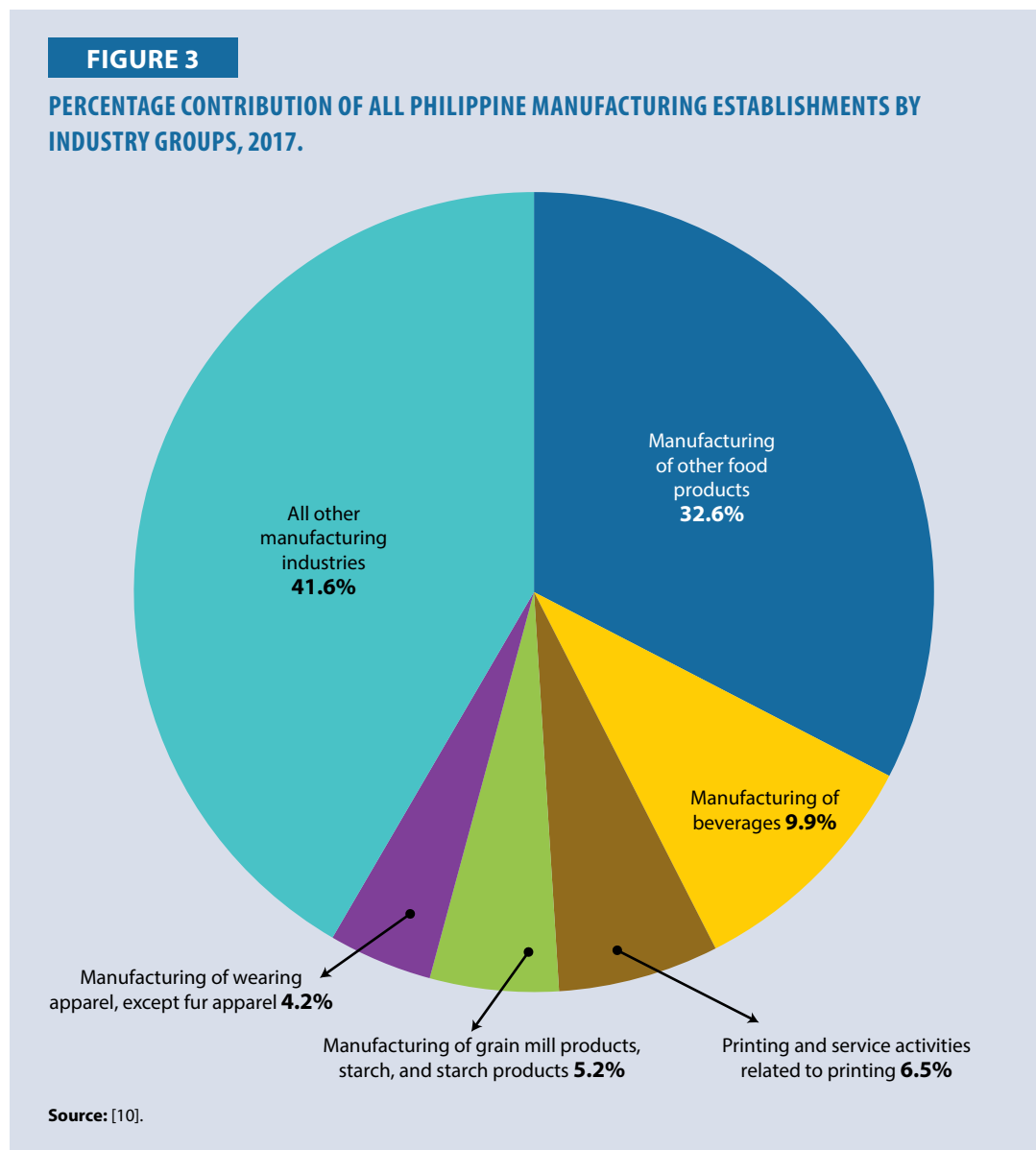
PERCENT CONTRIBUTION TO GDP BY SECTORS AND SUBSECTORS, 1998–2019.

Industry	Annual																						
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
1. Agri., hunting, forestry, and fishing	11.6	12.4	11.9	11.9	11.8	11.8	11.6	11.3	11.2	11.0	10.9	10.4	9.7	9.6	9.2	8.7	8.3	7.9	7.3	7.1	6.8	6.5	
a. Agriculture and forestry	9.5	10.3	9.9	9.9	9.8	9.7	9.5	9.1	9.0	8.9	8.7	8.2	7.7	7.8	7.5	7.1	6.8	6.5	6.0	5.9	5.7	5.4	
b. Fishing	2.2	2.1	2.0	2.0	2.0	2.1	2.1	2.1	2.1	2.2	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	
2. Industry sector	31.0	29.7	29.4	28.6	28.3	28.2	27.9	27.6	27.7	27.6	27.8	26.0	27.1	26.8	26.9	27.2	27.7	27.8	28.2	28.3	28.5	28.4	
a. Mining and quarrying	0.6	0.6	0.5	0.5	0.8	0.8	0.7	0.8	0.8	0.9	0.8	0.9	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	
b. Manufacturing	21.5	21.3	20.9	20.7	20.5	20.3	20.1	20.0	20.0	19.5	19.5	17.8	18.5	18.8	18.5	18.9	19.3	19.3	19.3	19.7	19.5	19.2	
c. Construction	5.7	4.7	4.9	4.3	4.0	4.0	3.9	3.7	3.9	4.2	4.4	4.5	4.8	4.2	4.6	4.7	4.7	5.0	5.2	5.2	5.6	5.7	
d. Electricity, gas and water supply	3.2	3.1	3.1	3.1	3.0	3.1	3.2	3.0	3.0	3.0	3.0	2.9	3.0	2.9	2.8	2.8	2.7	2.7	2.8	2.7	2.7	2.7	
3. Service sector	45.1	45.9	44.0	44.2	44.2	44.6	45.4	45.6	46.3	47.0	46.9	46.4	46.4	47.3	47.3	46.9	46.9	47.4	47.8	47.9	48.3	49.0	
a. Transport, storage, and communication	5.1	5.2	5.2	5.6	5.9	6.3	6.7	6.8	6.8	7.0	6.9	6.6	6.2	6.3	6.3	6.2	6.2	6.4	6.3	6.1	6.1	6.2	
b. Trade and repair of motor vehicles, motorcycles, personal, and household goods	12.8	13.6	13.5	13.7	13.7	13.7	13.9	14.0	14.2	14.5	14.1	13.7	13.8	13.9	14.0	13.8	13.7	13.9	14.0	14.1	14.1	14.5	
c. Financial intermediation	4.7	4.7	4.5	4.5	4.5	4.6	4.6	4.9	5.2	5.4	5.3	5.3	5.5	5.6	5.6	5.9	6.0	6.0	6.0	6.1	6.2	6.5	
d. R. Estate, renting, and business activities	8.7	8.6	8.0	7.7	7.5	7.6	7.8	7.9	8.1	8.2	8.6	8.6	8.6	9.0	9.0	9.1	9.2	9.3	9.5	9.6	9.5	9.3	
e. Public administration and defense; compulsory social security	4.9	4.7	4.4	4.3	4.2	4.1	4.2	4.0	4.0	3.8	3.7	3.8	3.7	3.7	3.6	3.5	3.4	3.3	3.3	3.3	3.6	3.8	
f. Other services	8.9	9.1	8.5	8.4	8.4	8.2	8.2	8.1	8.1	8.1	8.3	8.4	8.5	8.7	8.8	8.5	8.4	8.6	8.6	8.6	8.8	8.8	
Gross domestic product	87.7	88.0	85.3	84.7	84.3	84.6	84.9	84.5	85.1	85.6	85.6	82.8	83.2	83.7	83.4	82.8	82.9	83.1	83.3	83.4	83.6	83.9	
Gross national income	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	

Source [9].

Note: Percentage distribution is based on constant 2000 prices.

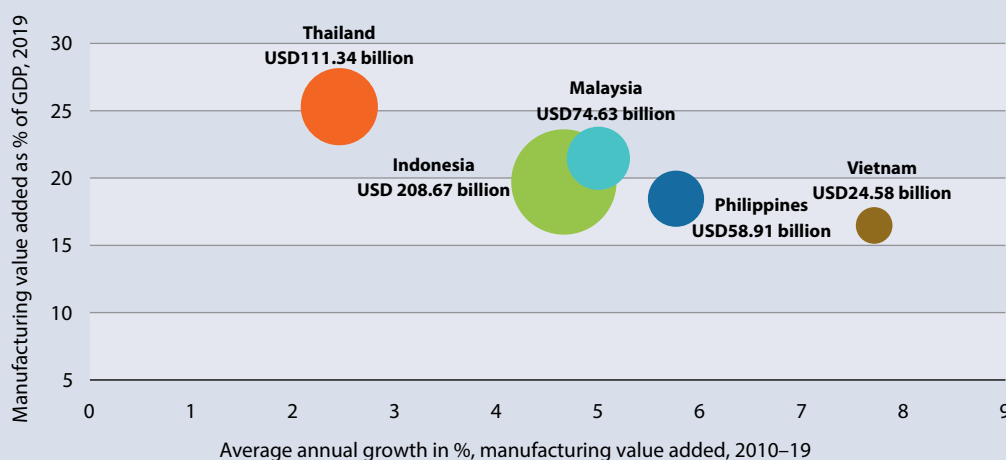
In terms of business generation, the Annual Survey of Philippine Business and Industry (ASBPI) released in March 2020 recorded a total of 24,200 establishments in 2017. (ASBPI is one of the survey activities of PSA. It was conducted in 2018 with 2017 as the reference period [12].) As shown in Figure 3, the top five manufacturing establishments by number are (1) manufacture of other food products; (2) manufacture of beverages; (3) printing and service activities related to printing; (4) grain mill, starches, and starch products; and (5) wearing apparel manufacturing [10]. Based on the 2019 MSME Statistics, manufacturing had the third-largest number of establishments among MSMEs while it took the lead among large enterprises [2, 11].



With 1.3 million manufacturing establishments noted in 2017 [10], it employed over 1.6 million workers in the country, thereby having the second-largest share among the industry groups in 2019 [2]. According to Technical Authority and Skills Development Authority (TESDA), the majority of this labor force was working in the fields of chemicals, tools, and die manufacturing, and animal production industry, while the highest employment growth rate was in the air and spacecraft subsector of manufacturing as of 2018 [12].

FIGURE 4

MANUFACTURING PERFORMANCE OF SELECTED ASEAN COUNTRIES.



Source: [13].

Aside from growth and employment shares, the manufacturing performance is also assessed based on the manufacturing value added (MVA). According to the World Bank [13], the Philippines had an average of USD58.91 billion MVA in the period 2010–19 (see Figure 4). However, it is important to note that the Philippines grew faster than other ASEAN countries with an MVA growth of 5.8%, which was almost double compared with the global average of 3.1% in the same period [13]. This is a good indicator for the country to maximize the full potential of its manufacturing industry. The ASEAN Economic Community (AEC) has also increased its efforts to help the ASEAN to challenge the top manufacturing hubs and increase its leverage in the global trade market. These efforts are channeled through free trade agreements (FTAs) among member countries and economic bilateral partnerships with major markets [14, 15].

Despite the remarkable performance of the manufacturing industry in the past years, sudden economic shocks have been experienced since December 2019. This situation was brought about by the COVID-19 pandemic that exacerbated the growth rates across all sectors of the economy. The manufacturing sector was deemed most critical, along with wholesale–retail trade and government services since these are labor-intensive sectors [16]. The share of manufacturing in the Philippine GDP declined by about 22.1% in the second quarter of 2020 compared with the second quarter of 2019 [17]. The crisis has also negatively affected other sectors, as seen in Table 3.

TABLE 3

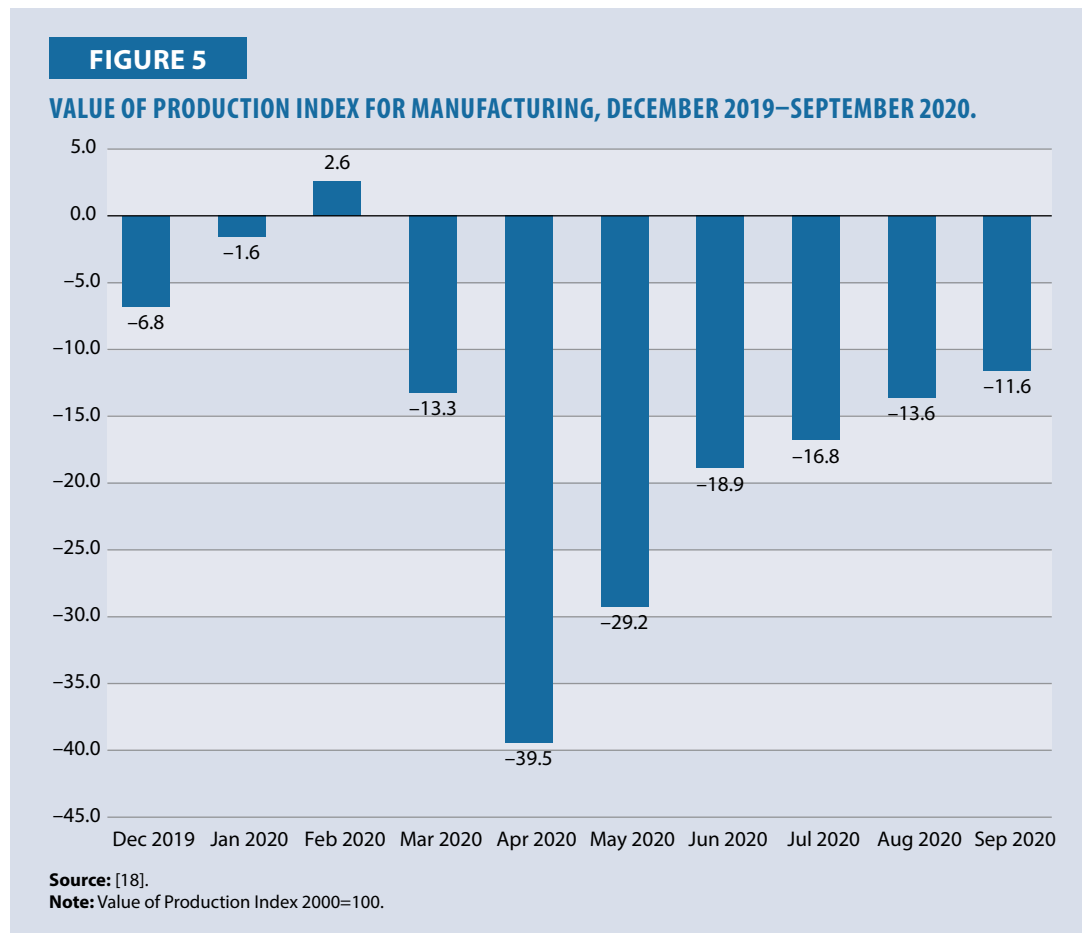
GDP CONTRIBUTION OF THE INDUSTRY SECTOR, Q2 2019 VERSUS Q2 2020.

Selected sector	Q2 of 2019	Q2 of 2020	% change
Industry	1,493,273	1,151,788	–21.3
Mining and quarrying	56,818	42,917	–32.1
Manufacturing	909,831	716,454	–22.1
Electricity, steam, water, and waste management	152,196	143,311	–1.7
Construction	374,429	249,107	–27.9

Source: [17].

Note: GDP contribution is based on 2019 constant prices.

According to the PSA [18], the Value of Production Index (VaPi) for manufacturing also reduced by 11.6% in September 2020, preceded by a 13.6% decline in the previous month (see Figure 5). This was the seventh consecutive month that VaPi had a decrease amidst the drastic impact caused by the COVID-19 outbreak, e.g., massive closure of factories and movement restriction. Production of all manufacturing subsectors fell, except for food manufacturing with 11.6% growth, basic metals (12.3%), chemical products (5.6%), and miscellaneous manufactures (1.6%). Nevertheless, the National Economic and Development Authority (NEDA) shared its optimism on gradual recovery of this sector as more factories reopened amidst an easing of movement restriction [19].



Manufacturing is considered by the International Labour Organization (ILO) as the most risk-sensitive sector affected by COVID-19 [20]. This is influenced by disruptions in the global supply chain where the world experienced a supply shock, at the peak of the pandemic, caused by lockdowns [21]. The major trading partners of the Philippines, i.e., PR China, Japan, Hong Kong, Singapore, and the USA were the countries most affected by the pandemic, which limited the flow of supplies. In effect, lesser demands for the nonessential manufactured items are estimated to cause losses up to PHP855.2B in revenue as per the Philippine Institute for Development Studies' (PIDS) projections [21]. The Department of Trade and Industry (DTI) has enumerated the manufacturing sectors that were and will be heavily affected. These include aerospace, automotive and auto parts, electronics, footwear, furniture, iron and steel, pharmaceuticals, plastics, shipbuilding, and textiles and garments [22].

To cope with global supply limits, DTI's Board of Investments (BOI) manifested the need to strengthen the capacity of local manufacturers and lessen the country's dependence on imports.

Part of this initiative is the repurposing of manufacturers' products to produce COVID-19-related items such as personal protective equipment (PPEs) and diagnostic and clinical-care equipment. For example, the companies that were in the field of ready-to-wear garments repurposed to produce PPEs, while beverage companies could get into the manufacturing of alcohol-based disinfectants [23–25].

Other government efforts in addressing the challenges of COVID-19 are focused on programs for business continuity. These include Recharge PH; *The Bayanihan to Heal as One Act* or the Republic Act No. 11469; COVID-19 Assistance to Restart Enterprises (CARES) Program; and financial programs in partnership with the Philippine government banks. Recharge PH is a national recovery program crafted by NEDA towards a healthier and more resilient Philippines. It aims to reduce the impact of COVID-19 while restarting the social and economic activities of the country.

One of the strategies is to digitize enterprises by creating products and solutions with technology building blocks [26, 27]. *The Bayanihan to Heal as One Act* provides sufficient funding to productive sectors, including the manufacturing industry, as a means of recovery from the impact of the pandemic. Through this act, MSMEs are qualified for loan grants up to PHP500,000, depending on their asset size and annual sales [28]. As this RA 11469 was signed into a law, it allotted PHP10 billion budget to Small Business Corporation (SB Corp) in support of its CARES Program for the MSMEs who suffered business reversal [25, 29]. It may be noted that SB Corp is a government financial institution created in virtue of the Republic Act 6977 (now amended as the Republic Act 9501 or the Magna Carta for MSMEs). Its main objective is to foster growth among MSMEs through financial access and inclusivity [29].

Similarly, the Land Bank of the Philippines (LBP) and Development Bank of the Philippines (DBP) have allocated a total of PHP30 billion for their financial programs to SMEs. Recipients of the aforementioned initiatives are mostly MSMEs because of their vulnerability to financial resources and economic disruptions. As they comprise the bulk of the Philippine establishments, efforts toward ensuring business continuity for this sector will aid in the economy's recovery [25].

COVID-19 has pushed Filipinos to search for more innovative and technologically advanced solutions to battle the pandemic. The Department of Science and Technology (DOST) has developed tools varying from contract-tracing applications, health monitoring tools, and goods/supply delivery systems with artificial intelligence (AI), robotics, and internet of things (IoT) [30, 31]. As Aldaba [25] has emphasized, enterprises with greater innovation emerge resilient and create leverage even with economic slowdown, which allows them to adapt to the rapidly changing market conditions. Now, I4.0 has been gaining more importance, especially in times of disruptions [25].

I4.0 and Smart Manufacturing in the Philippines

The Philippines is quite behind on capacity building for I4.0. As per the World Economic Forum's assessment of countries' readiness for the future of production, the Philippines was categorized as a legacy country, along with India, Thailand, Mexico, Turkey, and Romania. Legacy countries are those that have a complex production system but with weak drivers of production. Specifically, the country was said to be facing hindrances as the country had a (1) weak technology base; (2) weak human capital (knowledge and competencies of workers); and (3) poor infrastructure in keeping up with the future of production [33, 34]. This is similar to the classification by the APO where the Philippines recorded low competitiveness scores in

R&D and innovation [35]. While global economies are transitioning or have already advanced to I4.0, most establishments in the Philippines are still moving from Industry 2.0 to 3.0. A few are already in the 3.0 phase, but much fewer are in the fourth industrial revolution (FIRe) phase [33]. Similarly, the Philippine manufacturing industry is also lagging in the adoption and implementation of smart manufacturing technologies.

A few companies in the country have taken steps towards technological transformation but they are mostly classified as large ones. These firms have the financial capacity and global partners to innovate and plan their digital transformation. Schneider Electric, for instance, a multinational company providing energy and digital transformation, has launched its first smart factory in Cavite, the Philippines. It has incorporated IoT architecture into its systems, allowing real-time monitoring and control of its production processes. The smart factory is not yet fully automated as it still has manual operations and mostly consists of sensory tools that have elevated its capacity for mass production and operational efficiency [36]. IoT devices have also been used in smart farms, traffic management, and high-end condominiums in the Philippines. In general, IoT allows interlinking of devices using wireless connectivity to centralize the control of the system. This technology is not yet notable in the country, but is part of the Department of Information and Communications Technology's (DICT)'s Roadmap for Digital Startups that promotes interrelated digital ecosystems among startups [32, 37].

Applications of robotics in the country are mostly in subsidiaries of foreign companies such as Seiko Epson Corporation, which is a global market leader in Selective Compliance Articulated Robot Arm (SCARA) robots. In 2019, the company launched its industrial robots in the Philippines, capable of assembly of electronic components such as printers and watches [38]. In the same year, Toyota Motor Philippines started to utilize its high-tech press line machine, which is the first in the country to produce side member panels (largest part of a vehicle's body shell) using this high technology in the local automotive industry. This is in partnership with DTI's Comprehensive Automotive Resurgence Strategy (CARS) program, which aims to boost automotive manufacturing in the Philippines [39]. Dadios, et al. [32] have also documented a case study of an automated coco sugar production using robotics systems. It regulates the status and temperature of the cooking chamber that results in efficiency of production.

As mentioned earlier, technological adoptions toward smart manufacturing are still rarely observed in the Philippines [40]. The country's weak science, technology, and innovation (STI) culture has contributed to this state. As emphasized by NEDA [41], many sectors are not recognizing, appreciating, and acknowledging the role of STI. Aside from these, there are also problems in technology-transfer and adoption among MSMEs and backbone sectors like agriculture and fisheries [41]. The country also suffers from a shortage in workforce that specializes in STI. Although graduates in science, technology, engineering, and mathematics (STEM) had increased from 2017 (213,853) to 2018 (247,608) by 14%, the number was still way below the country's target of 331,800 graduates in 2018. Moreover, the bulk of the graduating students are business administration and education degree holders [42].

Education is also among the sectors that were significantly affected by the coronavirus outbreak in the country. The country's Department of Education had announced in May 2020 that, in the opening of basic-education classes for the school year 2020–21, the mode of learning would be virtual or remote. Delivery of classes would be in the form of blended learning, distance learning, homeschool, and other modes, in accordance with the local COVID-19 severity [43]. The call for

remote learning has exposed the poor digital infrastructure of the Philippines. Filipinos living in both urban and rural areas are suffering from slow internet connections as the average speed in the country is far lower than the global average [44]. The poor digital infrastructure in the Philippines is said to be due to lack of foreign and local competition among telecommunication companies, as well as the difficulties in securing permits for building transmission towers [45].

