Chapter 13

Enhancing Regional Architecture for Innovation to Promote the Transformation to Industry 4.0

Krisnamurthy Ramanathan

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Chapter 13

Enhancing Regional Architecture for Innovation to Promote the Transformation to Industry 4.0

Krishnamurthy Ramanathan*
Management of Technology and Innovation, Australia

1. Introduction

Industry 4.0 is talked about extensively as the 'fourth industrial revolution' that will have a major impact on manufacturing value chains at both local and global levels, not just in industrially advanced high-cost nations but also in less industrialised low-cost nations (Schwab, 2016). While many descriptions and definitions of Industry 4.0 exist, a simple way of looking at it at an overall level is as a 'collective term for technologies and concepts of value-chain organization' (Hermann, Pentek, and Otto, 2015). Deloitte (2015), in its study of challenges and solutions for the digital transformation and use of exponential technologies, points out that Industry 4.0 has four main characteristics: vertical networking of smart production systems through the use of cyber-physical production systems (CPPS); horizontal integration of real-time optimised global value-creation networks; cross-disciplinary through-engineering across the entire value chain and across the full life cycle of both products and customers; and acceleration of individualised solutions, flexibility, and cost savings in industrial processes through the use of exponential technologies. Hermann, Pentek, and Otto, (2015) point out that an Industry 4.0 scenario needs to take into consideration six design principles: interoperability, virtualisation, decentralisation, real-time capability, service orientation, and modularity.

* The views expressed in this chapter are those of the author and do not necessarily reflect the views of the organisations that the author is associated with. Mention of firm names, commercial products, and/or technologies are not intended to imply endorsement. The contents of the chapter are aimed to stimulate discussion on policy and practice issues and are not intended to express a judgement about the practices of the nations, firms, and other entities mentioned in the chapter.

The positive impact that Industry 4.0 can have from a circular economy perspective is that it can, if well designed and used, help to minimise the leakage of both biological and technical materials, especially the loss of materials, energy, and labour (Nguyen Stuchtey, and Zils, 2014).

However, Ubisense, a global firm specialising in location intelligence solutions, found out, through its 2014 Smart Manufacturing Technologies Survey of 252 manufacturing engineers and product designers, that 40% of manufacturers have no visibility into the real-time status of their manufacturing processes, more than 80% rely on human observation to support process-improvement initiatives, nearly 85% of quality issues can be attributed to worker errors, nearly 10% of manufacturing personnel spent considerable time daily looking for equipment and products, and over 10% of cycle time per product is non-value-added time (Ubisense, 2015). This suggests that even in industrially advanced settings, there are many barriers to Industry 4.0 that need to be overcome and that perhaps there is a need for a phased-out approach in transitioning to Industry 4.0.

The Association of Southeast Asian Nations (ASEAN) region is one of the fastest growing regions in the world, with a population of over 625 million and a combined nominal gross domestic product of over US$2.6 trillion in 2015. The possibilities of enhanced trade and technological cooperation due to the ASEAN Economic Community (AEC), the ASEAN+3 (ASEAN + China, Japan, and the Republic of Korea), and the East Asia Summit (ASEAN, ASEAN+3, and Australia, India, New Zealand, Russia, and the United States) make it attractive for the ASEAN region to leapfrog to an Industry 4.0 setting to enhance the global competitiveness of its businesses while ensuring sustainable manufacturing.

While leapfrogging to Industry 4.0 can be conceptually attractive for the ASEAN region, there could be many barriers to its adoption. A report by Roland Berger (2014) on Industry 4.0 readiness in Europe highlights the challenges faced not just at the firm level but also within the business ecosystem and the national economic setting. Based on this analysis, the report suggests that different European nations could be classified as frontrunners, potentialists, traditionalists, and hesitators with respect to transitioning to Industry 4.0. While these are terms coined by the authors, frontrunners refer to countries where leading firms in manufacturing have advanced to Industry 4.0, along with critical partners in their supply chain, supported by robust government policy initiatives to accelerate this transformation. Potentialists are nations where there is, as the name implies, high potential for an Industry 4.0 transformation and several large firms have already started applying the approaches in selected areas, but leadership at the firm level and governments need to show great commitment to enable a major transformation to be realised. Traditionalists refer to countries where, despite Industry

4.0 awareness, manufacturing has yet to incorporate it comprehensively into their strategic thinking. Hesitators are countries where the manufacturing sector, for reasons such as lack of skills or resources, is wary of embarking upon an Industry 4.0 strategy.