Nevertheless, the 2019 Philippines Innovation Ecosystem Assessment under USAID Philippines' Science, Technology, Research, and Innovation for Development (STRIDE) project reported improvements across all elements of the innovation ecosystem, compared with the 2014's assessment. Key elements include human capital education, research and knowledge creation, knowledge transfer, startups, and collaboration. The evaluation was based on the survey and interview responses from the government, industries, startups, and academic sectors. Overall, the improvement was mainly attributed to (1) the government's continuous efforts in policymaking initiatives and plans towards strengthening innovation; and (2) increased willingness of the government–industry–academia collaboration [46].

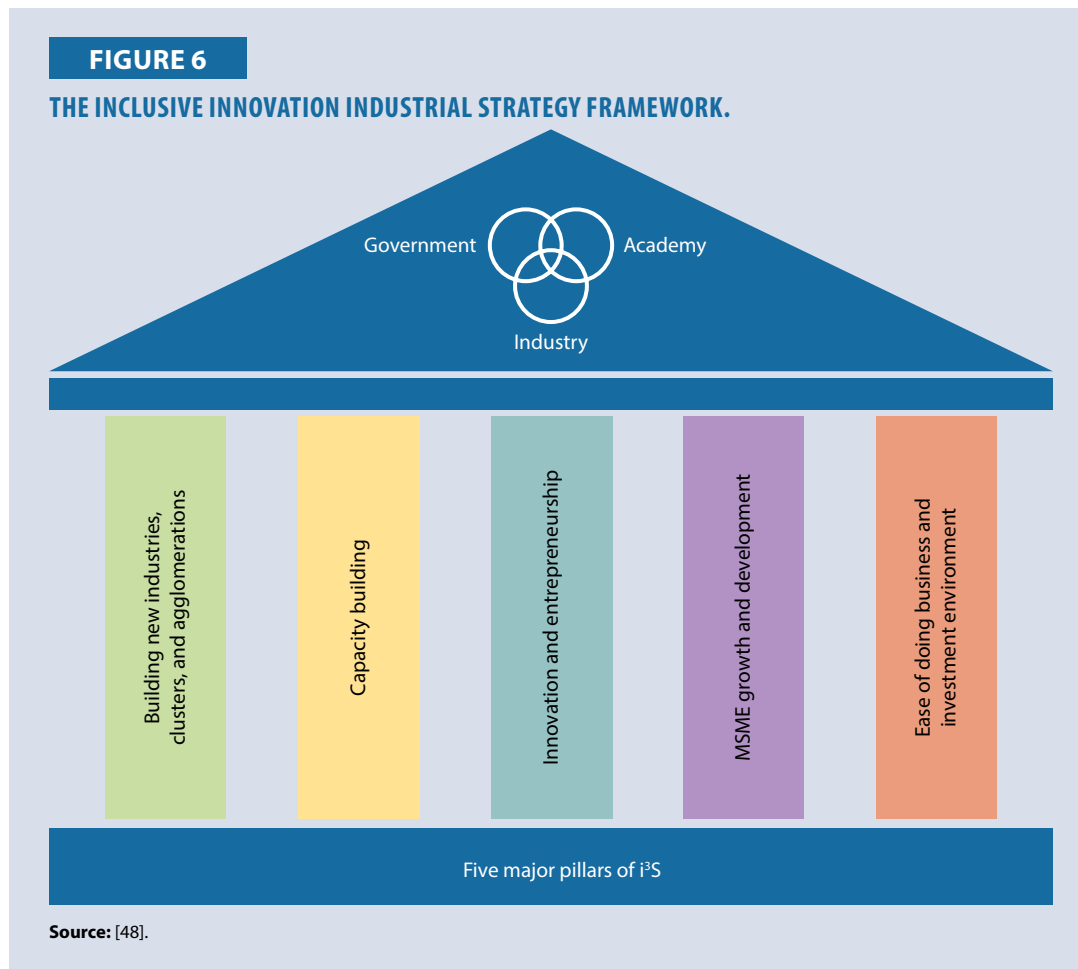
Status of Smart Manufacturing Promotion and Implementation

The Philippines has strived for inclusive innovation with the aim to develop globally competitive industries through innovation, research and development, strengthening of industry clusters, and removing barriers to growth. Based on the 2019 findings of USAID STRIDE, the stakeholders had observed positive changes in the innovation ecosystem of the Philippines since 2014. This is parallel to the results of the Global Innovation Index where the country had ranked 50th in 2020, which marked a big leap from its 54th rank in 2019 and 73rd rank in 2018 [25, 47]. The government, industries, and academia have legislated and launched various policies and interventions to realize this goal.

One of the promising policies is the Inclusive Innovation Industrial Strategy (i³S). It was crafted by the DTI-BOI with the aim to improve not just the industry sector but also the existing level of poverty by reviving the manufacturing sector and connecting it with agriculture and services sectors. Hence, the industrial strategy was made inclusive to create more jobs and promote innovation in all regions of the country. The i³S policy was initially based on five major pillars. These were:

1. creation of new industries and industry clusters;
2. human resource development and making the workforce more I4.0 ready by upgrading the education curricula and improving digital skills;
3. development of innovation and entrepreneurship, which is at the heart of this strategy;
4. MSME and startup development; and
5. enabling ease of doing business through simplification and automation of processes to reduce transaction costs and address the high costs of power and logistics [48].

As the Philippines is now challenged with new technologies and other global and domestic developments, i³S focuses on the outlook of I4.0, to ensure that the country's current production



system is transformed and well-positioned for the future. In achieving this, the industrial policy has expanded into six strategic actions derived from the five pillars. These are:

1. **Embracing I4.0:** Manufacturing enterprises should utilize new technologies that would strengthen competitiveness and sustainability.
2. **Innovative SMEs and startups:** Inclusion of SMEs and startups in technological breakthroughs will prepare them for I4.0.
3. **Integrating production systems:** This can be achieved by linking manufacturing to other key sectors and facilitating access to global markets.
4. **Ease of doing business:** This aims to simplify the business process in manufacturing and improve the digital infrastructure and logistics of the country.
5. **Upskilling/reskilling of workforce:** This can be achieved through technical training programs and R&D on smart manufacturing technologies, along with incentivizing programs to promote STEM curriculum.
6. **Innovation and entrepreneurship ecosystem:** This will help commercialize R&D outputs and strengthen the startup network [49, 50].

Overall, the policy is focused on pursuing connectedness in the country by strengthening the triple-helix relationship between the government, the academia, and the industry. The government will be the main governing body that facilitates addressing the constraints of progress among industries. Through i³S, government agencies are called to collaborate in the R&D and physical innovation infrastructure, human resource development, innovation policy formulation and monitoring, alignment and implementation of innovative programs, and provisioning of financial support in the implemented programs [51]. The government agencies in close coordination with DTI-BOI are shown in Table 4.

TABLE 4
GOVERNMENT AGENCIES IN COLLABORATION WITH I³S.

Focus	Agencies
R&D and physical innovation infrastructure	Department of Information and Communications Technology (DICT); Department of Science and Technology (DOST); Department of Agriculture (DA); and Commission on Higher Education (CHED).
Human resource development (HRD)	Technical Education and Skills Development Authority (TESDA); Department of Labor and Employment (DOLE); and Department of Education (DepEd).
Innovation policy formulation and monitoring	National Economic and Development Authority (NEDA).
Alignment and implementation of innovation programs	Department of the Interior and Local Government (DILG); Local government units (LGUs)
Financial support in the implementation of innovation programs	Department of Finance (DOF); and Department of Budget and Management (DBM).

Source: [51].

In 2017, DTI's inclusive innovation-led industrial strategy has 12 industrial sectors to prioritize, including aerospace manufacturing, electrical and electronics, automotive, chemicals, shipbuilding/RORO, tourism, transport and logistics, construction, IT-BPM, agribusiness, tools and dies, and furniture and textile creative industries [51]. In 2020, climate change, digital trade, and innovation and R&D were added to the list of priorities. The policy aims to implement bolder trade regulations, increase infrastructure, and intensify investing to ramp up these priority sectors. These industries were prioritized because of their crucial contribution to the economic transformation [25, 50, 51].

In promoting i³S, the DTI has been conducting Annual Manufacturing Summits since 2016, which bring together different stakeholders from private sectors, industry associations, business chambers, academia, the research community, and government agencies. Other activities include business matching, trade fairs, and exhibits. Similarly, the Development Academy of the Philippines (DAP), through its Center for Governance, had its seminar series on I4.0, with the aim to have a basic understanding of the I4.0 concept, current trends, and how they affect the country's industries. In 2020, DAP continued this program through a webinar series, which focused on the best practices and working models related to I4.0 that may apply to MSMEs. These online learning sessions aim to enable the participants to appreciate and compare models, practices, and applications of I4.0 initiatives of select countries in order to obtain ideas on how to further improve the productivity and competitiveness of the MSMEs in the Philippines.

Embracing FIRE technologies as part of the strategic actions of the i³S, DOST has been the forefront agency in advancing smart manufacturing in the country. One of its programs is the Advanced Manufacturing Center (AMCen), which aims to be the country's leading research center in innovative 3D printing technologies, processes, and materials. It provides shared facilities for advanced additive manufacturing technologies in the Philippines, initiated by two of DOST's line agencies, namely the Industrial Technology Development Institute (ITDI) and the Metals Industry Research and Development Center (MIRDC). The program consists of two major projects that focus on R&D of advanced manufacturing materials handled by ITDI, while MIRDC is to facilitate product innovation through rapid prototyping. Also, DOST-MIRDC initiated the Advanced Mechatronics, Robotics, and Industrial Automation Laboratory (AMERIAL) that provides training and consultation for technology advancement and competitiveness of the metals and engineering industry. The laboratory is an industrial automation facility, consisting of various equipment used in smart factory and Industry 3.0, cobots, and an automation studio. This project may assist the transformation of Philippine MSMEs from Industry 2.0 to Industry 3.0 including the DOST-assisted Small Enterprises Technology Upgrading (SETUP) program cooperators.

By the end of 2020, the DOST plans to include the SETUP co-operators transition to I4.0 and be called SETUP 4.0 or smarter MSMEs. This is to align with the growing acceptance of I4.0 which allows small enterprises to shift to online and contactless operations, especially amidst the pandemic. Large companies, majority of which operate in the automobile, electronics, robotics, and metal fabrication industries, are also beginning to adopt smart technologies [25]. For food production and processing, the Smart Food Value Chain Program of DOST Philippine Council for Industry, Energy and Emerging Technology Research and Development (PCIEERD) has utilized smart and innovative technologies throughout the value chain, ranging from raw inputs to distribution of products for consumption [46].

Further, DTI's Securing Manufacturing Revitalization & Transformation (SMART) Program intends to technologically upgrade processes, products, services, and development of new business models toward I4.0. SMART is currently targeting the manufacturing of jeepneys with internal combustion engine (ICE) and electric vehicle (EV) technology through DTI-National Development Corporation Co-investment Program, Electrified Vehicle Incentive Scheme Program, and Industrial Transformation Program. Firms that aspire to be funded by the SMART program should be eligible as per a list of criteria. Overall, DTI has proposed to allocate PHP25 billion to PHP30 billion (USD493 million to 592 million) to support the priority industries and programs [25, 51].

Given the increasing initiatives for smart manufacturing, it is equally essential for the workforce to be ready for these technologies. As previously mentioned, through its AMERIAL project, DOST has been providing training to create a pool of skilled and highly qualified workforce. The agency has also crafted its Harmonized National R&D Agenda (HNRDA) 2017–22. Section IV of this program focuses on the development of industry, energy, and emerging technologies through continuous R&D. Similarly, the Science for Change Program (S4CP) was established to accelerate science, technology, and innovation through increased investments in S&T human resource development. It consists of four major components including (1) Niche Centers in the Regions (NICER) for R&D; (2) R&D Leadership (RDLead) Program; (3) Collaborative Research and Development to Leverage Philippine Economy (CRADLE) Program; and (4) Business Innovation through S&T (BIST) for Industry Program.

Research grants and incentives were also provided to promote local research involving innovation. The Balik Scientist Law (RA No. 11035) provides benefits and incentives to encourage overseas Filipino researchers to practice in the country. Moreover, programs on educational curriculum lean toward STI promotion through scholarship grants, advanced science training for high-school students, and TESDA's Free Access to Technical-Vocational Education and Training (TVET) [46]. These programs can help contribute toward gradual readiness of the workforce to adopt smart manufacturing technologies. With the adoption of smart manufacturing technologies, processes and work procedures can be made easier. As a result, workers can be more effective and efficient in meeting their objectives and targets.

To enable inclusive innovation, the two important legislations, the Philippine Innovation Act (RA 11293) and the Innovative Startup Act (RA 11337), were approved in 2019 primarily for the development of MSMEs and startups. Both aim to promote innovation through education, training, funding, and incentives, thereby serving as a key driver of sustainable and inclusive growth [49]. DICT is seen to be the pioneering agency for helping startups grow their businesses through digital adoption as crafted in the Philippines Roadmap for Digital Startups in 2016. Moreover, in 2018, another roadmap for startups was formulated in partnership with DICT, DTI, and DOST. This is a five-year plan called Startup Assistance and Program 2019–23, which aims to assist and develop strategies for 1,000 startups. Like MSMEs, startups would have a vital role in the innovation endeavor of the country, given that the young population has an embedded capability for AI, robotics, fintech, and machine learning [46].

To strengthen the innovation performance and address the gap in innovation and entrepreneurship, DTI outlines the innovation strategies in the Inclusive Filipinnovation and Entrepreneurship Roadmap (IFER). It focuses on the market-oriented policy that diffuses R&D with commercialization. In partnership with DOST and various universities, it enables researchers to assess commercial and societal value via experiential learning to improve commercialization outcomes. The establishment of Technological Business Innovation (TBI) offices at universities encourage students to engage in technopreneurship. In support, agencies like DepEd, CHED, and TESDA have also included entrepreneurship classes for K-12 students to align with the Youth Entrepreneurship Act [47, 50].

The Philippine Development Plan (PDP) 2017–22 of the National Economic Development Authority, aligned with the *AmBisyon Natin 2040* (Our Vision 2040), was crafted to enhance the social fabric, reduce inequality, and promote growth potential [52]. Unlike the i3S framework, the PDP 2017–22 is a more holistic approach to national development. It prioritizes not just the enterprises and the manufacturing sector, but also human development, the government, and the environment.

Tools and Techniques for Readiness Assessment at Enterprise Level

In the Philippines, (1) Global Innovation Index (GII) and (2) Readiness for the Future of Production framework by the World Economic Forum (WEF) were most cited by DTI in assessing the country's maturity for Industry 4.0 [47]. The WEF placed the Philippines under 'legacy' countries. Its report concluded that the country was lagging in I4.0 adoption due to weak innovation and technology base, poor infrastructure, and weak human capital [48]. Overall, the Philippines scored low on readiness for the future of production, with a score of just 4.5 out of 10 [34]. In terms of the Global Innovation Index assessment, the Philippines ranked 50th in 2020, the highest rank ever achieved

by the country since 2014, and had the most significant progress over time in terms of innovation, along with PR China, India, and Vietnam [47].

The Philippines has not structured a national index to diagnose the readiness and maturity of its domestic enterprises. However, DTI is planning to adopt Smart Industry Readiness Index (SIRI) as the WEF has endorsed it internationally as a standard tool for I4.0. Currently, the only accredited assessor of SIRI in the country is the TUV SUD Philippines, and so far, no company has been subjected to SIRI. DTI and DOST have expressed interest in becoming SIRI assessors in the country and were supposed to send representatives for training. However, this was halted due to the pandemic [53].

In 2019, DTI conducted a smart manufacturing survey with over 200 manufacturing firms in the country using the survey tool from the Manufacturing Enterprise Solutions Association (MESA). MESA's assessment contains eight dimensions, namely, (1) planning and scheduling; (2) manufacturing activity management; (3) equipment connectivity and data management; (4) material management and handling; (5) equipment maintenance; (6) quality; (7) shop floor visibility; and (8) cyber security. These dimensions measure the technology's utilization level and smart-manufacturing preparedness of enterprises. Results in the survey showed that manufacturing enterprises had poor adoption of digital technologies and high barriers to I4.0. The firms' inadequate financial capability was reported as the most challenging hindrance in digital transformation, followed by a lack of awareness and motivation for the rest of the firms. Other problems cited were poor digital infrastructure and market conditions. Overall, the technology utilization score was only 18 out of 40, which implies a slow pace of digital transformation [25, 54].

Firms that adopt technologies are mostly the large, foreign-owned ecozone locators and exporting manufacturers, while MSMEs are quite behind. In terms of geographical distribution, technology utilization is concentrated in the Mega Manila area including three regions out of the total 17 regions, thus indicating a wide digital imbalance. The three regions are, National Capital Region (NCR), Region 3, and Region IV-A. In terms of planned investments, all enterprises (large, medium, small, and micro) showed openness to invest in software and machinery in the next five years, with large firms being the most likely to invest. Small enterprises displayed the most diverse planned investments in the next few years. In general, there is a low level of transformation among manufacturing firms despite the fact that a majority of them are aware of the opportunities and challenges of transforming to I4.0. Specifically, 70%, 60%, and 70% of the micro, small, and medium enterprises and exporters are open and familiar with I4.0, respectively [25].

With regard to awareness with the terms I4.0 and smart manufacturing, another survey conducted by DOST XI showed that 67.7% recognized the importance of technology and the need to upgrade to accommodate business needs. Also, 52.4% said their operations were already equally dependent on both technology and people.

For a majority of respondents, it was their first time to hear about cyber-physical systems (65%); augmented reality (49%); industrial internet of things (46%); and big data analytics (42%). This mirrors the unfamiliarity of the respondents with I4.0 and smart manufacturing. For cloud storage/technologies, robotics, artificial intelligence, RFID, and 3D printing, respondents were either 'vaguely familiar' or 'familiar' by a margin of 0–3%. Among emerging technologies in smart manufacturing, 3D printing and robotics were the leading technologies in the 'very familiar' category. However, these accounted for 11% and 9% of the respondents only, respectively.

FIGURE 7

FAMILIARITY WITH THE TERMS I4.0 AND SMART MANUFACTURING.

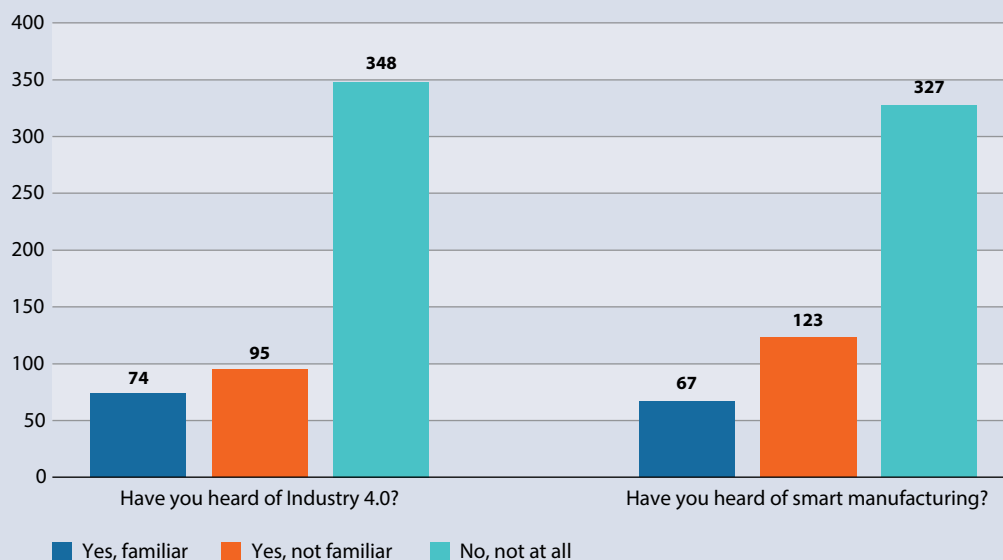
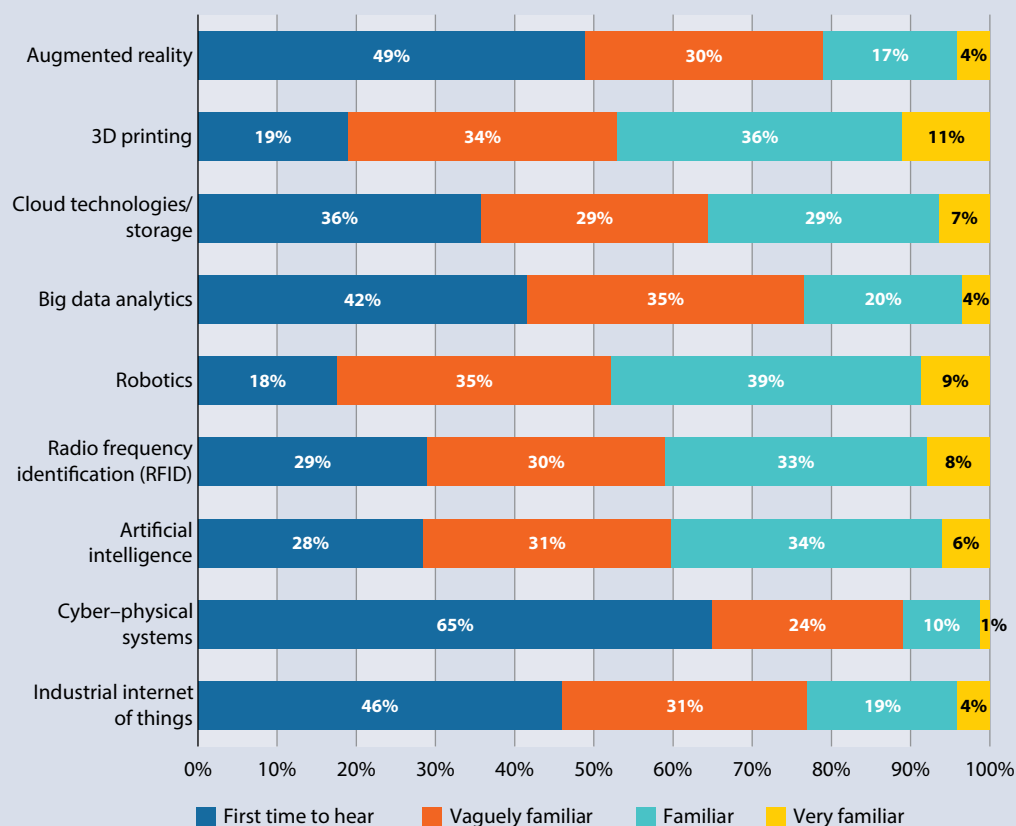


FIGURE 8

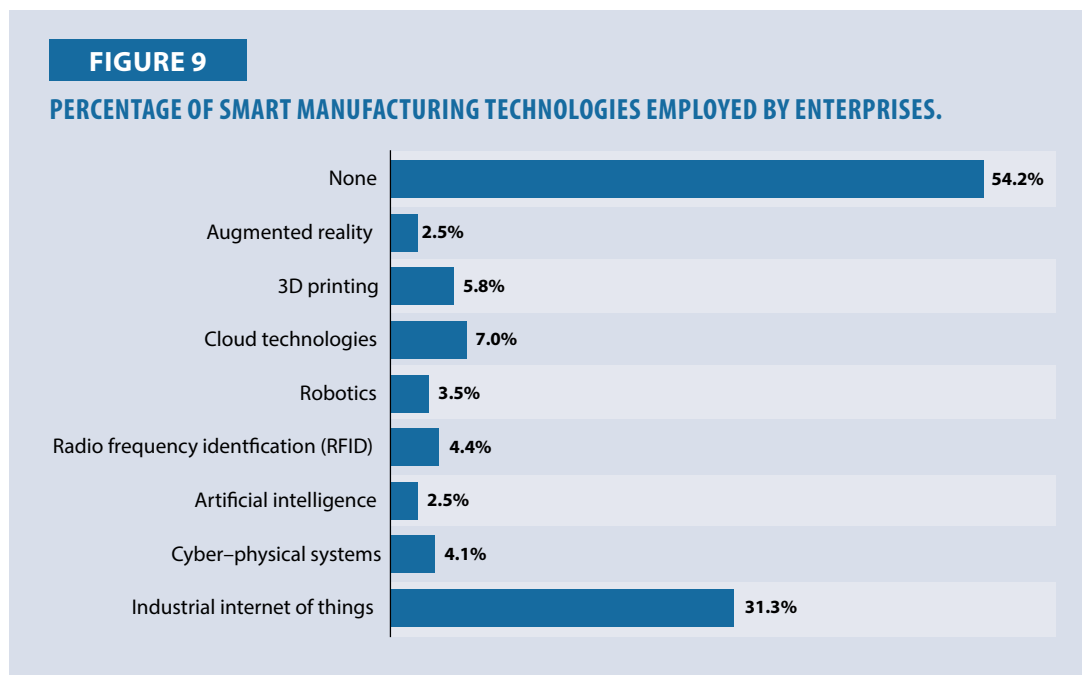
PERCENTAGE OF FAMILIARITY WITH EMERGING SMART MANUFACTURING TECHNOLOGIES.



Nevertheless, 436 out of 517 respondents were willing to test their enterprises' readiness and maturity for smart manufacturing. In actuality, only 8.1% had already implemented smart manufacturing strategies. In a test of their readiness and maturity, 48.6% stated they were already seeking solution partners to help adopt smart manufacturing technologies. However, only 8.5% had allocated for a budget, while 72.6% did not have an account to adopt smart technologies. The main reason for this was the high cost of digital technologies, lack of infrastructure, lack of employee expertise with smart technologies, lack of employees with data analytical skills, and lack of knowledge.

The majority were willing to overcome these challenges. However, 45.3% had no established team dedicated to gear their organizations towards smart manufacturing. More than half (54.2%) were not using smart manufacturing technologies yet. Notably, the most employed technology among respondents was industrial internet of things (IIoT), accounting for 31.3%, while other technologies had a usage rate of 2.5–7% only. This may be attributed to the enterprises' current smart manufacturing level, with 68.7% not making smart manufacturing efforts because they perceive it as not relevant to the business. In fact, 71.6% admitted that the products in their portfolio were not yet digitalized.

With these results, it can be implied that the country is not yet ready for I4.0. However, this survey can be further improved by encouraging more large enterprises to respond to produce a more comprehensive perspective of smart manufacturing in the Philippines.



Proposed Framework for Smart Manufacturing Implementation at National Level

A national framework would be an essential guide to enable smart manufacturing implementation. Although the country's innovation plans have started to recognize and align with FIRE initiatives, there is no dedicated framework for smart manufacturing. As previously mentioned, DTI has structured an industrial policy called the Inclusive Innovation Industrial Strategy (i³S), but it integrates a more holistic approach to I4.0. It focuses not only on manufacturing but on all key sectors, including agriculture, services, and other industries. Thus, it is strategic to design a smart-manufacturing-specific framework for its implementation, especially because this sector has been termed as the

country's new growth source. It will serve as a basis for policymakers and stakeholders to formulate roadmaps to monitor and measure smart manufacturing transformation progress in the Philippines.

I^{4.0} is the proposed framework, representing the four strategic I's for the national smart-manufacturing implementation, namely, inculcate, improve, integrate, and institutionalize (see Figure 5). The I^{4.0} framework is anchored on i³S; Philippine Development Plan (PDP) 2017–22; and the *AmBisyon Natin 2040* (Our Vision 2040). It is intentionally structured in this manner to align with and provide a more systematic approach to shaping a smarter manufacturing industry in support of the country's aspirations. *AmBisyon Natin 2040* signifies the Filipinos' desire for a comfortable, secure, and peaceful life. In realizing the *AmBisyon Natin 2040*, NEDA has crafted the PDP 2017–22 in collaboration with the government, the private sector, and the civil society. It entails the country's comprehensive plan to have inclusive growth, a globally competitive economy, and a high-trust resilient society.

A significant contribution toward the opportunities in the industry is the implementation of i³S. It creates an environment of innovation-centered initiatives in all key sectors (manufacturing, agriculture, and service) to reinforce domestic and global linkages. i³S has six strategies incorporating innovation to achieve globally competitive sectors. It covers (1) capacity building of employees for human resource development; (2) inclusion of MSMEs and startups in the innovative ecosystem; (3) embracing I4.0 technologies; (4) integration of production systems with agriculture and service sectors, along with linkages with domestic and global value chains; (5) linking innovation with entrepreneurship; and (6) promoting ease of doing business. These strategies have formed the backbone when designing the I^{4.0} framework for smart manufacturing implementation in the Philippines.

The I^{4.0} framework aims to strengthen the country's manufacturing sector by employing smart manufacturing systems and solutions. The application of new technologies (see Table 4) enables firms to operate efficiently and improve productivity while reducing costs, thus helping manufacturing to be more competitive. This framework intends to contribute to the realization of the Philippines' existing plans and long-term vision, with the primary objective of reducing poverty in the country. It consists of four components, namely, (1) inculcate smart manufacturing awareness, practices, skills, and competencies; (2) improve digital infrastructure and financial support; (3) integrate collaboration, innovation, and entrepreneurship; and (4) institutionalize the National Policy Framework for Smart Manufacturing.

Each component includes strategies that need to be considered to ensure smart manufacturing implementation with the collaboration of the quadruple-helix stakeholders comprising the government, the academia, the industry, and civil society organizations (CSOs). With the government's mandated responsibilities, it should spearhead and address the issues that may restrain the progress of the framework's implementation.

As a facilitating body, the government should encourage all stakeholders, especially in the private sector, to be actively involved in the smart manufacturing framework; and monitor and evaluate the manufacturing industry's performance. The government agencies identified in Table 5 should closely coordinate with other stakeholders to facilitate the strategies under the four components. As the knowledge- and skills-building sector and technology incubator, the academia should provide more smart manufacturing-related research outputs, improve the educational curriculum to cultivate both theoretical and applied knowledge of smart manufacturing technologies, and increase awareness activities about the emerging digital transformation in the country. The private sector's participation

in all innovation initiatives is significant for the industry to fully implement and assess the effectiveness of the framework. The firms (mostly large enterprises) that have already employed smart manufacturing are essential players in identifying the gaps and opportunities and provide recommendations, given that they have the experience and technical knowledge of the new technologies. Their factories can be utilized as model facilities to foster technological learning and appreciation, coupled with the government's innovation programs. Creating partnerships between manufacturing firms will help elevate the status of the manufacturing sector. CSOs play a vital role in mitigating the unintended and known adverse effects of smart manufacturing on society. Smart manufacturing may offer a vast array of benefits, but it also comes with possible drawbacks such as but not limited to substitutes for labor, environmental consequences, and data privacy issues. Thus, CSOs can advocate accountability, fairness, and ethical use. That this can minimize the risks that may arise from new technologies, is an important aspect to consider in crafting regulations and institutional frameworks. CSOs can also be associates in capacity-building and digital-literacy efforts at the grassroots level to extend innovation to unprivileged communities and promote community-led developments. In general, the proposed framework embraces the quadruple-helix approach to nurture collaboration and presents a more comprehensive perspective in implementing the smart manufacturing framework. Moreover, I^{4.0} and its underlying strategies are not a one-way process, but the whole framework relies on the continual cycle and simultaneous execution of the four strategic 'I's.

FIGURE 10

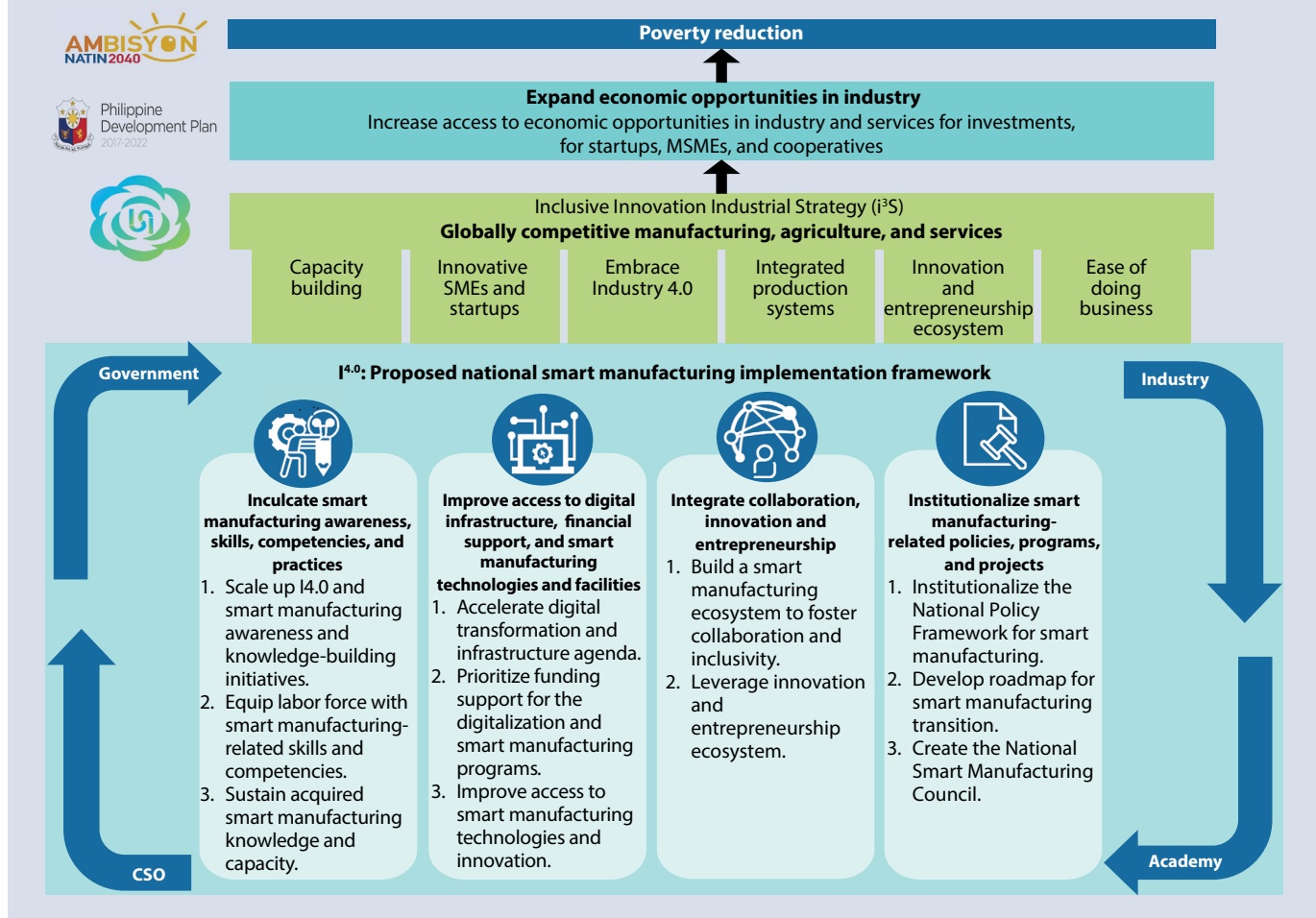
PROPOSED NATIONAL SMART MANUFACTURING FRAMEWORK I^{4.0} IN THE PHILIPPINES.

TABLE 5

SUMMARY OF I^{4.0} FRAMEWORK'S COMPONENTS, STRATEGIES, AND THEIR LEAD STAKEHOLDERS.

Component	Strategies	Sub-strategies	Lead stakeholders
Inculcate smart manufacturing awareness, practices, skills, and competencies	Scale up I4.0 and smart manufacturing knowledge building and awareness initiatives	Assess the smart manufacturing readiness and maturity of Philippine firms	DTI-BOI
		Develop smart manufacturing knowledge management products <ul style="list-style-type: none"> • Smart manufacturing guidebook, modules, and learning materials • R&D outputs 	Technology providers and consultants, academia, research community, PIDS
		Facilitate national awareness programs and activities related to I4.0 and smart manufacturing	DAP, LGUs, CSO, DTI-BOI, and BSMED
	Equip labor force with smart manufacturing-related skills and competencies	Realign educational programs responsive to the smart manufacturing demands	DepEd, CHED, TESDA, and HEIs
		Form task force for skills training and development programs to intensify capacity-building for smart manufacturing	TESDA, DOST, and DTI
		Leverage investments/agreements from international quality standards and expertise	TESDA, DTI, SSG, and foreign investors
		Update the Philippine Qualifications Framework (PQF) to align with the FIRE skills requirements	National Coordinating Council (NCC), DOLE
	Sustain acquired smart manufacturing knowledge and capacity	Recognize smart manufacturing champions to motivate smart manufacturing adoption	Industry firms
		Build innovative consultants and industry experts	DOST
Improve access to digital infrastructure, financial support, and smart manufacturing technologies and facilities	Accelerate digital transformation and infrastructure agenda	Expedite the digital connectivity programs such as National Broadband Program, and Free Wi-Fi in Public Places Program	DICT
		Secure basic infrastructure to support expansion in digital connectivity	DOE
		Fast-track the implementation of the Digital Government System	DICT
		Strengthen cyber and data security measures of smart manufacturing systems	DICT and its Industry Partners
		Endorse ICT policy reforms to improve digital connectivity	DICT, BOI, LGUs, & other national agencies
	Prioritize funding support for the digitalization and smart manufacturing programs	Increase budget allocation for digitalization	DOF, DBM, BOI
		Provide financial grants to manufacturers, especially MSMEs, to access smart manufacturing technologies	LBP, DBP, SB Corporation, and NGO financial institutions
		Unify all government and NGO financial institutions in providing financial assistance to adopt smart manufacturing technologies	LBP, DBP, SB Corporation, and NGO financial institutions
	Improve access to smart manufacturing technologies and innovation	Intensify science, engineering, technology, and innovation (SETI) activities on smart manufacturing through R&D	DOST
		Strengthen the implementation of Securing Manufacturing Revitalization and Transformation (SMART) Program	DTI

(Continued on next page)

(Continued from previous page)

Component	Strategies	Sub-strategies	Lead stakeholders
Integrate collaboration, innovation, and entrepreneurship	Build a smart manufacturing ecosystem to foster collaboration	Establish smart manufacturing networks through Regional Inclusive Innovation Center (RIICs)	DTI, DOST
		Create a web-based smart manufacturing platform	DOST, DTI, TESDA, and DICT
	Leverage an innovation and entrepreneurship ecosystem	Smart manufacturing as part of the priorities for innovation in the National Innovation Agenda and Strategy Document (NIASD)	National Innovation Committee (NIC)
		Strengthen the intellectual properties (IP) system to facilitate smart manufacturing commercialization process	IPOPHIL
Institutionalize smart manufacturing-related policies, programs, and projects		Develop a culture of innovation and entrepreneurship among MSMEs and startups	NIC, DOST, DTI
	Institutionalize the National Policy Framework for smart manufacturing		DTI, NEDA
	Develop a roadmap for smart manufacturing transition		DTI and key stakeholders
	Create a smart manufacturing inter-agency body		DTI, key government agencies, and industry partners

Inculcate Smart Manufacturing Awareness, Practices, Skills, and Competencies

The first component of the I^{4.0} framework aims to widen the recognition of I4.0 and smart manufacturing among industries, enterprises, and individuals while honing their skills aligned with the requirements needed for smart-manufacturing technologies. It will then focus on reinforcing the learnings gained, apply them in real life, and obtain evidence-based feedback and coaching for others to improve continuously. In other words, this component aims to change the perception of Filipinos towards technologies and gain massive support and interest to engage from the industry through the following strategies:

Scale up I4.0 and Smart Manufacturing Knowledge Building and Awareness Initiatives

A low level of awareness and knowledge among companies is a significant obstacle to the adoption of smart-manufacturing technologies. Based on the survey conducted by DOST XI, most businesses are not even familiar with the terms I4.0 and smart manufacturing or the related technologies such as IoT, CPS, AI, and BDA. The lack of awareness results in a lack of usage, leading to a slow transition to FIRE. To bridge this gap, there is a need to assess the industry's current position, nurture awareness about the paradigm shift, and understand the fundamental aspects of smart manufacturing.

Assess smart manufacturing readiness and maturity of Philippine firms: Evaluating the overall state of firms' operations is an essential consideration before the transformation. It seeks to understand the technological preparedness of firms and create strategic action plans to help them in the transition from Industry 2.0 to 3.0 and 4.0. Given its coverage of industry development, DTI-BOI should lead the assessment through the use of tools such as SIRI. The country may also develop its own specific smart manufacturing readiness and maturity index to ensure a tailored tool and benchmark, based on SIRI.

Develop smart manufacturing knowledge management products: Smart manufacturing guidebooks, modules, and learning materials should be made available to manufacturers aiming to build smart manufacturing knowledge. A common understanding should be set of the descriptions,

benefits, and applications of the enabling technologies of smart manufacturing indicated in Table 4. This will guide companies to understand the appropriate technology investment applicable to their procedures and explain how it affects their businesses to become more productive and efficient. Technology providers and consultants such as TÜV SÜD, Siemens, and Yokogawa can formulate the learning materials in collaboration with the academia, the research community, and the industry.

Facilitate national awareness programs and activities related to I4.0 and smart manufacturing:

Raising awareness about the importance of innovation is a preparatory step to appreciate industrial transformation. It is necessary to rapidly scale up all I4.0 and smart manufacturing-related awareness initiatives to respond to the low awareness around new technologies. This can be achieved through webinars, course trainings, and workshops that are free and accessible to all. As the country's national productivity organization (NPO), the DAP can be the leading agency to plan, conceptualize, and facilitate effective programs that raise knowledge levels regarding I4.0 and smart manufacturing. The programs can be extended to communities through assistance from CSOs and LGUs. The topic's complexity should be relayed in a way that those who are technologically lagging can appreciate the emerging technologies and their positive impacts on communities. The BOI and Bureau of Small and Medium Enterprise Development (BSMED) can also be tapped to extend awareness among MSMEs on smart manufacturing-related policies, projects, programs, and activities.

Equip Labor Force with Smart Manufacturing-related Skills and Competencies

The smart manufacturing industry's success not only depends on the deployment of technology but also on the labor force employed. The employees must have the required skillsets to operate advanced machines, deal with information and data flow, and ensure that the processes follow the standard operating procedures. According to the WEF's The Future of Jobs Report 2018, 51% of the Filipino workforce needs to reskill to adapt to new work landscape. The knowledge of smart manufacturing and a highly trained labor force apparently influences the low adoption rate of smart manufacturing technologies among enterprises.

Realign educational programs responsive to smart manufacturing demands: Education plays a vital role in ensuring the skills readiness of the labor force. DepEd, CHED, and TESDA, supported by DTI, DOST, and DICT, are suggested to continuously upgrade the existing curricula and integrate courses that could foster a learning environment conducive to smart manufacturing innovation. Programs to be developed should align with the industry needs and extend support to academic institutions in terms of research funds for faculty and students. This may go beyond a classroom-centric approach and allow learners to work on real-world applications like analyzing an industry's big data sets (e.g., Project SPARTA) and exposure to training on AI, robotics, and augmented reality, among others. It should also start at the early stages of student development and reinforce learnings to life applications. The design of programs should collaborate with higher educational institutions (HEIs), training providers, and members of the private and industry sectors. The graduates are expected to have a strong foundation in smart manufacturing systems and technology. It may be noted that Smarter Philippines through Data Analytics Research and Development, Training and Adoption (SPARTA) is a free online course for data science. It aims to train Filipinos handle big data generated by government agencies. This program is an initiative of DOST in collaboration with DAP and Analytics Association of the Philippines (AAP).

Creativity is a vital skill in generating new ideas for innovation. Integrating arts in disciplines such as science, technology, engineering, and mathematics (STEM) in the education curriculum would produce

an agile workforce. Thus, the transformation of DepEd's STEM to science, technology, engineering, arts, and mathematics (STEAM) will nurture a more innovative smart manufacturing industry.

Form a task force for skills training and development programs to intensify capacity-building for smart manufacturing: A governing body should be established to develop and harmonize all smart manufacturing training and other activities that involve representatives from smart manufacturing technology users, solution providers, training institutes, and government agencies. It aims to unify smart manufacturing skills programs, offer technical training on smart manufacturing technologies, and produce a globally competitive smart manufacturing-ready workforce. As the leading technical vocational education and training (TVET) provider in the country, TESDA is endorsed to spearhead the task force and identify other encompassing stakeholders needed to supplement the skills programs. The industry's cooperation in the skills development process would also play a crucial role in crafting programs. Efforts should be made available to involve smart manufacturing firms and solution providers in this process as they have relevant experience with these technologies.

The task force will harmonize and amplify the smart manufacturing training activities and facilities initiated by various government agencies. Notable programs include the DOST's AMeRIAL and AMCen projects; I4.0 Pilot Factory, Digi Hubs, Fabrication Laboratories, and SME Academy and Innovation Center of DTI; and the Regional TVET Innovation Center of TESDA. These activities provide technical assistance, workshops, and training hubs for technologies.

Leverage investments/agreements from international quality standards and expertise: The passage of the 11th Regular Foreign Investment Negative List would allow the entry of foreign educational institutions specializing in teaching advanced high-technology skills such as robotics, engineering design, additive manufacturing, IoT, and augmented reality. It is expected to attract more foreign-owned training centers that specialize in short-term high-level skills development. It would then stimulate knowledge transfer from international institutions to local industries, thus enabling firms to leverage technological advancements, perform higher value-added functions, and produce high-quality outputs. Similarly, the memorandum of understanding (MOU) between TESDA, DTI, and Skills Future Singapore (SSG) would strengthen international-standard skills training in the country.

Update Philippine Qualifications Framework (PQF) to align with FIRE skills requirements: There is a need to integrate the smart manufacturing qualifications standards in PQF to address skills mismatch issues in future work. It would enhance workers' employability, by ensuring that their qualifications fit the requirement, with the assistance of the Department of Labor and Employment (DOLE). Under the National Skills Program, DOLE initiated a web-based national skills registry system that enrolls skills registrants in the country. It helps employers expedite the selection and hiring process, thus assuring that skills registered are correct and up to date. This program will be relevant to utilize in the context of smart manufacturing employers and job seekers.

Sustain Acquired Knowledge and Capacity

Recognize smart manufacturing champions to motivate smart manufacturing adoption: Local companies that are already smart-manufacturing-ready or have successfully implemented smart manufacturing technologies in their operations should be recognized as smart manufacturing champions and benchmarked for other enterprises. Smart manufacturing champions play a vital role in extending their best practices and learning by coaching others to improve productivity through new technologies. Highlighting their success stories will likely influence more companies to be open to technological and organizational changes and imply that smart manufacturing

transformation is possible in the Philippine setting. This recognition can be documented and integrated into the smart manufacturing knowledge guidebook and modules.