Clearly, the initiatives to be taken by the nations in each category to advance to Industry 4.0 would be different. Frontrunner nations, such as Germany and Sweden, would set the pace while hesitator nations would have much to do to make the transition. This study has implications for the ASEAN region since it underscores the importance of looking at interrelated aspects such as the industrial base of each nation, business conditions, information technology (IT) infrastructure, technological capability, manufacturing skill pool, government policy on sustainability and innovation, and links to the global manufacturing value chain. There could also be a concern in some of the less advanced ASEAN nations as to whether Industry 4.0 will strengthen or hurt its small and medium-sized enterprises (SMEs).

This chapter will develop a conceptual framework to examine a nation's readiness to Industry 4.0. An eclectic approach will be used to develop the framework, which will then be used to make a preliminary assessment of the Industry 4.0 readiness of the ASEAN nations. Barriers will be identified and possible initiatives that could be taken to promote the transitioning to Industry 4.0 will be examined. This examination will encompass possible arrangements that could be taken within the ASEAN region. Suggestions will also be made for further work to strengthen and refine the findings of this chapter.

2. Industry 4.0 and the Internet of Things

Today, the term Industry 4.0 is used to describe a new wave of technological advancement that Schwab (2016) refers to as the 'fourth industrial revolution'. It refers to the way in which the organisation and management of the value chain in manufacturing is undergoing a dramatic transformation (Deloitte, 2015). According to Rüßmann et al. (2015) of the Boston Consulting Group, this transformation is being driven by several foundational technological advances that enable sensors, machines, workpieces, and IT systems to be linked along a value chain beyond a single enterprise. Deloitte (2015) refers to these foundational technological advances as 'acceleration through exponential technologies'. While the broad Industry 4.0 literature (Albert, 2015; D'Aveni, 2015; Deloitte, 2015; Hermann, Pentek, and Otto, 2015; Iansiti and Lakhani, 2014; and Mohr and Khan, 2015) classifies these exponential technologies in many ways, they include the industrial internet of things (IoT), big data and analytics, simulation, advanced robotics, artificial intelligence (AI), additive manufacturing (3D printing), cloud-based software platforms, and augmented reality.

A review of literature shows there is some confusion in the use of the terms 'Industry 4.0' and 'IoT'. While Albert (2015) states that the term 'Industrie 4.0 (Industry 4.0)' was adopted by a coalition of universities, companies, labour unions, and government bodies in Germany to represent the country's vision for the future of manufacturing and is used widely in Europe, Deloitte (2015) points out that the term IoT appears to be used in the same context in the United States (US) and the English-speaking world. While both these terms recognise that manufacturing and production systems are facing a radical transformation due to advances in digital technology, Albert (2015) points out that industrial IoT and Industry 4.0 have a cause–effect relationship in the sense that industrial IoT is the basis for, and will result in, Industry 4.0.

2.1. Main Characteristics of Industry 4.0

Based on the work of Deloitte (2015) and Rüßmann (2015), it could be said that the four main characteristics of Industry 4.0 are the following:

- vertical networking of smart production systems;
- horizontal integration of global value chain systems;
- through-engineering across the entire value chain; and
- adoption of exponential technologies for individualised solutions, flexibility, and cost savings.

At the core of these main characteristics are the cyber-physical production systems (CPPS). CPPS refers to an online network of sensors, machines, workpieces, and IT systems that can extend beyond a single enterprise and encompass the entire value chain (Deloitte, 2015; Rüßmann et al., 2015). They interact with each other using standard internet-based protocols and analyse data to configure themselves, adapt to changes, and predict problems and failures (Rüßmann et al., 2015).