Build innovative consultants and industry experts: Qualified consultants who have experience and knowledge about the latest smart manufacturing practices are needed to continue developing the industry. It seeks to establish a network of local scientists, researchers, inventors, and engineers from public and private institutions to address smart manufacturing problems. DOST could identify the accredited smart manufacturing experts under its ‘One Expert’ portal and recommend incorporating smart manufacturing into their system. The web-based platform would help firms access technical advice and consultations from experts located anywhere in the Philippines.

Improve Access to Digital Infrastructure, Financial Support, and Smart Manufacturing Technologies and Facilities

The question of resources is critical to digital transformation. Of particular importance in this context are: suitability of the existing ICT infrastructure, availability of funding support, R&D investments, and access to smart manufacturing technologies. These are the most-cited challenges faced by the companies that resist switching to smart manufacturing. The second component of the I^{4.0} framework aims to address these issues and provide the following strategies:

Accelerate Digital and Infrastructure Agenda

Smart manufacturing adoption will be fully realized if the country’s digital divide is addressed. Reliable and fast communications networks and services should be made available, affordable, and accessible to every firm, especially MSMEs, to enable smart operations. For instance, a smart factory empowered with a technology such as IoT requires high-speed internet to interact with other machines and perform operational tasks. Without the high quality of connection and ICT infrastructure, disruptions in production may occur, thereby leading to low productivity instead of the supposed efficiency promised by smart manufacturing. Notably, the Philippines lags in digital connectivity and infrastructure among neighboring countries. Thus, policy reforms should be reviewed and programs to facilitate digital transformation should be fast-tracked to provide an ICT-enabling environment for manufacturers to shift to smart manufacturing.

Expedite digital connectivity programs: DICT should prioritize the implementation of the National Broadband Program and the Free Wi-Fi in Public Places Program to support the increasing demand for broadband services. These programs serve not only the smart manufacturing transformation but also benefit other businesses, the government, and the public. The expansion of services should include the countryside to provide equal broadband access. CSOs may be tapped to gather inputs from the communities’ experiences in connectivity issues, to offer a comprehensive plan to address the digital divide. Simultaneously, they can educate the communities on the benefits of high-speed connections and how they can be part of the ICT improvement in the country.

Secure basic infrastructure to support ICT adoption and application: Electricity and access to roads and ports should also be considered to facilitate broadband projects, particularly in remote areas. The Department of Energy (DOE) is suggested to establish a robust national electricity infrastructure to ensure that basic and critical power infrastructure will be in place to support the expansion of digital connectivity needed for smart manufacturing transition in the country.

Fast-track the implementation of the Digital Government System: A full implementation of the Digital Government System, offering a technology-enabled government, would promote confidence

among manufacturers to invest in advanced technologies as the system signifies a strong foundation toward digitalization. Hence, the government, under the direction of DICT, needs to accelerate the development of critical solutions toward the digital system. It would enable the government agencies to remotely perform their mandates and implement their programs, projects, and activities.

Strengthen cyber and data security measures of smart manufacturing systems: Data and cyber security threats pose a challenge to smart manufacturing as it heavily relies on data connectivity. There is a need to integrate strategic programs and platforms in the National Cybersecurity Plan that are responsive to issues arising from smart manufacturing and I4.0. A unified platform with DICT and its cyber security partners from the private sector must be established to assist in data protection, cyber security threats, attacks, and other issues.

Endorse ICT policy reforms to improve digital connectivity: To harness the potential of digital transformation, the government will need to evaluate the programs and interventions in the ICT sector to align with the onset of FIRE. Policymakers may consider removing the entry barriers to increase the number of network providers. Currently, limited players are present in the country due to regulatory restrictions. This reform could promote competition among independent network providers, increase investments, and speed up the overall quality of broadband services at affordable rates. The inclusion of telecommunications and infrastructure under the 2020 Investment Priority Plan (IPP) of BOI would provide incentives for new private investments towards ICT improvement. Qualified investors may be entitled to tax and duty exemption, lower fees, and other incentives.

Further, multiple permits and licenses required to deploy networks, as imposed by national and local governments must be redefined to abide by the mandated period for issue of clearances and certifications as per the country's Ease of Doing Business Act of 2018. This would simplify and harmonize the processes to speed up broadband deployment and encourage more market players. Infrastructure sharing should also be fortified to reduce costs for network and service providers while enabling the development of new and innovative services for the public. This would also help expand the coverage of ICT services across the country, especially in unserved and underserved communities.

[Prioritize Funding Support for Digitalization and Smart Manufacturing Programs](#)

Increase budget allocation for digitalization: Funding is necessary to facilitate digitalization-related initiatives. The country needs to realign the budget in line with its pressing need for digitalization, especially amidst the pandemic and the country's vision towards FIRE. Increasing the allocation would expedite smart manufacturing implementation, including the acquisition of smart manufacturing technologies for training purposes, provisioning of more capacity-building and awareness programs, enhancement of the existing digital infrastructure, and other initiatives that would drive the country towards I4.0. An integrated long-term financial plan for the full-program budget of digitalization and smart manufacturing transition should be made available by DOF and DBM. It would serve as a guide for overall project allocations and project development updates. The BOI may present to the Legislative Branch to secure budgetary support for smart manufacturing implementation.

Provide financial grants to manufacturers, especially MSMEs, to access smart manufacturing technology: There is a need to finance enterprises to transform to smart manufacturing. The lack of adequate capital and investment is a major factor that hinders companies, especially MSMEs, in adopting new technologies. As part of the 2020 IPP-preferred investment activities, firms that

venture into smart manufacturing and innovation-centered initiatives would be financially supported. Assistance also covers business and research opportunities as well as fiscal and non-fiscal incentives. Funding can be facilitated through LBP businesses to invest in strategic industries like smart manufacturing.

The private sector may also invest in startups and MSMEs to explore new digital business models. Funding startups would allow large companies to focus on their actual operations while having external partners to develop their next digital innovations. This would typically be achieved through competition where startups and MSMEs pitch their business models and get selected to receive the funding grants. On the other hand, the academia could also subsidize their spinoffs and provide access to facilities for the initial phase of their organizations.

Unify all government and NGO financial institutions in providing financial assistance to smart manufacturing: Both public and private sectors offer various financial assistance programs but are fragmented. LBP, DBP, SB Corporation, and other NGO financial institutions should collaborate and create a special holding department to facilitate all smart-manufacturing-related grants and fundings. This would strengthen and streamline financial programs to capacitate more assistance to manufacturers.

Strengthen Access and Development of Smart Manufacturing Technology and Facilities

Intensify science, engineering, technology, and innovation (SETI) activities through R&D on smart manufacturing: With the proliferation of new technologies and innovation in smart manufacturing, the Philippines should intensify its SETI initiatives through R&D to take advantage of the trends in the manufacturing industry and compete in a global perspective. First, the government should invest more in R&D. There is a need for high-quality R&D outputs that focus on smart manufacturing processes, systems, and technologies. The academia and research communities can harness partnerships with countries having smart-manufacturing-ready industries as well as with government agencies doing smart manufacturing research activities. All R&D activities related to smart manufacturing can be subsumed into the DOST-PCIEERD's online compendium of PH technologies. Information should be available on the research, progress updates, and details of scientists and researchers. Private companies and the industry are also encouraged to participate in the sharing of R&D. This would promote coordinated R&D and bridge the information gap that may exist in research activities conducted by an institution. Particularly, the creation of national and regional research committees on smart manufacturing would provide directions and set priority research areas in smart manufacturing development.

Strengthen the implementation of Securing Manufacturing Revitalization and Transformation (SMART) Program: The SMART program is part of DTI's efforts to engage the manufacturing sector in innovation and digital transformation as a preparation for FIRE. It would support projects related to I4.0 technologies adoption, industry-led innovation and R&D, global value chain upgrading, standards development, and technology-intensive investments, especially in rural areas.

Integrate Collaboration, Innovation, and Entrepreneurship

The third component of the framework aims to create an environment conducive to smart manufacturing innovation with strong collaboration of key stakeholders. It also intends to foster inclusivity of smart manufacturing by strengthening the bridge between innovation and entrepreneurship. The key action points are discussed ahead.

Build a Smart Manufacturing Ecosystem to Foster Collaboration and Inclusivity

Establish smart manufacturing networks through Regional Inclusive Innovation Centers (RIICs): RIICs would help expand smart manufacturing developments in every region, promoting inclusive innovation through productive collaboration between industries, academia, government agencies, startups, MSMEs, and other related agents in the ecosystem. These centers would accelerate the establishment of a smart manufacturing network across Philippine manufacturers. Under RIICs, priority industries are based on a region's existing comparative advantage, capitalizing the strategies aligned to its specific needs. Priority manufacturing industries identified under i³S include electronics, automotive, chemicals, aerospace, shipbuilding, tourism, transport, IT-BPM, construction, agribusiness production, tools and dies, and furniture and textile creatives.

Create a web-based smart manufacturing platform: Integration of all smart manufacturing efforts would strengthen the promotion of the ecosystem and avoid overlapping smart manufacturing initiatives by different institutions. DOST, DTI, TESDA, and other key stakeholders, with the technical assistance of DICT, could develop a website for all smart manufacturing-related information pertinent to smart manufacturing framework, roadmap, plans and policies, projects and programs, knowledge management outputs, and databases. It would act as a one-stop shop aimed at providing seamless access to smart manufacturing services. The platform could also be linked to the Filipinovation portal containing other innovation-related sites.

Leverage Innovation and Entrepreneurship Ecosystem

Smart manufacturing as part of the priorities for innovation in the National Innovation Agenda and Strategy Document (NIASD): The National Innovation Committee (NIC) may consider smart manufacturing's inclusion in the innovation priorities to stimulate the country's capacity toward FIRE. Smart manufacturing should be integrated into the comprehensive strategies and action plans to improve innovation governance aligned with the mandate of the Philippine Innovation Act.

Strengthen intellectual properties (IP) system to facilitate smart manufacturing commercialization process: The Philippines has generally remained low in technology transfer and commercialization of R&D output due to IP filing issues. There is a need to simplify and streamline administrative and registration procedures of IP filing to reduce costs, thus encouraging more commercial outputs. Implementing the National Intellectual Property Strategy (NIPS) would allow the IP system to be more systematic, comprehensive, and effective in delivering reliable service for Philippine creators and innovators.

Develop a culture of innovation and entrepreneurship among MSMEs and startups: This could be achieved through mentorship programs on certification and licensing, as well as capability training on crafting business plans, market research, and feasibility studies. The aim would be to transform creative ideas into commercially viable products. The NIC may also assist MSMEs and startups in registering patents, layout designs, registration of trademarks, and geographical indications, along with other marks of ownership, industrial designs, utility models, and deposit of copyrights.

The presence of technology hubs would allow MSMEs and startups to connect and network with industry experts and large players in the manufacturing industry. The establishment of more Technology Business Incubation (TBI) offices in universities would encourage startups to engage in smart manufacturing solutions and innovation. Recipients would be provided with business

development training in innovation and technopreneurship. Notable programs include the Innovative Development through Entrepreneurship Acceleration (IDEA) Program, the Philippine Startup Development Program, and the Google Launchpad Accelerator Program. Moreover, the recently passed MOU between DICT, DTI, and DOST would develop the Startup Assistance Program 2019–23 and amplify the support to 1,000 startups.

Institutionalize Smart Manufacturing-related Policies, Programs, and Projects

Institutionalize the national policy framework for smart manufacturing: Institutionalizing the strategies and programs presented in the previous three components would strengthen smart manufacturing implementation and allow more support from government agencies and other stakeholders. Given the extensive involvement in the country’s preparation for I4.0, DTI should craft a national policy on smart manufacturing that aims to provide support, benefits, and programs that could transform the manufacturing industry and its related services to be smarter and FIRE ready. This policy should recognize the importance of smart manufacturing technologies for overall operations in manufacturing. DTI and NEDA may harmonize the country’s industrial policies and strategies, streamline projects and programs, facilitate industry upgrades, and attain sustainable and inclusive growth that are all anchored on *AmBisyon Natin 2040*. It should formulate policies covering the three ‘I’ components, namely, inculcate, improve, and integrate.

The inculcate component would scale up actions for all levels and areas of education, training, and human resource development toward sustainable smart manufacturing awareness and capacity building of the workforce. The smart manufacturing readiness and maturity index would be performed, deployed, and analyzed to provide more insights on smart manufacturing implementation at the enterprise level.

The improve component would strengthen the country’s ICT infrastructure and digital connectivity; support full or partial subsidy in digitalization and all smart manufacturing-related programs and initiatives; and enable continuous development of smart manufacturing technologies.

The integrate component would strengthen and deepen the interactions and partnerships among different actors in public and private sectors; encourage entrepreneurial attitude in fostering innovation to stimulate growth ambitions among manufacturers; and support and promote the access of MSMEs and startups to smart manufacturing development programs.

These components are recommended to be incorporated in the national policy. Guidelines should be developed for their coordinated implementation. The leading government agencies identified in each component could coordinate in stipulation of each stakeholder’s roles and responsibilities.

Develop a roadmap for smart manufacturing transition: A roadmap should also be developed by DTI, integrating all the inputs from different stakeholders. The roadmap would guide stakeholders on the assigned responsibilities and track the progress of the transformation. It should cover areas in the planning, implementation, reporting, monitoring, and evaluation of the roadmap results. The roadmap must be time-bound with specific, measurable, achievable, realistic, and timely (SMART) objectives. A separate roadmap for large enterprises and MSMEs may be developed to cater to the differences between their current situations, needs, and capabilities, among others. A monitoring-and-evaluation framework/criteria must also be put in place to determine if the goals are being achieved on time, and to measure the effectiveness of smart-manufacturing-related policies, plans, and programs being implemented.

Create a smart manufacturing interagency body: An interagency body should be established, composed of the relevant government agencies; academia; representatives from the industry, including manufacturing firms, financial institutions, and CSO (to complete the quadruple-helix); and committees from the House of the Representative and the Senate. This body would provide overall guidance and supervision, and facilitate development of the country's smart manufacturing.

Conclusion

The Philippines has continuously strived to keep abreast with the new manufacturing trends, and aims to develop a globally competitive manufacturing through innovation. Efforts to promote and implement smart manufacturing include conducting annual manufacturing summits, business matching, trade fairs, and awareness programs that serve as a means for bringing together different stakeholders and consultations in preparation for the transition to I4.0. One promising policy that supports the transition is i³S that aims to grow competitive manufacturing, agriculture, and services industries. Innovation is at the center of this policy and its strategic actions. Other innovative programs initiated by the government have been in areas such as training, facilities, technological upgradation, R&D, and commercialization. However, these programs were observed to be fragmented and limited, and no systematic plans were available to directly address the smart manufacturing transition.

To strengthen the preparation of the country's shift to smart manufacturing, the I^{4.0} framework was proposed to provide a specific approach designed solely for the implementation of smart manufacturing in the country. It aims to guide the formulation of new policies and roadmaps to legitimize and recognize smart manufacturing. The framework relies on the iterative process and simultaneous execution of four general components. Thus, new strategies may emerge along with the implementation of the framework. These strategies will be implemented to collaborate with the quadruple-helix stakeholders comprising the government, the academia, the industry, and CSOs. In general, the government would be the principal agency to lead the execution of strategies, crafting of policies, and ensuring the framework's successful implementation. With the academia's help, it would act as the knowledge- and skills-building sector and technology incubator. The industry would be the learning partner in terms of sharing best practices and model factories for those who have adopted smart manufacturing technologies. CSOs would have a vital role in ensuring sustainable and ethical use of technologies and extending smart manufacturing initiatives to the less-advantaged communities to promote inclusive innovation.

The Philippine manufacturing still has a long way to transform to smart manufacturing. However, with full collaboration of the key stakeholders involved to maximize the opportunities given to them, the country would achieve its goal of having a globally competitive manufacturing industry.

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VIETNAM

Introduction to Country-specific Smart Manufacturing

Background Statistics on Manufacturing Sectors in Vietnam

As per the Socioeconomic Report 2019 from General Statistics Office (GSO) of Vietnam, the country's GDP stood at 7.02% in 2019. This made Vietnam one of the three countries with the highest GDP growth in Asia. Notably, the industry and construction sector grew by 8.9%, contributing 50.4% to the GDP growth [1].

In 2019, the processing and manufacturing industry, with a growth of 11.29%, continued to play a key role in the economy's growth, contributing 2.33% to GDP. Among all the industries, the processing and manufacturing industry accounted for 56% of the total value added by the industry as a whole, while employing 95% of the industry's labor force. Labor productivity of the processing and manufacturing industry stood at VND96.2 million (USD4,160) per person. The processing and manufacturing industry is considered to have good growth, in terms of both quality and quantity. However, compared with some industrially developed countries in Asia and the ASEAN-4 group, the labor productivity of manufacturing is low. The processing and manufacturing industry, with a growth of 10.9%, is still the bright spot and the driving force of the industry.

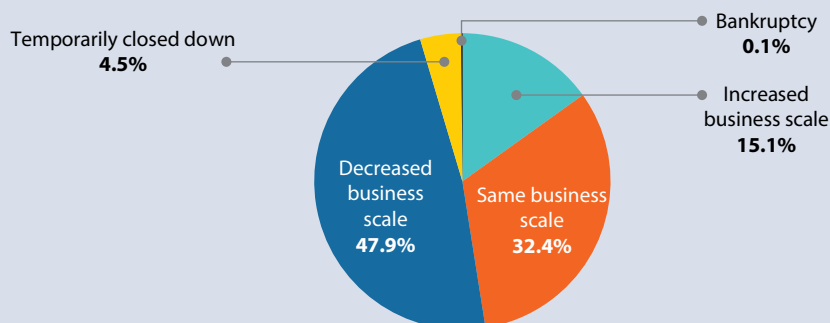
Despite a slow growth in global trade and economy, Vietnam's exports in 2019 were expected to grow by 7.8%, much higher than the world and regional averages. In particular, the processing and manufacturing industries grew by 9.8%. Products with high export growth such as wood and furniture, textiles, footwear, electronics, electric cables, and toys and sports equipment have all contributed toward enhancing the position of the manufacturing and processing industry.

Industry in general and processing and manufacturing industry in particular are also bright spots in attracting foreign investment. In 2019, Vietnam attracted 3,478 new projects, with a total capital of around USD31.8 billion. Processing and manufacturing industries accounted for the highest share with a total capital of USD21.56 billion, which amounted to 67.8% of total registered investment capital [2].

Impact of COVID-19 on Smart Manufacturing

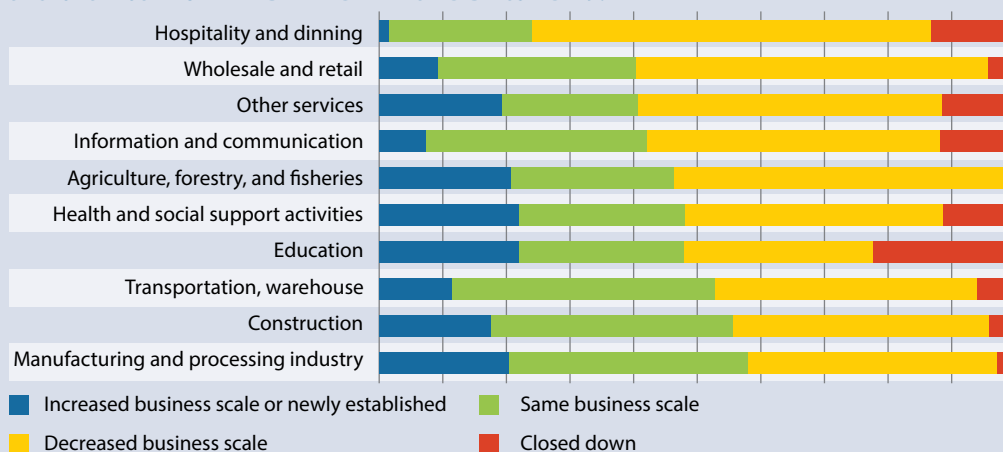
The survey on the effects of COVID-19 on SMEs done in 2020 revealed that as of mid of July 2020, while other countries were at the peak of the epidemic, many Vietnamese SMEs had almost returned to normalcy. However, negative effects were still present in 52.5% of the 783 surveyed enterprises, with 4.6% of the enterprises even suspending, closing, or dissolving their businesses. COVID-19 impacted all industries in the survey groups, but was led by tourism, accommodation, and food and beverage (70% of the enterprises downsizing and dissolving); wholesale and retail (59%); and services (59%). Comparing business results with the same period in the previous year, the indices recorded an average decrease of over 21%, impacting around 70% of the surveyed enterprises (see Figure 1) [3].

The survey results also show a negative picture of business performance. This is clearly reflected in the indicators related to finance, production, output market, and labor resources. More than 96% of

FIGURE 1**HOW COVID-19 IMPACTED THE SMEs.**

Source: Survey of SMEs in July, 2020.

the enterprises had difficulties on financial, production, and business fronts. As high as 96.7% of enterprises had financial problems due to reasons such as the failure of customers to make payments on time; receivables not getting collected when due (70.1%); and high costs due to trade difficulties on account of social distancing norms (27%). In addition, 30.5% of the enterprises said that financial difficulties led to their inability to pay dues. Also, 96.3% of the enterprises faced difficulties in production as sources of raw materials were hard to find and there was either a lack of labor supply due to the social distancing policy or a labor surplus due to reduced production scales. Regarding the business situation, due to customers canceling orders, the issue of delayed payment was reported as a common problem by 90.6% of the surveyed enterprises. Market demand fell sharply, thereby greatly affecting production and business activities, said 88.3% of the enterprises (see Figure 2).

FIGURE 2**SECTORS MOST VULNERABLE AND AFFECTED BY COVID-19.**

Source: Survey of SMEs in July, 2020.

Status of Smart Manufacturing Promotion and Implementation

Digital Capabilities through ICT Applications

To continue to have breakthrough development in a new period, for gradually narrowing the gap with developed countries, one of the most fundamental solutions is to have a strong digital

transformation, i.e., to promote smart manufacturing. According to research reports by Commonwealth Scientific and Industrial Research Organisation (CSIRO)'s Data61 on Vietnam's digital transformation scenario, if Vietnam is not active and has a low investment in digital transformation, it will result in a slow digital economy and stagnant productivity.

In recent years, ICT enterprises have developed strongly. Vietnam's ICT industry continues to achieve growth with high turnover, high export value, and an average annual growth rate of 20–30%. In 2018, the total revenue of the ICT industry was estimated at USD98.9 billion, and exports were estimated at USD94 billion. In the past 10 years, the size of the ICT industry has increased 16 times, making it one of the fastest growing economic sectors in the country. The large domestic ICT enterprises have turned to research, manufacturing, and production autonomously. At the forefront are Viettel Group, VNPT Group, FPT, CMC, and the upcoming Vingroup, along with many other corporations. Many startups are digital, some of which are quite successful [4].

ICT has been widely applied in various types of enterprises, and has helped increase labor productivity and competitiveness. However, Vietnamese enterprises, especially SMEs, are not properly aware of the roles of digital transformation and smart manufacturing in Industrial Revolution 4.0. SMEs have not actively approached technology and infrastructure systems, or transformed business organization models to meet technology trends. Most of the machinery used in Vietnamese enterprises is based on old technologies. Specifically, according to Vietnam Chamber of Commerce and Industry (VCCI), Vietnam's SMEs accounted for around 97% of the total number of enterprises with a low adoption level of science, technology, and innovation.

ICT application has been widely applied in the society, thereby contributing to improved quality of life of people and reduced social gaps, especially in the fields of education and health. ICT has been applied to develop e-governance, thereby contributing to administrative reforms. Legal documents have been issued to facilitate the application and development of ICT in all fields. Specifically, the Law on IT, Law on Cyber Information Security, Law on Cyber Security, and many Decrees have contributed significantly. However, the current legal environment has not kept pace with the requirements to perform digital transformation. Specifically, the lack of legal frameworks for the development of a sharing economy, sharing and opening of data of government agencies and enterprises, issues of protection of personal data and private information, and issues of rights and ethics in the application of artificial intelligence, limit the scope of digital transformation.

Vietnam has rapidly developed its telecommunications infrastructure, thus creating a foundation for socioeconomic development. The telecommunication infrastructure spans more than 600,000 km of fiber optic cable nationwide, with high access speeds of more than 27 Mbps. The number of fixed broadband subscribers is more than 13 million, of which more than 12 million subscribers use fiber optic services, with access speeds more than 10 Mbps. Total international bandwidth is more than 8.1 Tbps and mobile network coverage is 99.7%. 5G mobile network, a breakthrough in connection speed, has been licensed for testing. It would be an important platform for connecting the IoT infrastructure as part of the digital transformation. To facilitate digital transfer, it would be necessary to continue developing the digital infrastructure, especially the 5G mobile networks. Data protection and cyber security are areas where Vietnam still faces a big challenge.

In the context of digital transformation, digital data plays a very important role. Digital data is an asset, a resource, and a prerequisite for digital transformation. The development of databases in both public and private sectors has been focused. A number of national-scale databases has been

formed and brought into full play for provisioning of online services. Examples are National Business Registration Database, database of households participating in insurance, tax database, customs database, and social insurance database. Also, digital signature authentication service in Vietnam has been developed, and serves the purpose of electronic identification and authentication.

Coming to Vietnamese workforce, it has many advantages. However, by the end of 2018, Vietnam still had a shortage of 70,000 employees in the ICT field. As per data from a recent survey of the Institute of Information and Communication Strategy, Ministry of Information and Communication, 70% of graduates in IT need to be retrained to meet the job requirements. A majority of IT students do not have a grasp of their fields of work; 72% lack practical experience; while 42% lack the skills to work in groups. Among the newly graduated students, only about 15% meet the requirements of enterprises, with 80% of new graduates in computer programming being in need of retraining.

Priority for Smart Manufacturing

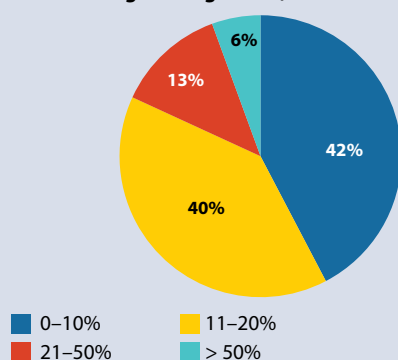
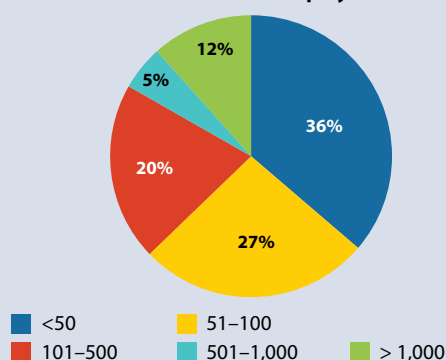
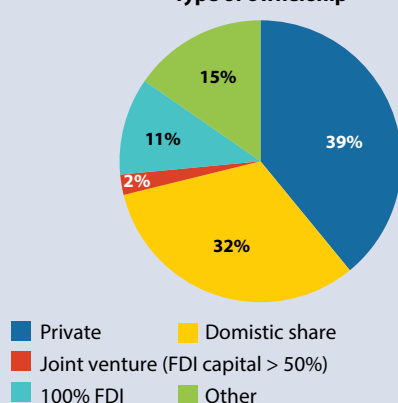
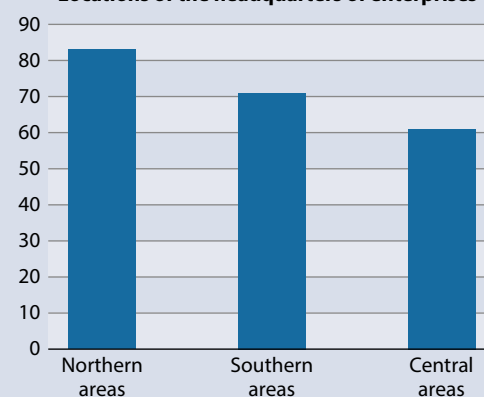
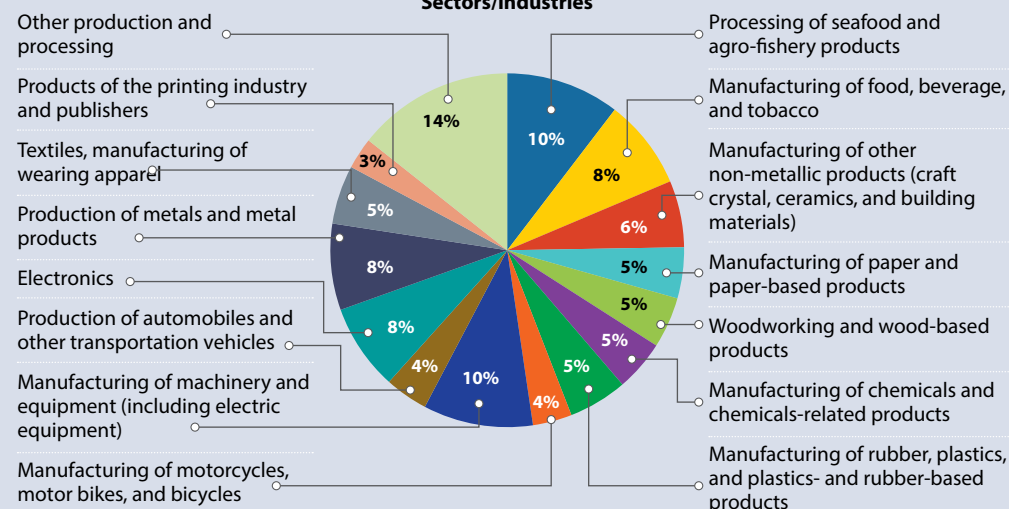
In 2019, a preliminary survey on the current status and applicability of smart manufacturing in Vietnam for 215 enterprises in the northern, central and southern provinces was conducted by Directorate for Standards, Metrology and Quality of Vietnam (STAMEQ). The survey explored the awareness around the role and applicability of smart manufacturing; the current status of smart manufacturing applications; difficulties and barriers in the application of smart manufacturing in Vietnam; and policy priorities according to their importance for smart manufacturing promotion. The survey results are shown in Table 1.

TABLE 1

ENTERPRISES ARE GROUPED BY 15 AREAS OF ACTIVITY.

Sl. no	Sectors and domains	Ratio (%)
1	Processing aquatic products and agro-fishery products	10%
2	Manufacturing of food, beverages, and tobacco	8%
3	Producing other non-metal products (ceramics, glass, etc.)	6%
4	Producing paper and paper products	5%
5	Wood processing and wood products	5%
6	Producing chemicals and chemical products	5%
7	Producing rubber, plastic, and products from rubber and plastic	5%
8	Manufacturing of motorcycles, motorbikes, and bicycles	4%
9	Manufacturing of machinery and equipment (including electrical equipment)	10%
10	Car manufacturing and other transport equipment	4%
11	Electronic	8%
12	Producing metal and metal products	8%
13	Textile and apparel production	5%
14	Products of the printing industry and publishing houses	3%
15	Other production and processing	14%

Among the surveyed enterprises, 39% were privately owned; 32% had owning forms of domestic shares; 2% had owning forms of joint ventures, with FDI accounting for more than 50%; 11% had owning forms of 100% FDI; and 15% had other forms of ownership (see Figure 3). The number of employees in the firms and the average growths in firm sales over the past three years are also depicted in Figure 3.

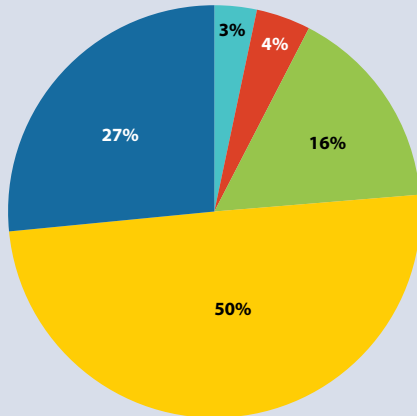
FIGURE 3**INFORMATION OF SURVEYED ENTERPRISES.****Average sales growth (in the last three years)****Total number of employees****Type of ownership****Locations of the headquarters of enterprises****Sectors/industries**

Survey data on the perception of the potential of smart manufacturing to help enterprises (see Figure 4) shows that out of the total number of surveyed enterprises, about 77% agreed with the opinion. Also, 27% of the surveyed enterprises completely agreed with the view that smart manufacturing plays a role in improving the quality of business management decisions. Only 7% of the enterprises believed that smart manufacturing did not play an important role in improving the quality of executive decision-making.

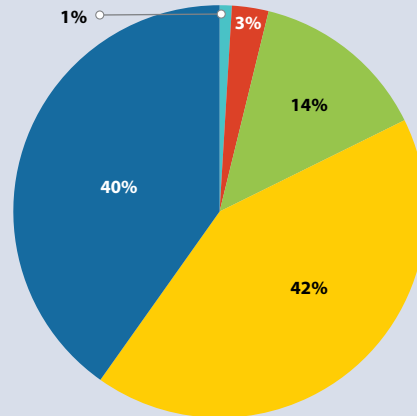
FIGURE 4A

SMART MANUFACTURING HAS GREAT POTENTIAL TO HELP ENTERPRISES.

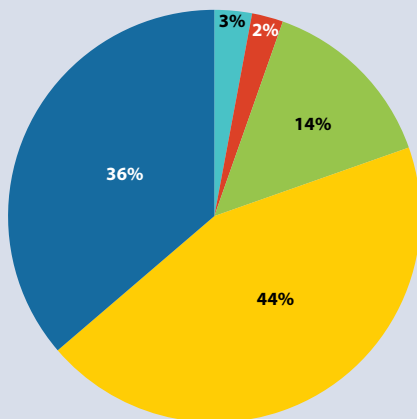
Smart manufacturing's potential in improving the quality of decision making



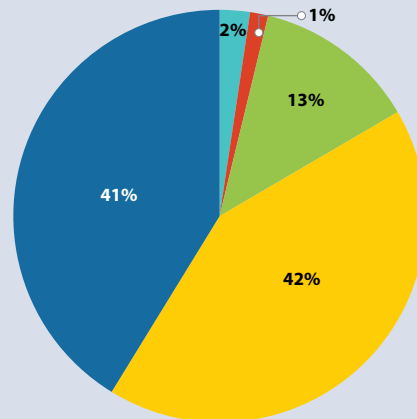
Smart manufacturing's potential in reducing labor costs



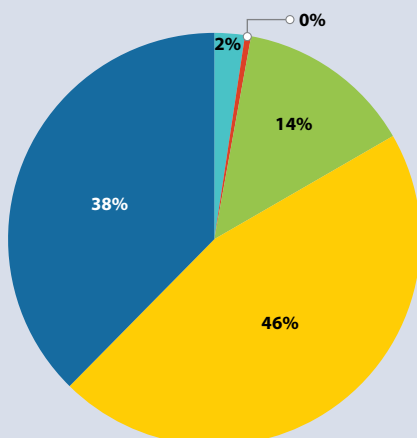
Smart manufacturing's potential in reducing material wastage



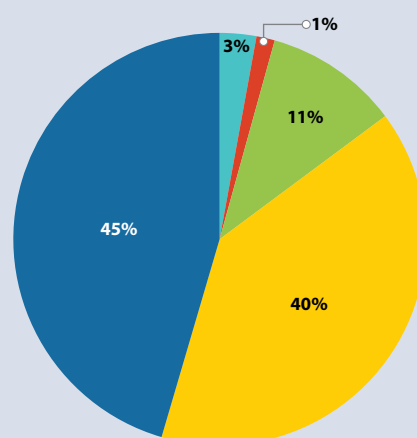
Smart manufacturing's potential in improving the operational efficiency of production line



Smart manufacturing's potential in improving quality of products



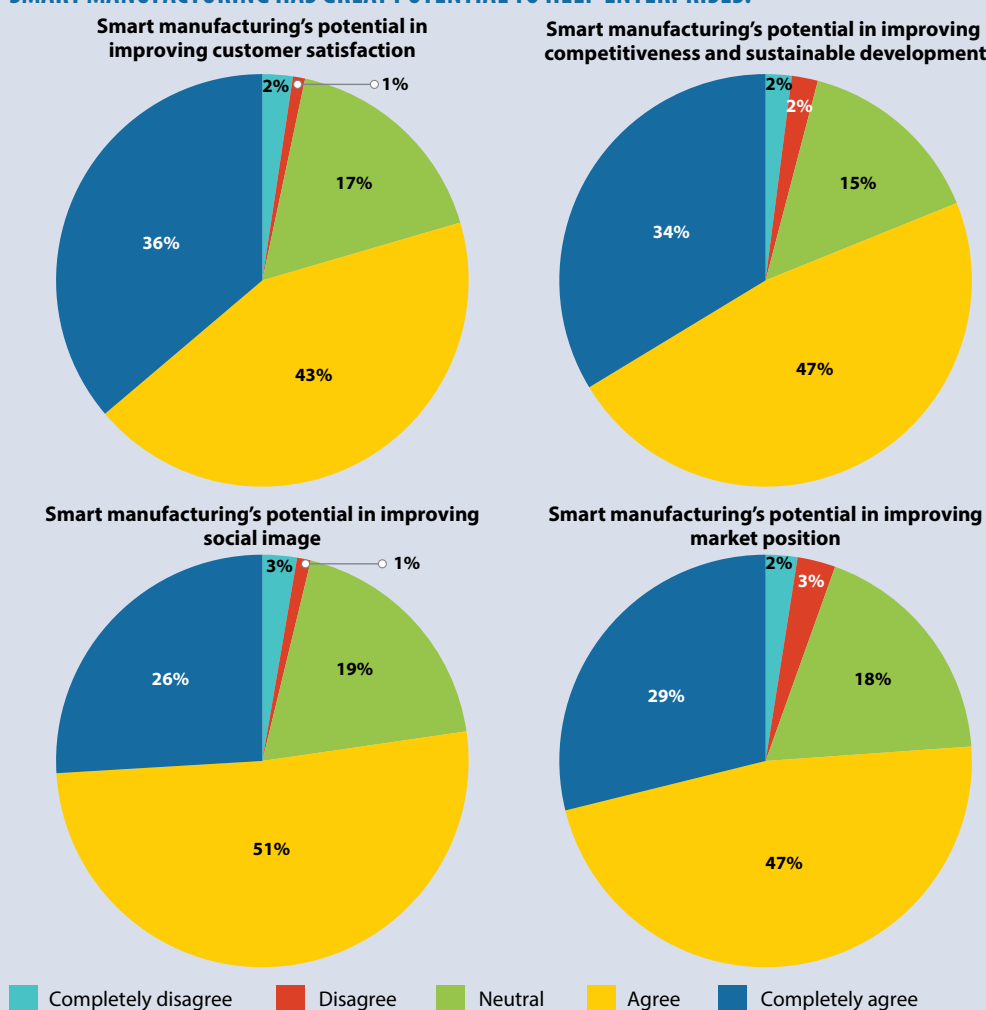
Smart manufacturing's potential in increasing labor productivity



■ Completely disagree
 ■ Disagree
 ■ Neutral
 ■ Agree
 ■ Completely agree

FIGURE 4B

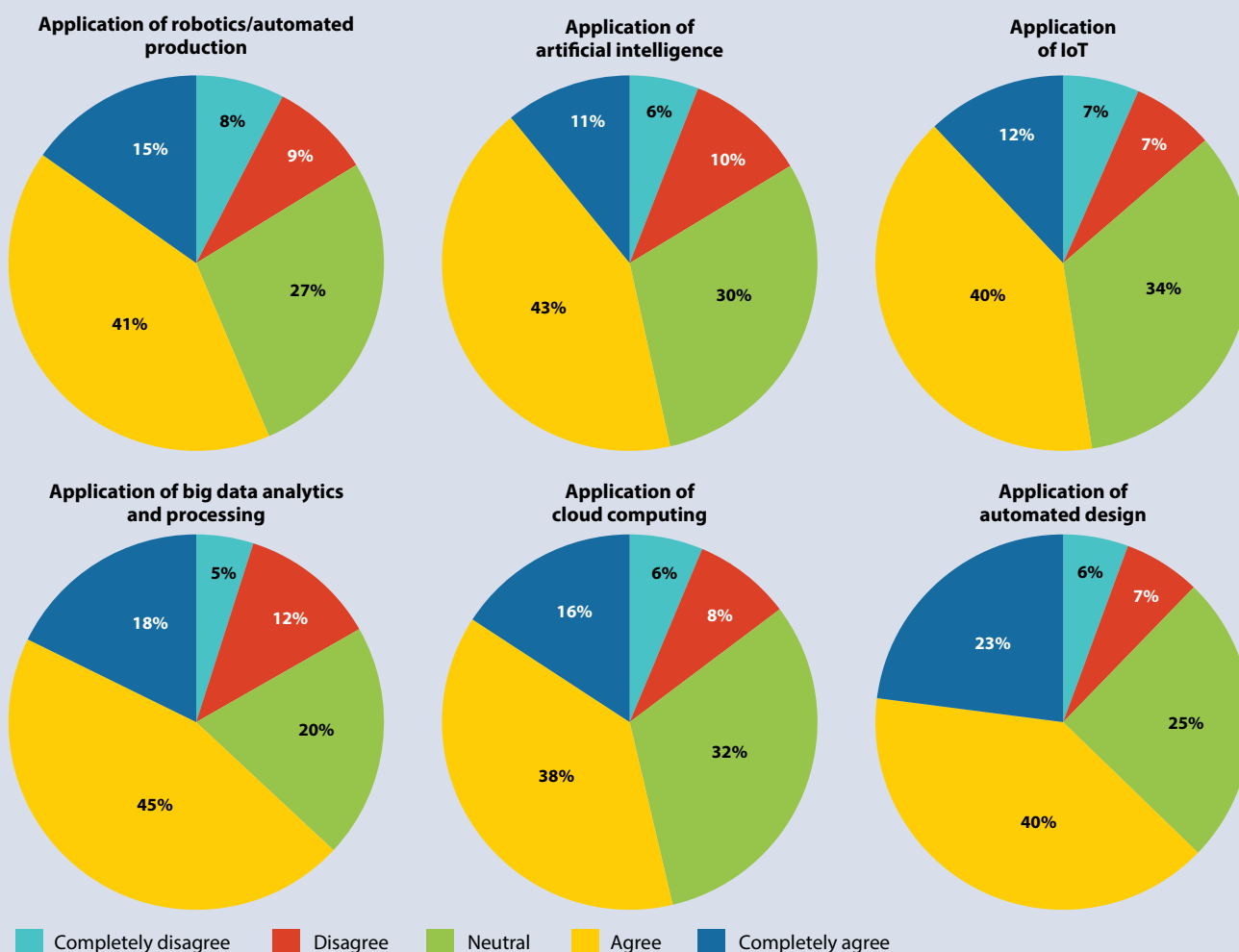
SMART MANUFACTURING HAS GREAT POTENTIAL TO HELP ENTERPRISES.



A majority of enterprises participating in the survey views that smart manufacturing was playing a role in (1) improving the efficiency of production line operations (83%); (2) reducing labor costs (82%); (3) reducing material wastage (80%); (4) increasing product quality (84%); (5) increasing labor productivity (85%); (6) providing a better position to respond to customer requirements (79%); (6) enhancing competitiveness and sustainable development (81%); and (7) increasing market position and social image (76%).

The perception of applicability of various technologies to smart manufacturing in the industry in Vietnam is depicted in Figure 5.

Among the surveyed enterprises, 18% think that big data analysis and processing is applicable to smart manufacturing; 83% see the possibility of applying big data analysis and processing to smart manufacturing; 15% think that robots and automatic production can be applied to smart manufacturing while 17% disagree with that; 11% think that AI can be applied to smart manufacturing while 16% disagree with that; 12% think that IoT can be applied to smart manufacturing while 14% disagree with that; 16% think that cloud computing can be applied to

FIGURE 5**PERCEPTION OF APPLICABILITY OF TECHNOLOGIES TO SMART MANUFACTURING.**

smart manufacturing while 14% disagree with that; and 23% think that automatic design can be applied to smart manufacturing while 13% disagree with that.

The current status of smart manufacturing applications that the surveyed enterprises have deployed in specific areas is described in Figure 6. Regarding the application of big data analysis and processing, results show that among the participating enterprises, on an average, 30% have learned it but have no intention of implementing it. As for other applications, only 7–10% have implemented and obtained encouraging results from robotics and automatic production, AI, IoT, cloud computing, and automatic design applications.

The survey results regarding some difficulties and barriers in the application of smart manufacturing in Vietnam are described in Figure 7. On understanding the value that each application can bring for enterprises to consider and choose, 5% of the participating enterprises said it was not difficult, while 49% of surveyed enterprises believed that it was difficult. In particular, 10% of the surveyed enterprises considered it very difficult to understand.