CPPS enables the vertical networking of smart production systems to enable factories to react rapidly to changes in demand and supply, quality fluctuations, and machinery breakdowns (Deloitte, 2015). Production performance and associated discrepancies and amendments, machinery performance, and quality issues are all recorded in real time, enabling better evidence-based response. This can enable customisation of production, facilitate lean manufacturing, and promote the effective use of total productive maintenance. A direct impact of effective vertical networking is both waste reduction and enhanced resource efficiency, both of which are central to the creation of a circular economy.

Horizontal integration of global value chains is also enabled by CPPS where the entities along the supply chain, inbound logistics, warehousing, production, warehousing, outbound logistics, marketing, sales, and after-sales service are networked to provide what Deloitte (2015) refers to as integrated transparency, high level of flexibility, traceability, and global optimisation. 'This will enable factors such as quality, time, risk, price, and environmental sustainability to be handled dynamically, in real time, and at all stages of the value chain' (Deloitte, 2015). Due to comprehensive information sharing and integrated transparency, horizontal integration of global value chains can enable waste reduction and better compliance with respect to social and environmental responsibility, thereby providing an impetus to move towards circular economy.

CPPS can also enable effective cross-disciplinary and cross-functional collaboration for through-engineering along the entire supply chain. Deloitte (2015) defines through-engineering as a seamless approach for the design, development, and manufacture of new products and services across the life cycle of both products and customers. Since product modification and new product development will require adaptation and upgrading of production systems, through-engineering through CPPS will enhance flexibility and response time by dramatically reducing lead times involved in modelling, designing, prototyping, and production system design. Adoption of new environmentally sustainable product design and production systems thus becomes feasible, thereby contributing towards the objectives of circular economy.

The use of exponential technologies such as advanced robotics, AI, 3D printing, and functional nanomaterials and nanosensors can be used to deliver individualised solutions, flexibility, and cost savings along the supply chain (Deloitte, 2015; Rüßmann et al., 2015). For instance, AI and advanced robotics have enabled the use of driverless automated guided vehicles in factories and mines; drones have been used to deliver spare parts and track inventory; and nanosensors have been used to make quality management more efficient (Deloitte, 2015). Additive manufacturing is already being used to produce customised products for special applications, and high-performance 3D printing can deliver new supply chain solutions that can reduce design, production, and delivery lead times; lower transport distances; and even lead to disintermediation of some supply chain entities (D'Aveni, 2014; Deloitte, 2015; Mohr and Khan, 2015; Rüßmann et al., 2015). Here again, the potential contribution towards circular economy is significant.

2.2. The Internet of Things

The International Telecommunication Union (ITU) defines IoT as 'a global infrastructure for the information society, enabling advanced service by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies' (ITU, 2015). A simpler definition is given by Whitmore, Agarwal, and Xu, (2015) who state that 'the core concept of IoT is that everyday objects can be equipped with identifying, sensing, networking, and processing capabilities that will allow them to communicate with one another and with other devices and services over the internet to achieve some useful objective'. Minsker (2015) refers to the three 'Ds' of IoT as connecting devices, data, and development platforms. These definitions reinforce Albert's (2015) statement that, 'industry IoT is the basis for, and will result in, Industry 4.0' since without an industry IoT, there can be no CPPS.

Lee and Lee (2015) identify five essential IoT technologies that are needed for the deployment of successful IoT-based products and services:

- radio frequency identification (RFID);
- wireless sensor networks (WSN);
- middleware;
- cloud computing; and
- IoT application software.

RFIDs have been used extensively in recent years to strengthen supply chain management. It enables the automatic identification and data capture using radio waves, a tag, and a reader (Lee and Lee, 2015). Data are stored in the tags using the standard electronic product code and the tags can be active (own power supply), passive (powered by radio frequency energy transferred from the reader), and semi-passive (using their own batteries to power the microchips while also drawing power from the reader). Active RFIDs can initiate communication with a reader and are used in manufacturing, hospitals, and remote-sensing IT asset management (Lee and Lee, 2015). Passive RFIDs, which are cheaper than active RFIDs, are used extensively in supply chains for inventory tracking and management, and warehouse management.

Atzori, Iera, and Morabito, (2010) define WSNs as spatially distributed autonomous sensor-equipped devices that can monitor physical or environmental conditions and, in conjunction with RFID systems, better track the status of things such as location, temperature, and movements through appropriate network topologies and multihop communication. The range of WSN applications has increased due to significant technological advances in low-power integrated circuits that have led to the development of low-cost, low-power miniature devices (Gubbi et al., 2013). Lee and

Lee (2015) give an example of the use of WSNs in aircraft engine and wind turbine performance tracking in real time to improve preventive maintenance and reduce downtime. Luo et al. (2015) provide a comprehensive description of how a WSN can be used to monitor the real-time temperature, humidity, and physical position status of perishable goods in a cold chain, thereby ensuring quality delivery and reducing wastage. These are two examples of how IoT can contribute towards waste reduction and better utilisation of resources.

Middleware may be regarded as a software layer that lies between the operating system and applications on each side of a distributed computing system in a network output (Lee and Lee, 2015). Global Sensor Networks is an open-source sensor middleware platform that facilitates the creation and use of sensor services with hardly any programming effort (Lee and Lee, 2015).

Cloud computing is now being used extensively as an on-demand, back-end solution for handling and processing large data stream. On-demand access is provided to a pool of configurable resources such as computers, networks, servers, storage, applications, services, and software through infrastructure as a service or software as a service (Lee and Lee, 2015). The massive data handling and processing capacity provided by cloud computing in real time makes it a critical element of the IoT system. ITU (2015) points out that as confidence in the information and communications technology (ICT) infrastructure and its ability to ensure data privacy and protection increases, IoT will evolve to what it calls the 'internet of everything' where connectivity will not only be between 'people to people' and 'machines to machines', but also 'people to machines' and 'people and machines to processes'. This would require the development of a vast number of industry-oriented and user-specific IoT applications that would ensure that information and messages are received and acted upon accurately and in a timely manner (Lee and Lee, 2015). While 'machines to machines' applications may not require data visualisation, 'people-oriented' applications will require visualisation to be presented in a user-friendly format. This will require IoT applications to be built with 'intelligence' (Lee and Lee, 2015). A generic categorisation of applications for enterprise use could be monitoring, big data and analytics, and information sharing and collaboration (Lee and Lee, 2015). These generic applications are relevant to enterprises in today's interdependent global business setting. A good example is supply chain management where firms must deal effectively with suppliers at multiple tiers, customers, and logistics service providers. The impact would not only be enhanced customer satisfaction and supply chain profitability but also a massive reduction in waste and lowering of the carbon footprint of the supply chain.

3. Literature-based Case Studies of the Potential Contribution of Industry 4.0 and the Internet of Things to the Circular Economy

Industry 4.0 holds considerable promise for sustainable industrial value creation. While it is regarded as a manufacturing paradigm that is still new, emerging literature based on recent developments in the field suggest that it is possible to postulate likely impacts that Industry 4.0 can have from a circular economy perspective. This section presents two short literature-based case studies that can help demonstrate the disruptive yet beneficial impact of Industry 4.0. The first case study on 'sustainable manufacturing in Industry 4.0' illustrates the positive impacts that a 'smart factory' can have from a circular economy perspective. The second case study shows how 'additive printing', a specific technology that will be a core technology in an Industry 4.0 setting, can contribute towards a circular economy. Possible applications outside manufacturing are also summarised at the end.

3.1 Sustainable Manufacturing in Industry 4.0

At the heart of manufacturing in Industry 4.0 will be the 'smart factory' where there is vertical integration of smart production systems, horizontal integration of value chain systems, and 'end-to-end' or through-engineering across the entire value chain (Stock and Seliger, 2016; Mohr and Khan, 2015).

Stock and Seliger (2016) and Kolberg and Zühlke (2015) visualise the smart factory as consisting of a CPPS where the manufacturing equipment use sensor systems to identify and localise value creation entities such as other machines, products being made, and people. Based on the monitored 'smart data', the actuators in the equipment respond in real time to changes. Exchange of smart data between the value creation entities and the value chain is executed through the cloud. Table 1 provides a summary of the value creation factors.