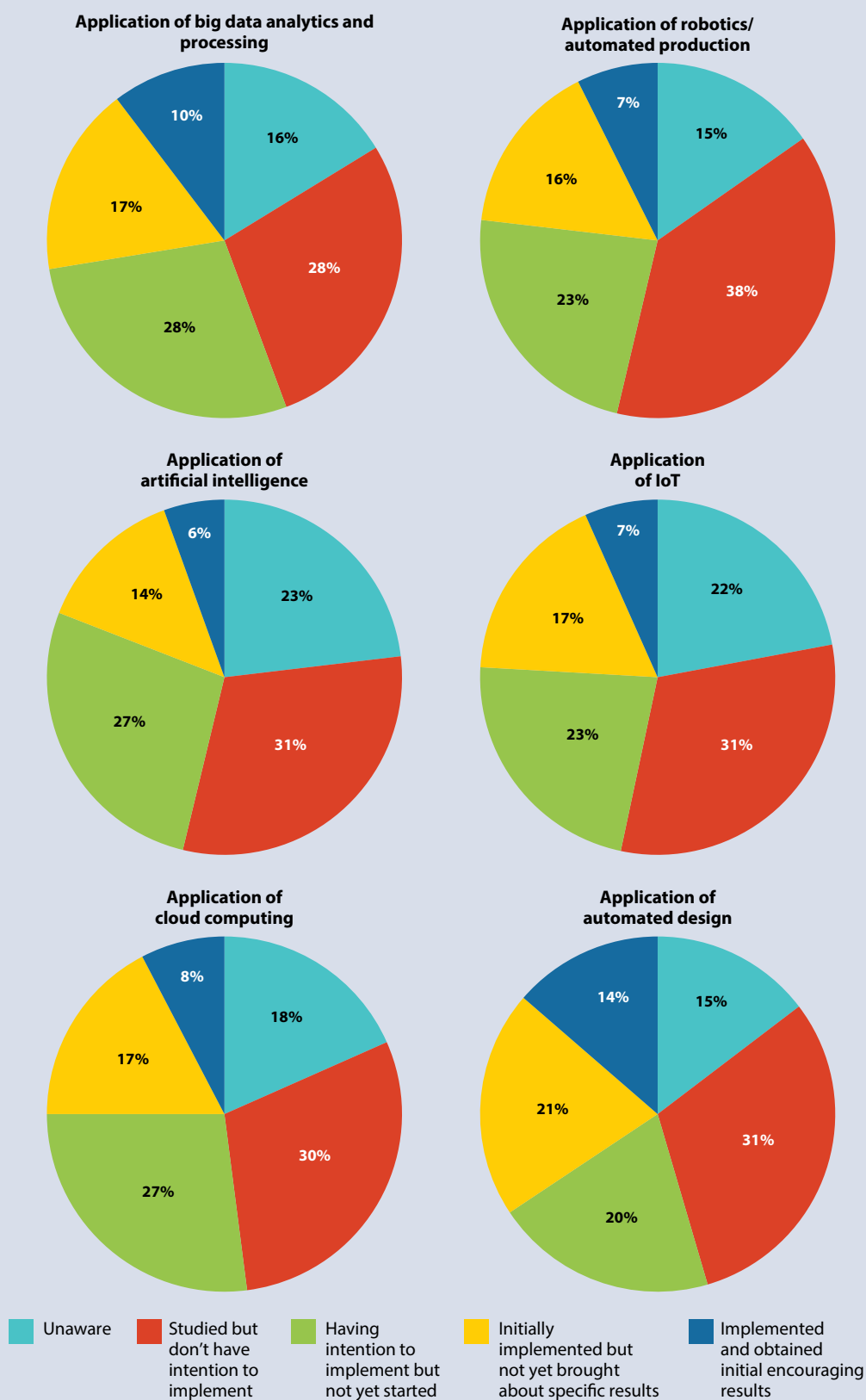
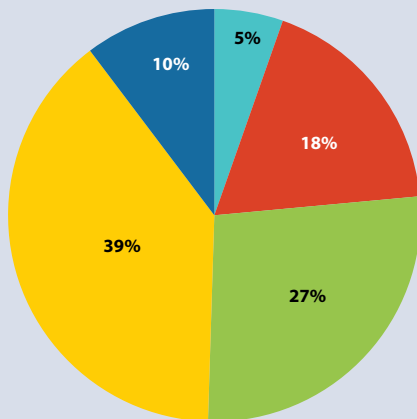
FIGURE 6**CURRENT STATUS OF SMART MANUFACTURING APPLICATIONS.**

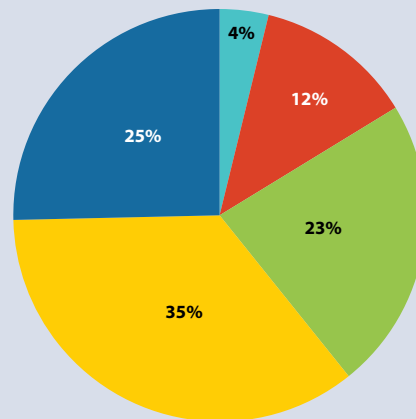
FIGURE 7A

THE DIFFICULTIES AND BARRIERS IN THE APPLICATION OF SMART MANUFACTURING.

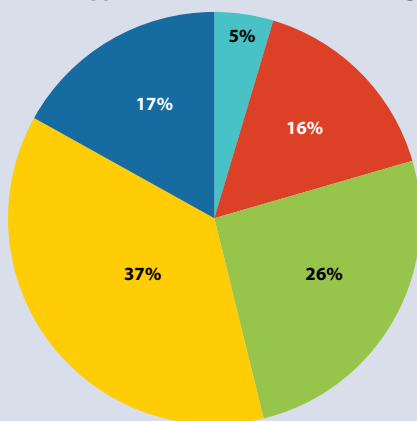
Understand the value that each application can bring to enterprises for consideration



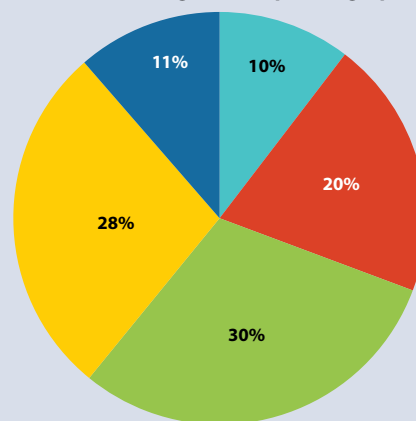
Infrastructure for application of smart manufacturing is still limited



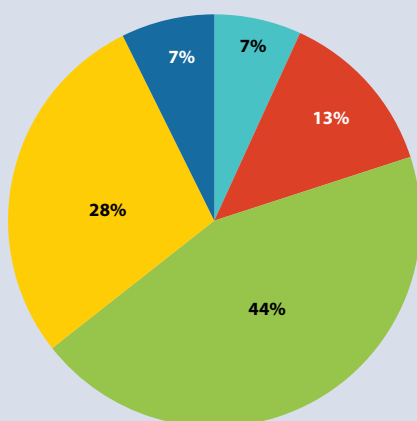
Qualifications and skills of employees are not ready for the application of smart manufacturing



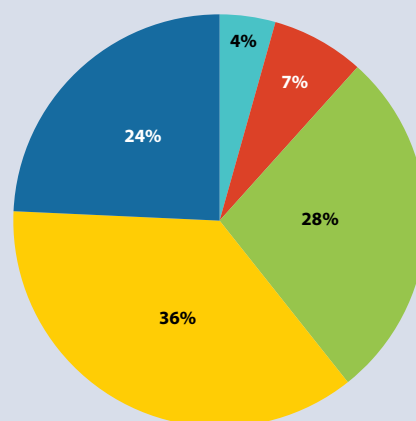
Leaders have not recognized smart manufacturing as the top strategic priority



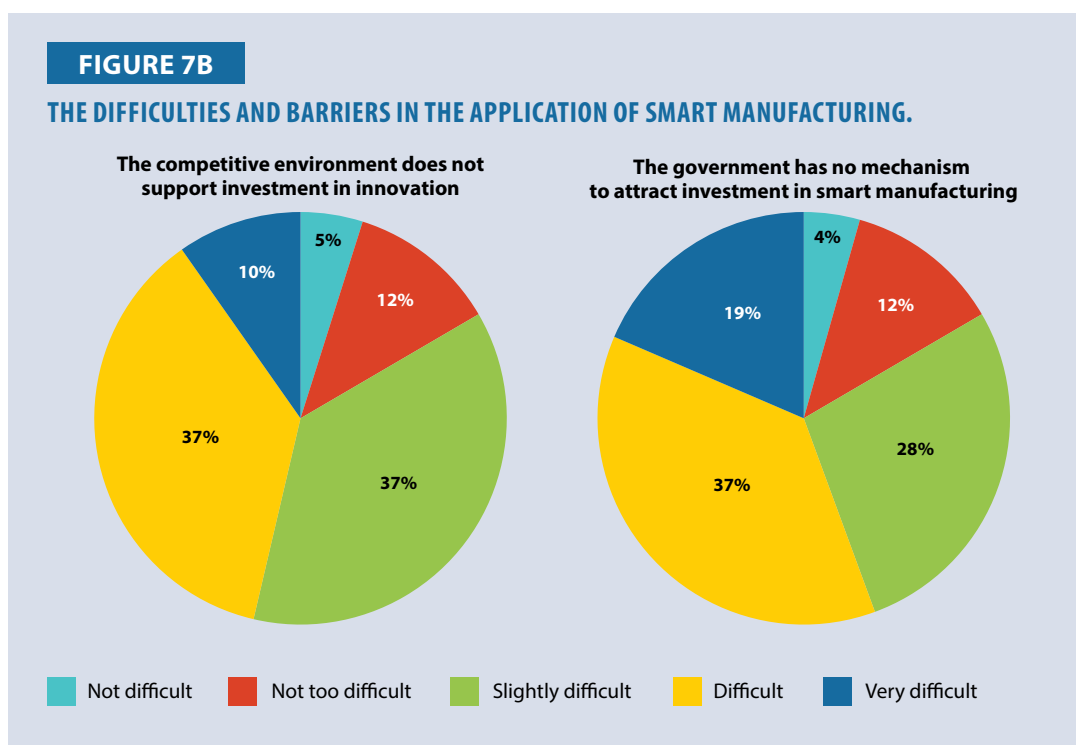
Benefits that smart manufacturing can bring are not higher than investment costs



Access to financial resources for investment in smart manufacturing is not easy



■ Not difficult
 ■ Not too difficult
 ■ Slightly difficult
 ■ Difficult
 ■ Very difficult



Further, 60% believed that the infrastructural conditions for smart manufacturing applications were still limited; 54% were of the view that qualifications and skills of staff were not ready for smart manufacturing applications; 39% believed that leadership had not considered it as the top strategic priority; 35% did not see the benefits of smart manufacturing applications to be much higher than investment; 60% did not find it easy to access financial resources for smart manufacturing application investment; 47% found that the competitive environment had not encouraged investment in innovation; and 56% said that an attractive government mechanism to promote investment in smart manufacturing applications was missing.

In the survey, the enterprises also ranked their policy priorities according to their importance in promoting smart manufacturing applications (see Figure 8). The top policy priority for the surveyed enterprises was that the government should support associations and consulting centers to help enterprises better understand the value of smart manufacturing and the ways to invest in it. After that, enterprises' policy priority was to support investment in training human resources for smart manufacturing applications; followed by forming a strategy to promote the application of smart manufacturing in Vietnam with clear goals to be achieved in the next five years through a comprehensive action plan.

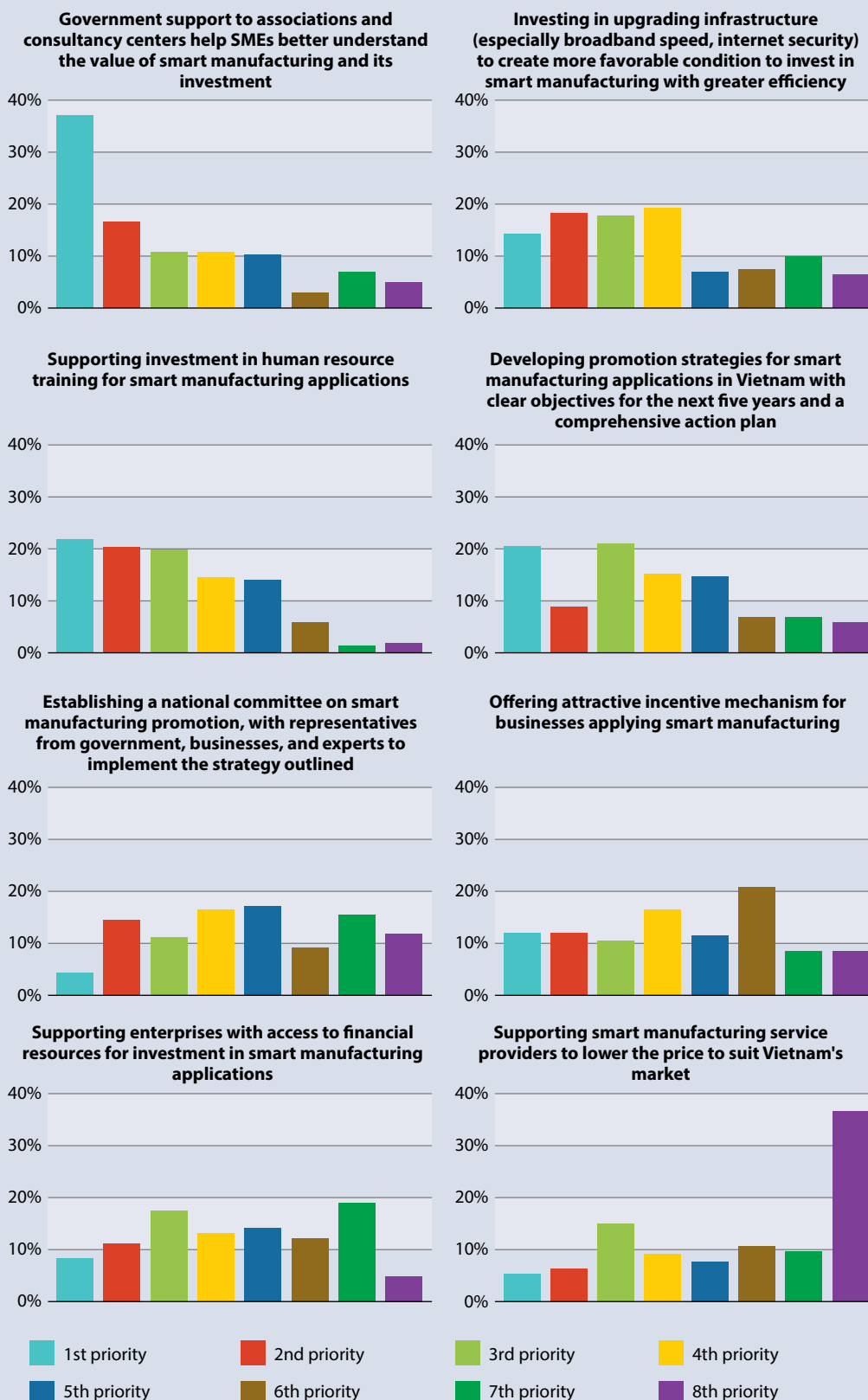
Smart Manufacturing Policy

Orientations and Policies of the Party and the State

On 22 March 2019, Resolution No. 23-NQ/TW on National Industrial Development Policy until 2030 with a vision for 2045 was issued, for Vietnam to become a modern, industrialized country. Under this Resolution, mechanisms and policies would be created to promote internal restructuring of the industrial sector toward higher value added and smarter levels. It is necessary to accelerate the integration of IT and automation in industrial manufacturing to create smart manufacturing processes and intelligent factory models and develop smart products and smart devices. So, smart technology standards and manufacturing techniques would be developed and issued. Besides, the

FIGURE 8

ENTERPRISES' POLICY PRIORITIES FOR PROMOTING SMART MANUFACTURING APPLICATIONS.



textile, garment, and footwear industries would be further developed, but with focus on high added-value-creating phases using smart and automated manufacturing processes. Tax reductions and exemptions at reasonable levels and over appropriate periods would be granted for priority industries and smart industries. This document also focuses on the implementation of technical regulations and standards in the industrial sector, as applicable to protect domestic production and consumers. These would be developed and implemented, while smart technology standards and manufacturing techniques would also be developed and issued.

On 27 September 2019, Resolution No. 52-NQ/TW on several guidelines and policies to actively participate in Industry 4.0 (I4.0) was issued. Vietnam has stepped up the application and development of science, technology, and creative innovation; and enhanced the ability to access and participate in I4.0. Two guidelines and six significant policies need to be implemented.

Directive No. 16/CT-TTg pertains to strengthening capacity to tackle challenges posed by I4.0. This Directive focuses on reviewing the strategies and action plans, and proposing and formulating targeted plans and tasks so that they are implemented following the development trends in I4.0. On 3 June 2020, the Prime Minister issued Decision No. 749/QĐ-TTg approving the ‘National Digital Transformation Program to 2025, with an orientation to 2030.’ The program aims to bring Vietnam into the group of 50 leading e-government countries (EGDI). Accordingly, Vietnam aims to become a digital, stable, and prosperous country, while pioneering in testing of new technologies and models. The National Digital Transformation Program aims to develop digital government, digital economy, digital society, and digital-technology Vietnamese enterprises with global capacity.

On 31 August 2020, Decision No. 1322/QĐ-TTg was approved for a national program to support enterprises to improve productivity and quality of products and goods in the period 2021–30. This is considered to be a major program to support enterprises in the application of science and technology solutions as well as in innovations for digital transformation and smart manufacturing. The general target of this program is to (1) support enterprises in improving their productivity and quality of products and commodities (quality productivity) through application of standards, technical regulations, advanced management systems, and tools to improve productivity and quality; (2) contribute to the increase in the proportion of total factor productivity (TFP) in economic growth; and (3) improve the productivity, quality, efficiency, and competitiveness of the economy. For the period 2021–25, the harmonious ratio of national standard system to international and regional standard system is 65%, with training and qualified certification for 600 experts in productivity and quality at ministries, departments, cities, and enterprises. For the period 2026–30, the harmonious ratio of national standard system to international and regional standard system is 70–75%; with training and qualified certification for 1,000 experts in productivity and quality (approximately 200 of them are to be certified regionally and internationally).

Action Plans from Ministries

The Ministry of Science and Technology plays the role of guiding the development of national standards, research, and application of smart manufacturing technologies and solutions. On 27 September 2018, the Ministry of Science and Technology issued Decision No. 2813/QĐ-BKHCN, approving the crucial national science and technology program to 2025, called ‘Research support, development, and technology application of I4.0.’ The program was built with the goal of applying research, development, and transfer of some key I4.0 technologies for Vietnam to create products for socioeconomic development; and supporting pilot innovation of some corporate governance and manufacturing business models in some critical areas in the direction of digital transformation.

The program content focuses on certain key I4.0 technologies for (1) creating products and services in areas such as medicine, economy, tourism, finance-banking, agriculture, processing and manufacturing, educational training, vocational training, transport, construction, and information and communication; (2) researching and applying several digital transformation solutions in enterprise management and general management; and (3) developing policies to promote credit for businesses investing in research, development, and application of I4.0 technologies.

The Ministry of Industry and Trade has been implementing many activities to support enterprises to improve their capacities to access I4.0, toward smart manufacturing. It has supported enterprises in implementing a number of typical projects, e.g., developing smart warehousing model; supporting the development and application of production monitoring module for LED and electronic product lines at Rang Dong Joint Stock Company; Online production monitoring and operating system (module for energy management and maintenance) at Saigon Beer Company; applying digital maps to manage and provide information on Vietnam's leather and footwear industry; automatic control system for medicinal high extraction equipment meets I4.0; and QCS automatic quality monitoring system in the production of industrial packaging paper at Van Diem Paper Joint Stock Company.

In 2020, many projects with direct participation of application enterprises were launched in the implementation plan. Examples include, development and pilot application of production planning and management software at Pho Yen Mechanical Joint Stock Company; support to build a pilot model to apply innovative solutions and a smart warehouse management system at Tien Phong Plastic Joint Stock Company; and industrial IoT for industrial factory for the purpose of building a model smart factory, applied at Massan Industrial Group and Duy Tan Mechanical Co., Ltd.

Activities of STAMEQ

STAMEQ is the agency helping the Ministry of Science and Technology to build a national standard system. Many smart manufacturing-related standards have been developed and published by STAMEQ. So far, there are about 500 Vietnam Standards called *Vietnamese Tiêu chuẩn Việt Nam (TCVN)* relevant to production. These include over 200 TCVNs of IT (e.g., IT infrastructure and IoT); 35 TCVNs of network security, (e.g., system security, information quality, network safety, and risk management); 16 TCVNs of automation (e.g., industrial automation and automation integration model); five TCVNs of robotics; nine TCVNs of smart agriculture (e.g., concept and terminology of mobile phone, standard of mobile communication, and evaluation index of mobile phone); five TCVNs of smart transportation (ITS system); over 74 TCVNs of waste and environmental pollution control; 67 TCVNs of traceability; over 30 TCVNs of advanced management systems; 70 TCVNs of services (e.g., supply chain safety, assessment of supplier capacity, financial services, and health services); and five TCVNs of human resource management and development.

STAMEQ has been a pioneer in implementation activities to promote smart manufacturing in Vietnam. STAMEQ cooperated with TUV SUD Digital Service to conduct the first pilot assessment with 15 enterprises for smart manufacturing access using SIRI. STAMEQ cooperates with CPC in implementing iBench productivity assessment solutions for Vietnamese enterprises, and developing online training programs and direct training for Vietnamese enterprises on smart manufacturing. STAMEQ and CPC have also agreed to sign an MoU on the contents of training cooperation on smart manufacturing for each industry field and each type of enterprise. STAMEQ cooperates with the KPC on smart manufacturing training programs for enterprises. They have jointly established

a training cooperation center located at STAMEQ to organize training courses for Vietnamese enterprises to provide vocational training and diploma services for enterprise employees, support startups, and introduce and support new global businesses.

Tools and Techniques for Readiness Assessment at Enterprise Level

Background for Enterprises using the Smart Manufacturing Tools and Techniques

Applying SIRI Assessment Indicators for Vietnamese SMEs

In 2019, a cooperation agreement on smart manufacturing evaluation program for 15 enterprises in Vietnam was signed between Vietnam National Productivity Institute (VNPI), STAMEQ, and Economic Development Board (EDB) Singapore. Based on the agreement, TUV SUV experts conduct smart manufacturing readiness assessment at 15 enterprises in Vietnam using the SIRI evaluation set. The assessment program in each enterprise consists of two main seminars, which focus on the introduction of I4.0 technologies and the application model (SIRI set) to evaluate enterprises based on the three main pillars of process, technology, and organization. This is considered to be the foundation for the process of establishing a roadmap and action toward I4.0 for enterprises. The whole roadmap consists of three steps, i.e., survey, roadmap setting, and action. From October 2019 to March 2020, the TUV SUV review team with the support of the VNPI's coordination team, participated in the assessment of selected enterprises.