Table 1. Summary Description of Value Creation Factors

Value Creation Factors	Summary Description
Equipment	Automated machine tools and robots working collaboratively with other value creation factors. These smart machines are likely to be organised into modular working stations which are error-proofed and have 'plug and produce' capability.
People	Overall decrease in the number of workers but with a high percentage of knowledge workers who will increasingly have to monitor the CPPS, engage in decentralised decision-making, and participate in through-engineering activities. Equipped with smart watches, 'smart operators' will receive, monitor, and take action in real time to prevent failures and machine downtime.
Organisation	Focus on decentralised decision-making with local information being used by workers and machines in conjunction with artificial intelligence. 'Smart planning' helps CPPS find the optimum between highest possible capacity utilisation at each work station and continuous flow of goods.
Process	Use of exponential technologies such as additive manufacturing and associated supporting technologies.
Product	Mass customisation of 'smart products' with integrated after-sales functionality and access for improved performance and lower total cost of ownership, along with inbuilt features to collect process data for analysis during and after production.

CPPS = cyber-physical production systems.

Source: Adapted from Stock and Seliger (2016); Kolberg and Zühlke (2015).

The intelligent cross-linked value creation modules in a smart factory offer the potential of sustainable use of resources such as materials, products, energy, and water. Table 2 summarises possible opportunities.

3.2 Impact of Additive Printing on Supply Chains and Supply Chain Management

The use of exponential technologies is a major characteristic of Industry 4.0. One such technology is what is known as additive printing, more popularly known as 3D printing. It is called additive printing because it adds materials rather than removes materials from a larger object, as is done in traditional manufacturing. Additive manufacturing essentially involves adding layers of fine powder or liquid sequentially. The materials used include a range of metals, plastics, and composites (Deloitte, 2015).

Four types of processes are used in additive manufacturing, each using a different additive process or additive technology described as follows (Deloitte, 2015):

- *Light polymerisation*, where a light-sensitive polymer is hardened through stereolithography, digital light processing, film transfer imaging, or polyjet process.
- *Extrusion accretion*, where a wire-shaped plastic is applied in layers by a process of fused deposition modelling or plastic jet printing.
- *Compounding of granular materials*, where a powder material is melted on to a work platform using a printer head or laser jet, using processes such as selective laser sintering, selective laser melting, direct metal laser sintering, electron beam melting, gypsum-based 3D printing, and 3D powder printing.
- *Layered lamination*, where a component is built up in layers through a laminated object manufacturing process.

Table 2. Potential Contributions of a Smart Factory towards a Circular Economy

Value Creation Factors	Summary Description
Equipment	Existing manufacturing equipment can be retrofitted with sensors, actuators, and control logics as a cost-efficient way of upgrading to reduce the heterogeneity of equipment within the factory. In addition to economic and environmental dimensions of sustainability, this could enable SMEs to move towards Industry 4.0.
People	Factory workers will become knowledge workers and, with responsibility for decentralised decision-making, will have to be extensively trained to effectively use smart data and support tools based on artificial intelligence. Work, work methods, individual feedback mechanisms, and incentives will have to be suitably designed and effectively implemented to foster intrinsic motivation and social well-being.
Organisation	If the organisation is suitably structured to foster decentralised decision-making and collaboration along the supply chain with a focus on resource conservation, then the implementation of smart grids, smart logistics, customer relationships, and other integrative approaches can promote holistic resource efficiency.
Process	The use of new technologies, such as additive printing and internally cooled tools for metal cutting, can lead to the design of resource conserving and sustainable manufacturing processes.
Product	Products can be designed based on 'cradle-to-cradle' principles. Through the adoption of exponential technologies, the application of identification systems for recovery of products for remanufacturing and real-time tracking of performance of products at the customer end, total costs of production and ownership can be reduced while promoting the sustainable use of resources.

SMEs = small and medium-sized enterprises.

Source: Adapted from Stock and Seliger, 2016.

Studies suggest that while the initial investment in 3D printing may be high, the prototypical cost curve flattens out and substantial cost savings can be made when strategically used along the supply chain (Deloitte, 2015). The major areas in a supply chain that can be impacted by 3D printing are customer relationships and product design, manufacturing, logistics, and inventory management. The impacts on a supply chain from a circular economy perspective have been examined comprehensively by Mohr and Khan (2015) based on an extensive literature review. Their conclusions are discussed below briefly.

Product design and customer relationships

- Due to the additive nature of 3D printing, product designers can customise and redesign products with a focus on attributes such as enhanced functionality and materials savings without being subject to 'design for manufacturing' constraints imposed by production facilities.
- It can also facilitate customer inclusion in the design process so that they become 'prosumers' who engage in customer co-creation.
- Closer customer involvement could also lead to redefining the 'how, where, and who' of an established supply chain, thereby making it necessary to change organisational arrangements and management priorities. For instance, it could lead to merging of design, manufacturing, and distribution.
- These new relationships and ways of working could lead to making what the customers want, when they want it, and how they want it, thereby reducing waste due to overstocking and obsolescence.

Manufacturing

- 3D printing produces less waste during production than conventional manufacturing processes, thereby contributing to a greener and more sustainable supply chain. The possibility of utilising recycled material further enhances its contribution to a circular economy.
- 3D printing replaces previously assembled parts by a single component and thus simplifies the manufacturing process significantly, leading to less parts, less movement of materials, and less assembly efforts, which lead to waste reduction and cost savings.
- The high ratio of output to volume to space occupied in a 3D manufacturing setting makes on-location production and consumption economically feasible. Locating the manufacturing facility closer to the consumer makes agile production possible, small lot production of high-technology products economically viable, and production to market lead times more competitive.

Logistics

- Since 3D printing replaces many of the assembly steps in manufacturing, it reduces process complexity and makes the flow of materials more transparent and easier to control.
- By placing manufacturing closer to the customer, warehousing could be rationalised and movement of physical goods globally can be reduced by sending electronic files to the point of production. These initiatives can reduce the demand for global transportation of physical goods, thereby significantly lowering the carbon footprint of the supply chain.

Inventory management

- Since 3D printing leads to component consolidation, it reduces the number of stock keeping units in the system and lowers the number of components to be kept in stock.
- Inventory management for 3D printing will also lead to a shift to inventory of raw materials (powders, liquids, filament coils) rather than semi-finished parts and components. Handling of these raw materials will be less complex, cheaper, and safer.

It appears from the above summary that 3D printing will certainly have a positive impact on the operations of a supply chain, from a circular economy perspective, through the reduction of waste and complexity, and the lowering of the carbon footprint of transportation. However, with the closer integration of the different entities in a supply chain, there will be concerns related to misuse of intellectual property and product liability. Identifying the skill sets needed by workers and managers in a supply chain will be another area of major concern. Furthermore, if 3D printing is likely to lead to the reshoring of currently offshored manufacturing in developing countries, then how will the low-cost workforce in these countries be affected? These aspects need careful consideration.

3.3 Possible Roles of the Internet of Things in Accelerating Development

While the focus of Industry 4.0 has been mainly on manufacturing, ITU (2015) presents other possible applications of IoT for fostering social well-being and accelerating economic development, especially in developing nations. A key area would be in health, where IoT can be used for tracking, anticipating, and mitigating the spread of infectious diseases by combining mobile positioning data with epidemiological, remote sensing, and geographic information systems data (ITU, 2015). IoT can also facilitate the widespread adoption of mobile health through which assistance can be offered to those with chronic diseases through wearable devices (ITU, 2015).

Other areas of IoT application include climate change and disaster management, precision agriculture, urban planning, electric grids, water and sanitation management, infrastructure and traffic control, and early warning for natural hazards (ITU, 2015). However, ITU cautions that all these applications cannot eventuate unless adequate and reliable ICT infrastructure is established, quality internet connectivity is widely available, and cyber-vulnerabilities are mitigated and minimised.