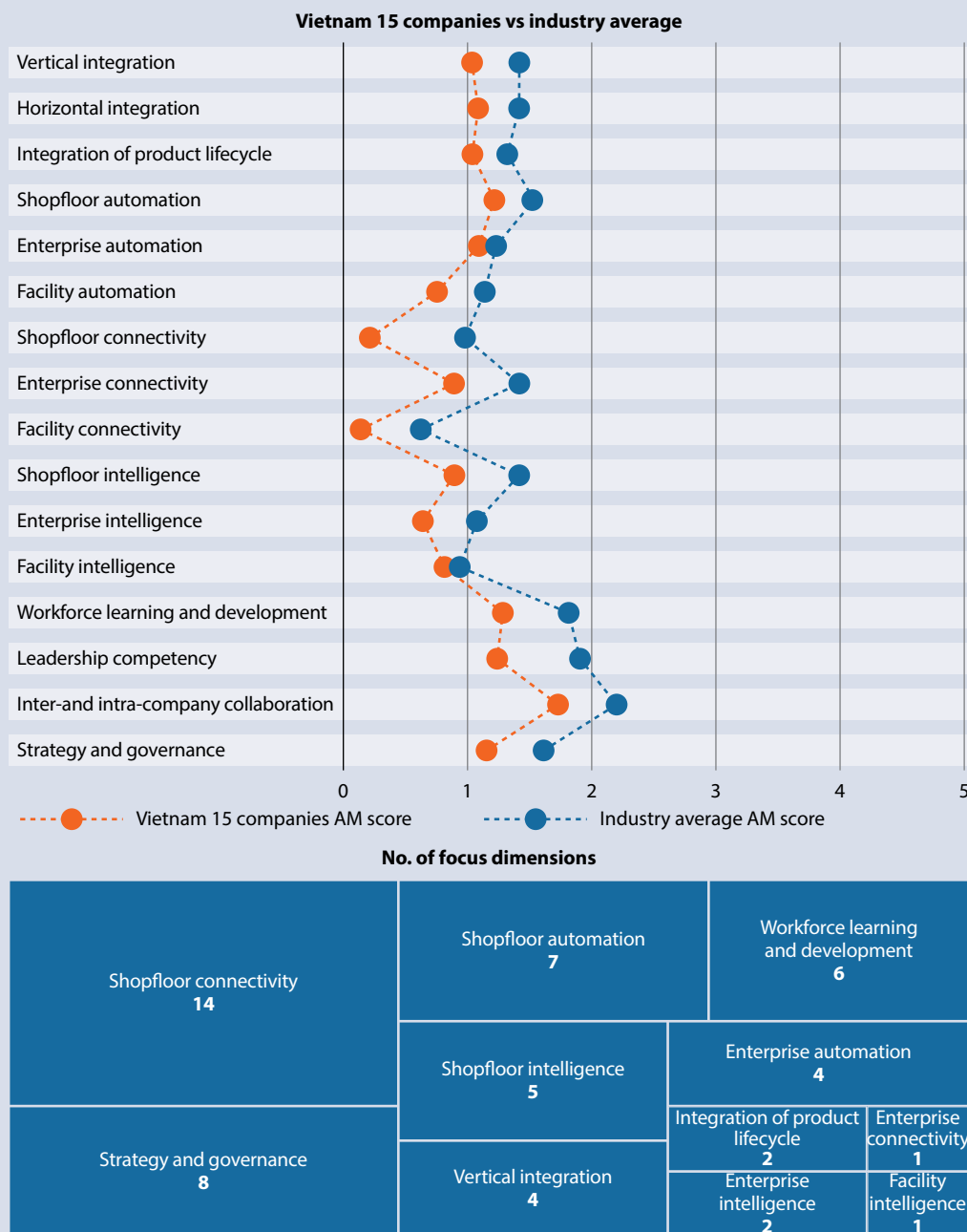
Through the surveys, most enterprises have changed their perception of I4.0, and understand the benefits of the I4.0 revolution for productivity and competitiveness. In addition, experts also conduct a comprehensive survey of current business activities to assess the application of I4.0 to internal processes, supply chain management, and life cycle management. They assess the level of automation, connection, and intelligence of the production function as well as of organizational management through leadership capacity, human resources, teamwork organization, and development strategy. The assessment of the indicators is combined with the assessment process of the unit's balance of revenues and expenditures and the key performance indicators (KPIs), thereby selecting priority indicators to focus on in the immediate term.

Through the evaluation process, Vietnamese enterprises still have a relatively low capacity to access I4.0, especially regarding the issue of connecting the shopfloor and the facilities (see Figure 10). Vietnamese enterprises also face many limitations in accessing consulting support and switching solutions to smart manufacturing based on SIRI's assessment platform. Thus, it is also found that Vietnamese SMEs need a separate set of assessment tools for smart manufacturing productivity and transformation capacity.

Vietnam Innovation Productivity Assessment

With the support of the APO, VNPI has developed Vietnam Innovation Productivity Assessment (ViPA), in accordance with the conditions of SMEs in Vietnam. The toolkit assesses 16 criteria on management aspects of enterprises including enterprise management, productivity management, and infrastructure for digital transformation and smart manufacturing.

The toolkit has the function of assisting enterprises in determining the current state of productivity. This helps them in building roadmaps for digital transformation and smart manufacturing, through which enterprises can develop short-term and long-term plans to improve productivity and move toward digital transformation and smart manufacturing in future.

FIGURE 10**AVERAGE ASSESSMENT MATRIX SCORE AND FOCUS DIMENSIONS.**

Enterprise management includes (1) leadership comprising four components of vision and mission, policy and objective, plan/strategy, and social and community responsibility; (2) customer orientation of enterprises comprising quick response to market requirements, customer satisfaction, and competitiveness; (3) human resource development including knowledge and skills training program to develop human resources, working environment to ensure safety and health of employees, policies to encourage employees, and policies to attract and develop talent; and (4) culture of innovation and improvement including product and process innovation, continuous improvement, knowledge sharing and management, and intellectual property strategy.

Productivity management includes (1) standards/management tools including application of management systems according to ISO 9000, ISO 14000, ISO 56000, ISA 95, ISO 45000, etc.; (2) application of productivity improvement tools such as 5S, *Kaizen*, and TPM; (3) application of advanced tools such as Lean, Lean 6 Sigma, and MFCA; (4) process control including quality assurance, administration management, production and business operations, and information exchange; and (5) performance management including use of machines and equipment to measure process performance, having a department dedicated to measuring and analyzing performance, periodically measuring production performance and productivity, and annual measurement of business performance.

Digital transformation infrastructure system includes (1) infrastructure including computers, networks, deployed human resources, regular investment in information technology, and internal as well as outsourced information technology projects; (2) strategy for business digital transformation including leadership awareness, implementation program, resource planning of finance and human resources, specific implementation plan, and specific solutions; (3) application of information technology to digital transformation in enterprises including internet work management tools such as chat and social networks, application of management software such as ISO online, measuring productivity, development of internal process management software, and application development of connection management software in the enterprise's link chain comprising suppliers, customers, and stakeholders; and (4) managing innovation activities in enterprises including products, processes, organization and management, and business model.

Smart manufacturing comprises (1) using the sensor system to monitor the process and includes optimal layout, control point definition, connection of integrated equipment system, and synchronization of sensor data; (2) building information technology solutions to exploit and manage data, including building production management solutions, building business management solutions such as warehouse and traceability, integrated production and business management solutions such as process linkages under ISA95, and chain management solutions such as oriented, planned, outsourced, and self-deployed; (3) synthesizing and building a database based on cloud estimation including single data synchronization, cloud-based data system on production and business, and enterprises data waterfall based on cloud computing; and (4) application of technology 4.0 solutions to data mining and business management including application of I4.0 solutions to build production-business integration modules for flexible production to meet specific requirements of retail customers; strategy, deployment of automation technology, robotics, and 3D printing in production of enterprises, application of block chain platform for enterprise management, and use of big data and AI to analyze the market and build business plans.

National Tools to Assess Smart Manufacturing Readiness at Enterprise Level

The I4.0 vision, and the roadmap to achieve this vision, will vary from business to business. Not every enterprise has a short-term ambition to realize the full vision of I4.0. Enterprises define their interim and final goals based on their respective backgrounds and situations. For this reason, the model allows for clear distinction by the aforementioned aspects. It is therefore important to evaluate (score) the willingness/participation of enterprises according to each criterion.

Based on an enterprise's responses to the criteria questions (in each pillar), a score with a value of 1–5 will be assigned to the enterprise's readiness on that criterion. A value 1 is assigned to enterprises that do nothing or have very little or no foundation to prepare for digital transformation. A value of 5 is assigned to best-practice enterprises, i.e., those enterprises that have successfully

performed all activities of digital transformation. The value 5 of the model also describes the state of fully realizing the target vision, i.e., when the entire value chain is integrated in real time and the components can interact with each other.

The readiness level is determined by the ratio of the total points achieved for the 16 criteria, divided by the total points for the set of criteria. For example, after the self-assessment, if an enterprise achieved 35 out of 80 points in the set of criteria, then the enterprise readiness is defined as $(35/80) * 100 = 43.75\%$.

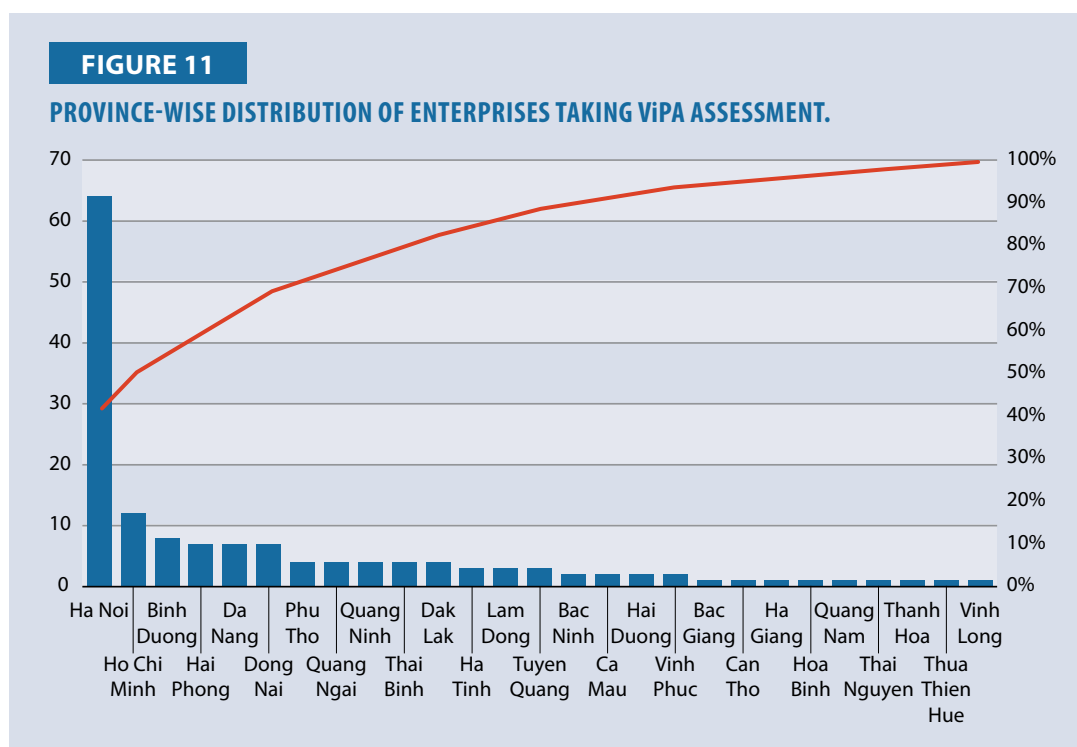
Based on the score achieved, enterprise willingness and participation are classified according to the five levels above. These five levels of readiness are categorized into five stages and 10 enterprise readiness levels. Such classification allows enterprise to see the overall picture of the business in a more general way and facilitates drawing conclusions about progress, requirements, and conditions related to digital transformation and toward I4.0. It also helps identify a number of specific actions based on the level of implementation. The five classifications are:

1. Not interested group (phase 1, level 1–2): This includes enterprises that are ‘outside’ and do not have any activities related to digital transformation or targeting smart manufacturing.
2. Newcomers group (phase 2, level 3–4): This includes enterprises with ‘basic qualifications,’ i.e., those that have taken the first steps in implementing I4.0.
3. Leading group (readiness level 3 or higher): This includes ‘experienced,’ ‘expert,’ and ‘leading’ enterprises, i.e., those that have made good progress in the process or implemented I4.0 and are at a much more developed level than other groups of enterprises.
4. Group of good practices: This is a group of enterprises that have relatively fully applied information technology solutions to connect production and business management data, and share knowledge in the supply chain/department. Their infrastructure has been invested and operated well toward smart manufacturing.
5. Leading group: This is a group of enterprises that have applied advanced solutions to manage and operate their businesses. They have applied software/sensors to connect between machines and equipment, and build big data to perform smart manufacturing.

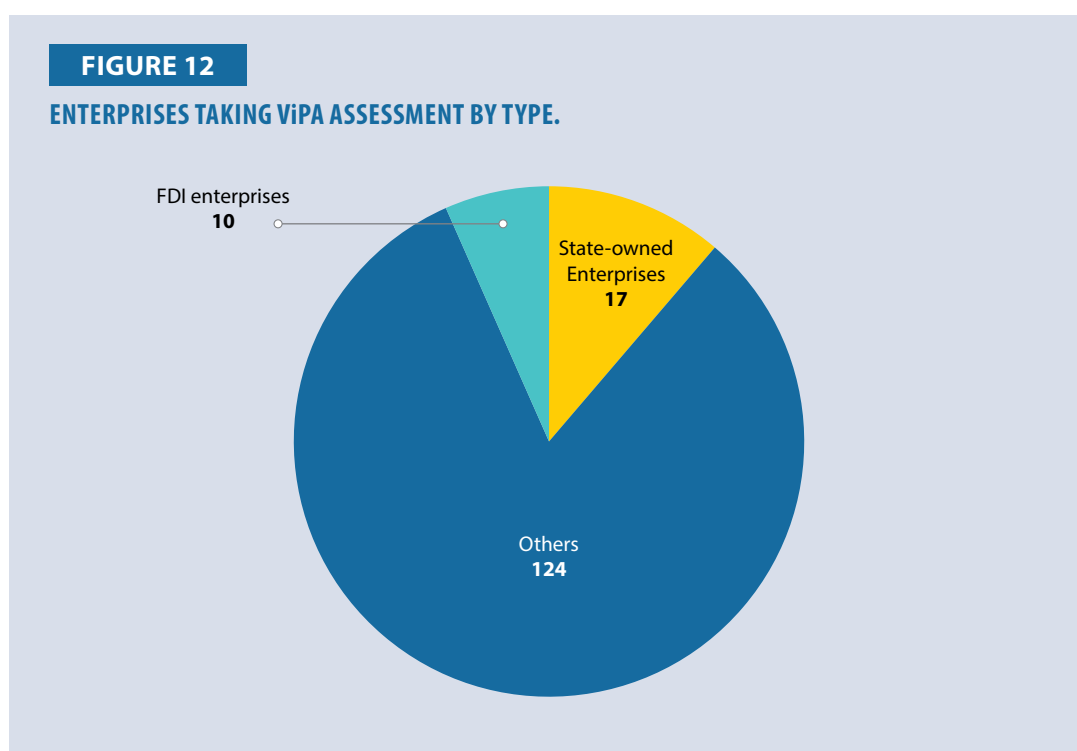
The ViPA toolkit is developed and applied for the self-assessment of enterprises, regardless of their type of production and business, ranging from manufacturing, processing, agriculture, forestry, and fisheries to other business services. Therefore, as part of the process, enterprises should pay attention to the purpose of self-assessment in order to clearly define the current state/level of enterprise readiness, thereby building a suitable roadmap toward digital transformation and smart manufacturing. When determining the level (1–5), the closer it is to the current state of the enterprises, the more convenient it is to establish a digital transformation vision, specifically with strategies toward I4.0.

Evaluation Results of Enterprises Ready to Transform to Digital and Smart Manufacturing

By October 2020, ViPA had the participation of 161 enterprises located in 27 provinces, as shown in Figure 11.



Enterprises participating in the assessment included enterprises of different types, including state-owned enterprises, non-state enterprises, and FDI enterprises. Of these, non-state enterprises accounted for the majority (124 out of 161), as shown in Figure 12.



The results of a preliminary assessment of the level of smart manufacturing access of Vietnamese SMEs based on 16 criteria of ViPA are depicted in Figure 13.

FIGURE 13 A

SMART-MANUFACTURING ACCESS OF VIETNAMESE SMEs TAKING VIPA ASSESSMENT.

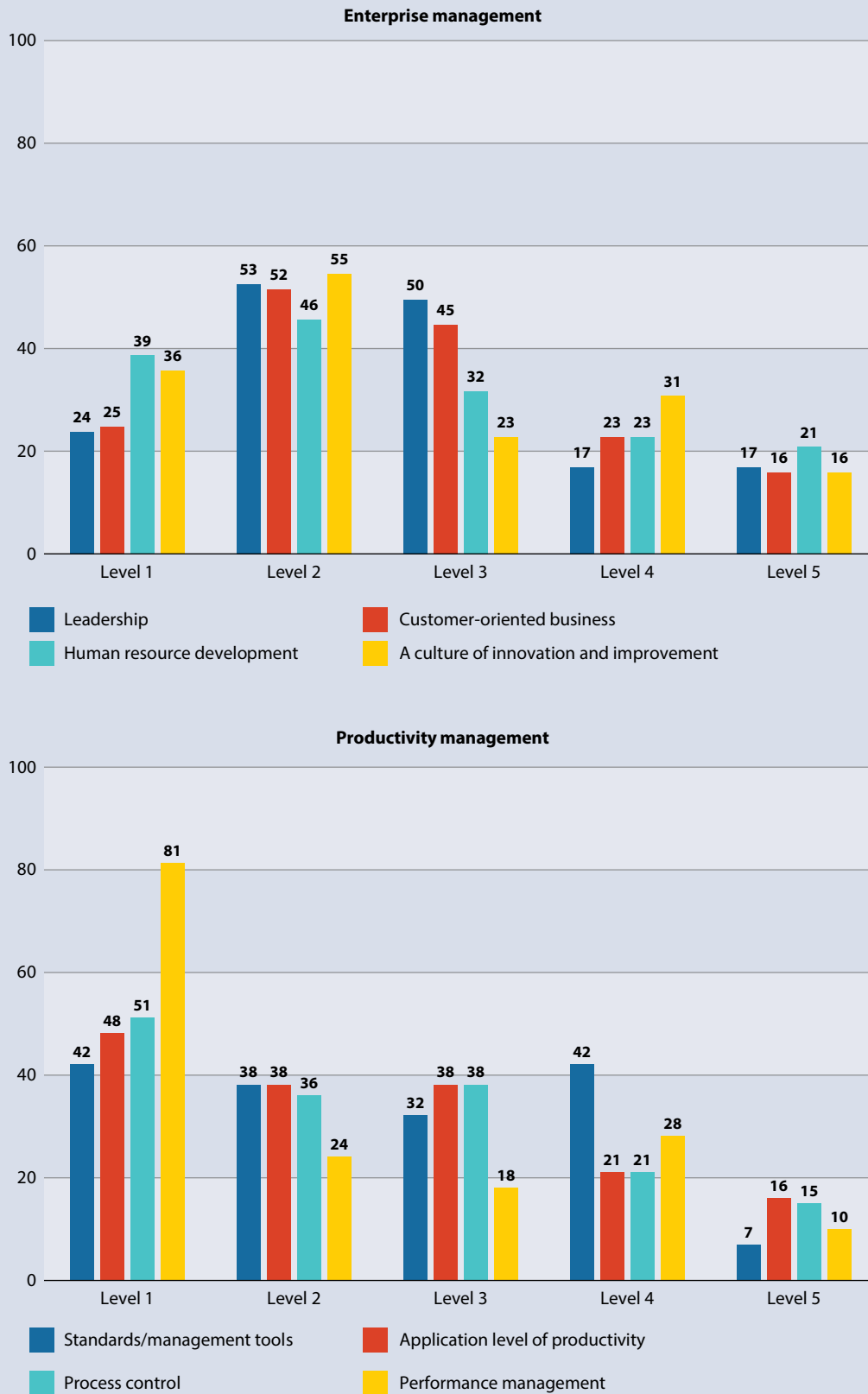
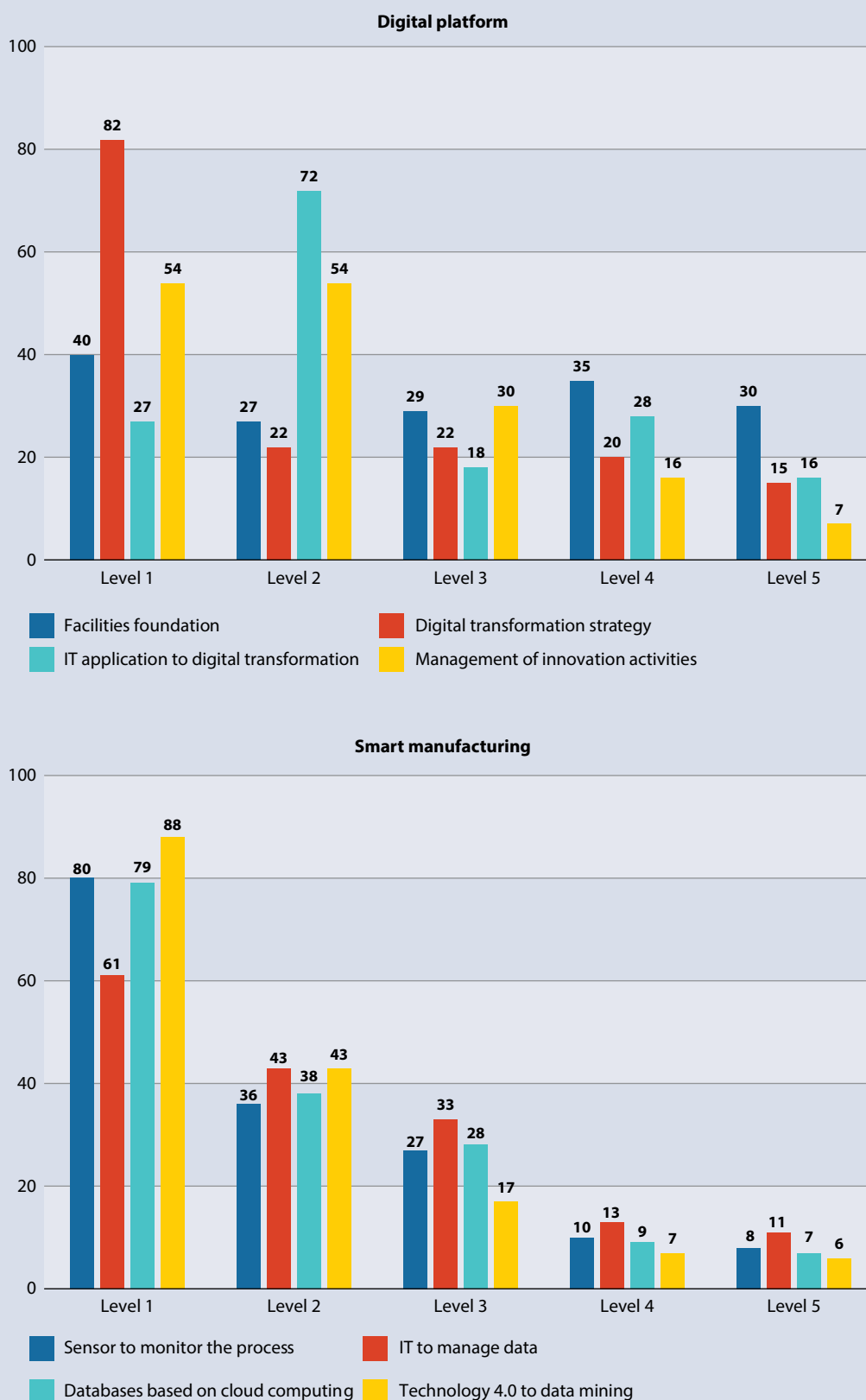


FIGURE 13 B**SMART-MANUFACTURING ACCESS OF VIETNAMESE SMES TAKING VIPA ASSESSMENT.**

Enterprise Management

For the pillar of enterprise management, most enterprises are at levels 1–3. This shows that enterprises still have many opportunities to improve their corporate governance methods, from establishing missions and visions, and doing strategic planning to moving toward digital transformation and smart manufacturing. The first step for enterprises that need to start smart manufacturing is to standardize and optimize the current production and business processes as the foundation for digital transformation. In the next step, enterprises can build a suitable roadmap to implement digital transformation and move toward smart manufacturing.

Productivity Management

For the pillar of productivity management, the majority of enterprises are at level 1. Of the 161 enterprises, 51 chose level 1 with criteria 7 (process control); 81 enterprises chose level 1 with criterion 8 (performance management); and only 48 enterprises choose level 5. This shows that the majority of enterprises are still limited in the criteria of process control (15/161) and performance management (10/161). This result is generally consistent with the reality of corporate governance among SMEs in the region that accounts for the majority of the total number of Vietnamese enterprises. In general, enterprises generally need to have innovative solutions to improve their productivity and efficiency. This is the way to ensure competitiveness in the current difficult context.

Digital Platform

A majority of enterprises participating in the assessment choose level 1 and 2 for criteria 9, 10, 11, and 12. Thus, the infrastructure system for digital transformation of Vietnamese enterprises is at a very low level. IT personnel are not yet fully professional, while the awareness among business leaders about digital transformation is still limited. Enterprises need to learn and research I4.0 trends in the field of enterprises production, determine their current capacities, and develop strategies for digital transformation, to avoid a lag or loss of their competitiveness.

In addition, enterprises are also less interested in innovative products, processes, management organizations, and business models. Of the 161 enterprises, 54 are rated 1 and 2 for the criteria of managing innovation activities. Only seven enterprises are rated 5 for this criterion. The results show that enterprises need to promote innovation activities in their businesses, do adequate research on the market/competitors, and develop alternative products to maintain and improve their productivity and competitiveness.

Smart Manufacturing

A majority of enterprises also arrange production stages based on their experience, supplier recommendations, or learning from similar enterprises. Enterprises have not developed any solutions to apply IT in production management. They do not really care or have plans to synchronize data to manage and operate production and business activities. They have no plans to apply I4.0 solutions.

Enterprises need to research to optimize the entire production area including equipment, factories, processes, inventories, transportation, and logistics. They also need to study the benefits of the IT system, and make investments in IT system applications to improve productivity and competitiveness in the digital age.

Framework for Smart Manufacturing Implementation at National Level

Need for Smart Manufacturing Implementation Framework and Gaps in Current Policy Framework

The survey results show that a majority of industrial enterprises in Vietnam are not ready for I4.0. Among the four pillars related to readiness to approach I4.0, enterprises have moderate readiness for business and productivity management. The readiness for digital platform and smart manufacturing pillars is on the lower side. There is a significant difference in the level of readiness to approach I4.0. For big enterprises, the percentage achieved is greater. State-owned enterprises, with a higher level of capital equipment, size, manufacturing concentration, and technology usage than the FDI and non-state firms, have a pioneering role in willingness to participate in I4.0. Interest in digital transformation and smart manufacturing is mainly concentrated among manufacturing and manufacturing enterprises. Approximately two-thirds of enterprises do not have plans to invest in digital transformation in the context of the I4.0, as many enterprises do not know what to do. Some enterprises plan to change their investment options for factory equipment and information technology.

Policy Implications

Although the SMEs sector is the driving force behind economic development in Vietnam, contributing 40% to the GDP and accounting for more than 20% of the exported value [5], a 2017 study by the Japan External Trade Organization (JETRO) found that SMEs in Vietnam faced many barriers, with the main obstacles being (1) lack of ability to continue access to financial resources; (2) limited participation in domestic and international value chains; and (3) limited business capacity. Besides, investment in technological innovations by enterprises, and government spending on science and R&D (around 0.2% of GDP per year), are still modest.

The policy implication of these findings is that efforts to improve the readiness level of enterprises for I4.0 should be an integral part of industrial development policies, business development in water, SOE reform, FDI attraction, etc.

Efforts should be made to help all domestic enterprises of different ownership types, especially SMEs, to grow in size, capital equipment, and increasing concentration and pressure ratios. Applying high technology and improving R&D capacity and training skills of employees are not only decisive factors for enterprises to develop and improve productivity and competitiveness but also to help them increase their readiness for I4.0, which determines their competitiveness and productivity in future. Solutions should be provided for building an ‘innovation network,’ with the participation of all parties (state, enterprises, social organizations, and investors) in the application of innovation. Innovation is highly critical to assist Vietnamese enterprises in achieving industrial development goals, enhancing productivity and competitiveness, and connecting with domestic and global value chains.

SOEs, due to their current status/starting point, have a number of advantages (e.g., size of labor, capital, technology level, and concentration) compared with other types of ownership. Increasing their willingness, labor productivity, and competitiveness is very important to develop them into a leading group toward I4.0.

Domestic SME development efforts should give priority to the application of I4.0 to improve key factors such as size, capital equipment level, concentration index, high-technology application, R&D capacity, skills training for workers, and connectivity and spillover, instead of focusing on quantity growth.

In order to increase the readiness to approach I4.0, the study found that the score on the enterprise management pillar was low. Many enterprises have advanced the implementation of labor restructuring strategy and technical standardization of the entire production chain in their departments; pursued application of ERP models and supply chain management; and increased collection and exchange of information about the manufacturing processes and products. Others, based on their current situation, need to upgrade existing strategies to I4.0 strategies. In addition, support for investment and technological innovation should also be prioritized and focused (e.g., applying relatively simple and low-cost technologies such as cloud storage/computing).

In the smart manufacturing field, enterprises need to focus on equipping production processes and products with IT features (e.g., IT integration of production data and products). They should collect and analyze data to optimize production or product development and support sales and marketing. For the smart manufacturing pillar, new enterprises need to collect and process data to increase the efficiency of planning and monitoring, for adjusting and optimizing their business and production processes. At the same time, it is necessary to have a solution to connect infrastructure, machines, and equipment with IT systems to automate the task of adjusting the processes in a timely and flexible manner.

For digital transformation infrastructure, enterprises need to promote external system integration and automated processes. The readiness level for workers' skills is improved if enterprises focus on equipping the necessary skills for aspects related to I4.0. This can be done not only with the efforts of individual enterprises, but also through linkages with leading enterprises and government support.

However, it should be noted that (1) the willingness to connect equipment to devices, systems, or products is only possible when there are large new investments (involving high risks) in a few enterprises; and (2) not all enterprises need to complete all the requirements of I4.0. Depending on the impact of I4.0 on the production and business process, enterprises determine the appropriate level of participation and the specific sectors. Enterprises can choose to use advanced technologies with low costs and wide applicability such as the cloud computing technology.

Finally, the availabilities (pillars, dimensions in each pillar, and their weights and scores) in the ViPA method should be 'adjusted' in future studies. The pillars and the criteria in each pillar, along with the questionnaire, should be developed through a series of consultations with experts and enterprises from different industries. Weights should be built through research. Since I4.0 affects all industries, in many fields, a connect between industries is required. Future surveys or assessments should be conducted with enterprises from all fields and localities.

Elements of Implementation Framework for Smart Manufacturing at National Level

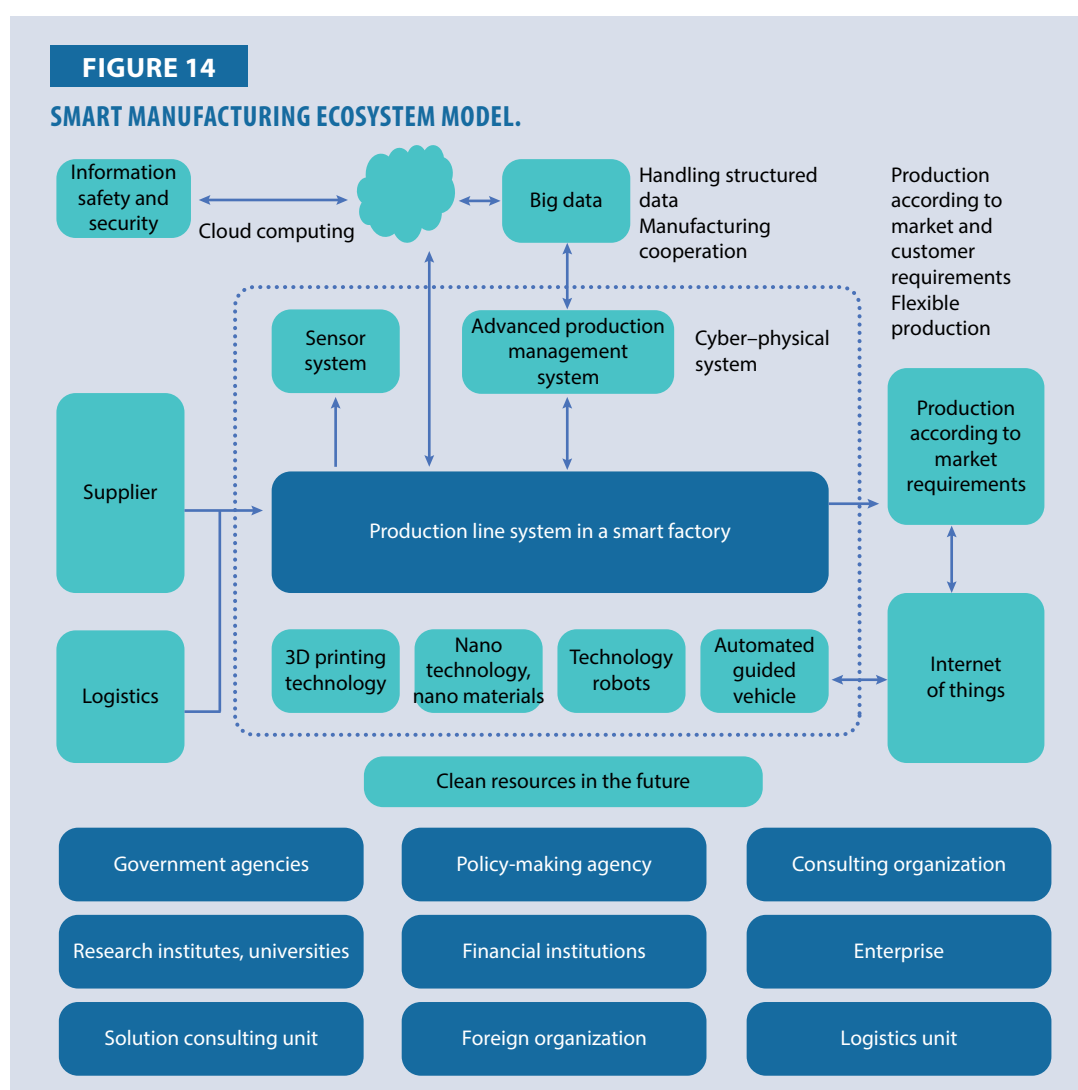
Framework Implementation Mechanism

In order to support enterprises in deploying smart manufacturing, the formation and development of a smart manufacturing ecosystem is very necessary. The proposed smart manufacturing ecosystem includes government agencies, policy makers, consulting organizations, training institutions, financial institutions, solution consulting units, and international organizations (see Figure 14), but most important are the efforts of the enterprises that are implementing smart manufacturing. The details are as follows:

Government agencies: These include ministries, sectors, and agencies responsible for implementing digital transformation and smart manufacturing programs and projects. Specifically,

the Ministry of Science and Technology has chaired the implementation of Directive No.16/CT-TTg on strengthening capacity to tackle challenges posed by I4.0; Decision No. 1322/QĐ-TTg approving the national program to support enterprises to improve productivity and quality of products and goods in the 2021–30 period; and Decision No. 2813/QĐ-BKHCN approving the crucial national science and technology program to 2025 titled, ‘Research support, development and technology application of I4.0.’

The Ministry of Information and Communications has presided over Decision No. 749/QĐ-TTg approving the ‘National Digital Transformation Program to 2025, with an orientation to 2030.’ The Ministry of Industry and Trade has focused on developing e-commerce and digital transformation in the industry.



Policy makers: They focus on research and propose policy mechanisms to promote smart-manufacturing-related activities in enterprises. Examples include legal corridors; mechanism for research and testing of sandbox; financial mechanism; mechanism for training high-quality human resources for smart manufacturing; mechanism to encourage the use and connection of data to ensure safety and security; mechanisms to promote enterprises to join the supply chain; financial, tax and investment incentive policies and regimes; and specific policies of local governments.

Smart manufacturing consulting organizations: They provide consulting on productivity, productivity boosting solutions, and digital transformation. Vietnamese enterprises are at a relatively low level of access to smart manufacturing, so consulting organizations need to focus on consulting activities on standard systems and basic productivity tools such as quality management systems.

Training organizations: They implement smart manufacturing training activities for enterprises. First of all, training organizations need to focus on educating enterprises on I4.0, digital transformation, and smart manufacturing. Particularly, it is necessary to focus on raising awareness for enterprises leaders. Training organizations should focus on training pertaining to smart manufacturing standards. STAMEQ was expected to announce the standard framework for smart manufacturing in early 2021. This would be an important direction for training organizations to deploy training courses for supporting enterprises on smart manufacturing standards. ISA 95 or IEC 62264 set of standards are the basic and most important sets of standards that need to be focused upon for training Vietnamese enterprises to deploy smart manufacturing. In addition, STAMEQ also cooperates with the KPC and the CPC to organize intensive training courses on smart manufacturing for Vietnamese enterprises.

Financial support agencies: The Ministry of Science and Technology implements programs and schemes to support enterprises in smart manufacturing implementations. The system of research, development, and application research programs supports enterprises to carry out R&D in product innovation. APO projects help improve the productivity and quality of Vietnamese enterprises' products and assist enterprises in implementing organizational innovation. The National Technology Innovation Program and the Technology Innovation Fund support enterprises in implementing technological innovation and production lines. The national program to support national innovation startups, and the annual business connection activities such as Techfest, TechDemo, and Techmart also support enterprises to innovate their business models. In particular, the National Program to support enterprises to improve productivity and quality of products and goods in the period 2021–30 is considered to be the most important program toward helping enterprises implement digital transformation and smart manufacturing.

Solution consulting units: They support Vietnamese enterprises to build and apply IT solutions. Solution consulting units help connect data of existing machinery and equipment systems of enterprises with the new systems being deployed by enterprises. These units help connect enterprises with the supply chain, while solution units help connect Vietnamese enterprises with foreign enterprises. Currently, commonly used IT solutions include enterprise resource planning, customer relationship management, supply chain management, and product lifecycle management.

International organizations: The APO is the most important international organization helping Vietnamese SMEs approach digital transformation and smart manufacturing. The APO's annual training programs on smart manufacturing play a very important role for Vietnamese enterprises. Besides, STAMEQ has cooperated with the CPC to train on smart manufacturing; with the KPC to establish training centers for smart manufacturing and innovation; and with TUD SUV for evaluation and construction of the smart manufacturing roadmap for Vietnamese enterprises.

[Delineated Role of Ministries and Agencies](#)

Going forward, projects to support smart manufacturing enterprises will be focused on implementing the National Program to support enterprises in improving the productivity and quality of their products in the period 2021–30. The participation of organizations and agencies is to be as follows:

Ministry of Science and Technology will be responsible for presiding over and administering the program's activities, while STAMEQ will be the standing agency of the program. MOST will guide relevant ministries, agencies, and localities to plan and implement the tasks of the program; research, formulate, and submit to competent authorities for promulgation mechanisms, policies, and solutions for promoting productivity and quality; build pilot projects for smart manufacturing; formulate and promulgate criteria and standards for quality productivity specialists for smart manufacturing; organize productivity and quality training activities in smart manufacturing; support training of productivity and quality experts on smart manufacturing in local areas; and implement propaganda activities and international cooperation in the field of smart manufacturing. MOST will also organize activities to honor and reward collectives and individuals with achievements in promoting productivity.

The Ministry of Industry and Trade, the Ministry of Agriculture and Rural Development, the Ministry of Health, the Ministry of Construction, the Ministry of Transport, and the Ministry of Information and Communications, within their competences, will be responsible for appointing the focal agency to organize and perform the tasks of the program; develop and implement a five-year plan, annually implement the program's tasks, integrate with national target programs, national programs, and other socioeconomic development programs. All this will be done in accordance with the development orientation of key products and goods of the sectors and fields, while focusing on key industrial and agricultural products and goods.

The Ministry of Finance will be responsible for allocating funds for the implementation of the program's tasks in accordance with the law on the state budget. The Ministry of Finance will coordinate with the Ministry of Science and Technology in reviewing and supplementing a financial management mechanism to implement the program (if necessary).

The People's Committees of provinces and cities will be responsible for appointing the focal agency to organize the implementation of the program's tasks; develop five-year plans, annually implement the program's tasks, integrate with national target programs, national programs and other socioeconomic development programs to improve productivity quality of key products and goods in their provinces. At the same time, the People's Committees of provinces and cities are responsible for allocating funds and mobilizing legal sources of capital to carry out the program's tasks in accordance with the law on state budget and regulations.

The Vietnam Chamber of Commerce and Industry, the Vietnam Association of Small and Medium Enterprises, the Vietnam Cooperative Union, and central and local enterprise associations will be responsible for mobilizing and introducing enterprises to join the National Program; coordinating with ministries, agencies, and localities to organize propaganda and knowledge dissemination programs on productivity and quality for enterprises; and participating in the consideration and selection of rewards for collectives and individuals having achievements in productivity and quality promotion activities.

Role of VNPI

Based on the necessity, and within the framework of the National Program to support enterprises to improve productivity and quality of products and goods, VNPI focuses on supporting enterprises through the following main contents:

1. Evaluate the difficulties and challenges of organizations and enterprises in the COVID-19 pandemic phase and the need for training and practical guidance on solutions to restore

and increase productivity. The novelty of the approach in the enterprise survey methodology is the use of the ViPA set of indicators, based on the current situation of enterprises on four pillars, i.e., enterprise management, productivity management, digital transformation, and smart manufacturing.

2. Build and operate IT platforms to support connection and training, and provide consulting on improving productivity and quality for organizations and enterprises.

In response to the pandemic and to better prepare for similar crises, VNPI desires to develop a digital expert platform to connect the experts and support the enterprises as well as individuals in productivity-related fields. The platform is expected to run on both PCs and mobile devices. This would enable connection and quick interactions between experts and enterprises and provision the training courses/knowledge shared by VNPI regardless of geographic barriers.

Considering the significance of the project, the platform should be well designed to better meet the current as well as future demands and needs of potential users. In this regard, the Technical Expert Service (TES) project provided by the APO was aimed at supporting VNPI in designing and developing the operation and management plan of the platform (see Figure 15).



The platform that connects objects includes experts; enterprises that need to be consulted and provided with solutions; enterprises that are capable of providing solutions (it may be noted that these enterprises do not provide consulting services and do not coincide with the expert audience);

and members or guests who can also join the platform to use the services or the value that the platform can provide.

The benefits of joining the program are listed below:

- Experts/enterprises providing solutions are evaluated and ranked by the system to create confidence for users.
- Experts (service providers) are connected with enterprises (who are consulted/trained). The system's features include interactive search and being contracted directly on the platform. In addition, the participants can exchange information and interact via chat, call, or video.
- Enterprises or members who need to find solutions/consulting services can post information on the message board, while experts/solution providers can search the queries and offer suggestions.
- The system participants are sent promotional information and notifications on free courses over the phone or through the system's information boards.
- It connects multi-dimensional enterprises with experts, solution providers, and members.

It is also a new approach and means for professionals to connect and participate in quick and easy support groups. Groups of experts with different geographical positions can be set up to analyze, find solutions, and consult on a large scale during and after the COVID-19 situation in three regions, namely, north, central, and south. The implementation of the IT platform is expected to connect domestic experts as well as foreign experts under APO programs for some training courses with new content that has not yet been found. Qualified domestic experts, in accordance with business requirements, develop a set of documents for training, online guidance on energy efficiency solutions, and digital transformation orientation for organizations and enterprises.

This content is intended to develop materials adapted for online training. The method of implementation is to use suitable tools such as recording teacher clips, combined with presentation-based teaching materials or teaching materials including practical images. Appropriate IT-based teaching suited to the needs and applicability of groups of experts is combined with enterprise infrastructure, which can be used for online teaching and instruction.

The online teaching materials are selected for topics of (1) management systems (basic tools to help enterprises capture and restore productivity and quality); (2) management systems and quality productivity improvement tools to help enterprises respond to increased productivity; and (3) management systems, tools, and solutions to help enterprises with step-by-step access to digital transformation and smart manufacturing.

VNPI focuses on organizing practice instructions for 80 organizations and enterprises on systems and tools for improving smart manufacturing to restore and increase productivity during and after the COVID-19 pandemic. Based on the results of the assessment of productivity performance and the willingness to digitally convert each enterprise as per the ViPA criteria, the team of experts, along with the enterprises, determines the KPIs and develops roadmap to implement the improvement plans. Enterprises are instructed to choose two priority issues to improve and agree to choose the right solution for sustainable energy. They are also required to determine the goals

and plan the implementation of the solution comprising personnel, implementation plan, implementation scope, and expected content.

In addition, VNPI also organizes information and communication activities on smart manufacturing solutions. Online seminars are held monthly, focusing on smart manufacturing solutions, IT applications, and digital transformation for recovery of enterprises' productivity growth during and after the COVID-19 pandemic. The content of the seminar is selected based on enterprises' concerns and experts' opinions. Besides, propaganda articles about mission results are also published in specialized newspapers and websites.

Timeline and Priority for Framework Implementation

In 2020, STAMEQ was to launch a national project to support the assessment of the digital and smart manufacturing capacities of 80 Vietnamese SMEs through the ViPA system. In 2021, STAMEQ would focus on publishing and guiding the Smart Manufacturing Standard Framework for Vietnamese enterprises. It would continue to organize domestic and foreign training courses on smart manufacturing for enterprises; connect and develop the smart manufacturing ecosystem on the ViPRO platform; and develop Vietnam's smart manufacturing system of standards and productivity experts' certification.

The orientation of promoting smart manufacturing through science, technology, and innovation has become an important goal of the National Productivity Master Plan.

1. The targets for 2025 are:

- Contribute toward achieving the target of increasing labor productivity by an average of over 7% per year (according to the Politburo's Resolution No. 52-NQ/TW dated 27 September 2019 on a number of policies to actively participate in the Public Revolution industry for the fourth time).
- Contribute toward achieving the goal of science-and-technology's contribution through total factor productivity (TFP) being about 45% to economic growth (according to Decision No. 283/QD-TTg dated 19 February 2020 of the Prime Minister on the approval of the plan to restructure the service sector by 2020, with an orientation to 2025).
- Develop a productivity improvement strategy based on science, technology, and innovation in at least 10 provinces/cities nationwide to achieve the goal of increasing the overall labor productivity of the whole economy.
- Implement productivity improvement programs, schemes, and plans based on science, technology, and innovation in at least two state economic groups.
- Develop productivity improvement plans and roadmaps and implement innovative activities that increase productivity in at least 300 medium-sized or higher enterprises and have a value to contribute to the sector and the locality.
- Select at least 10 colleges, universities, and vocational institutions that promote productivity growth through productivity research activities; provide training, fostering, and practical guidance to link the development of high-quality human

resources to businesses and the labor market; and build productivity improvement networks and clubs for students.

2. The targets for 2030 are:

- Contribute to the goal of increasing labor productivity by an average of 7.5% per year (according to the Politburo's Resolution No. 52-NQ/TW dated 27 September 2019 on a number of policies to actively participate in the fourth industrial revolution).
- Contribute toward achieving the goal of science-and-technology's contribution through total factor productivity (TFP) being about 50% to economic growth.
- Develop a productivity improvement strategy based on science, technology, and innovation in at least 30 provinces/cities across the country to achieve the goal of increasing the overall labor productivity of the whole economy.
- Implement programs, schemes, and plans to improve productivity based on science, technology, and innovation in at least five state corporations and other corporations.
- Develop productivity improvement plans and roadmaps and implement productivity-enhancing innovation activities in at least 500 enterprises (including public and private enterprises) that are of medium size or above and have a value to contribute to the sector and the locality.
- Select at least 20 colleges, universities, and vocational institutions that promote productivity growth through productivity research activities; provide training, fostering, and practice guidance to link the development of high-quality human resources for businesses and the labor market; and build productivity improvement networks and clubs for students.

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