4. Assessing the Industry 4.0 Readiness of the ASEAN Region

ASEAN was established on 8 August 1967 in Bangkok, Thailand, with the signing of the ASEAN Declaration (Bangkok Declaration) by the founding fathers of ASEAN: Indonesia, Malaysia, the Philippines, Singapore, and Thailand (ASEAN, 2016). It was subsequently joined by Brunei Darussalam, Viet Nam, Lao People's Democratic Republic (Lao PDR), Myanmar, and Cambodia over the period 1984 to 1999, making up the 10 member states of ASEAN (ASEAN, 2016). Its aims include accelerating economic growth, social progress, and sociocultural evolution amongst its member countries, alongside the protection of regional stability as well as providing a mechanism for member countries to resolve differences peacefully.

The ASEAN region is one of the fastest growing regions in the world, with a population of over 625 million and a combined nominal gross domestic product of over US$2.6 trillion in 2015. Of the 10 ASEAN nations, Singapore and Brunei Darussalam are classified by the World Bank as high-income (non-OECD) countries; [1] Malaysia and Thailand as upper middle-income countries; Indonesia, Lao PDR, Myanmar, the Philippines, and Viet Nam as lower middle-income countries; and Cambodia as a low-income country. This suggests that there is heterogeneity amongst the member states of ASEAN from an economic development perspective.

[1] As of 1 July 2016, low-income economies are defined as those with a gross national income (GNI) per capita, calculated using the World Bank Atlas method, of US$1,025 or less in 2015; lower middle-income economies are those with a GNI per capita between US$1,026 and US$4,035; upper middle-income economies are those with a GNI per capita between US$4,036 and US$12,475; and high-income economies are those with a GNI per capita of US$12,476 or more (World Bank http://www.worldbank.org/).

The possibilities of enhanced trade and technological cooperation due to the AEC, the ASEAN+3 (ASEAN + China, Japan, and the Republic of Korea), and the East Asia Summit (ASEAN, ASEAN+3, and Australia, India, New Zealand, Russia, and the United States) make it attractive for the ASEAN region to leapfrog to an Industry 4.0 setting to enhance the global competitiveness of its businesses while ensuring sustainable manufacturing. However, this will require major efforts on the part of businesses in these nations. Adopting Industry 4.0 will require changes to be made quickly and effectively in the industrial base, IT infrastructure, technological capability, technological skills, national policies on sustainability and technological development, and along the entire global manufacturing supply chain. Thus, from an Industry 4.0 transformation perspective, it is imperative that each nation assesses the current level of these critical determinants from an Industry 4.0 perspective. This assessment may be called Industry 4.0 readiness.

In the report of Roland Berger (2014), the Industry 4.0 readiness of the European Union (EU) was assessed by developing an index based on a comprehensive survey of the manufacturing sector in the EU in terms of production process sophistication, degree of automation, workforce readiness, innovation intensity, high value added, industry openness, innovation networks, and internet sophistication. These were rated on a 5-point scale and an overall 'Readiness Index' ranging from 1 to 5 (with 5 being the maximum) was developed for each nation. A matrix was then developed with the readiness index on the vertical axis and the manufacturing share as a percentage of GDP on the horizontal axis. Nations that had a high readiness index and high manufacturing share were rated as 'frontrunners'. Those with a high readiness index but low manufacturing share were termed 'potentialists', and those with a low readiness index but high manufacturing shares were called 'traditionalists'. Those with a low readiness index and low manufacturing share were referred to as 'hesitators'. Clearly, the 'frontrunners' are the Industry 4.0 champions while the 'potentialists' and 'traditionalists' must take focused action to take their industry into the next era. The 'hesitators' with unreliable industrial base and adverse economic conditions will not be able to future-proof their economies (Roland Berger, 2014).

Given the constraint that this study will not have the opportunity to undertake surveys of the manufacturing sector of the ASEAN nations, published information was used to develop an Industry 4.0 Readiness Index (I4RI) for the ASEAN nations. The Global Competitiveness Report (2015–2016) provides considerable information on the status of critical indicators of what it refers to as the 'pillars of development' of nations. To develop an I4RI for the ASEAN region, information on the following three major categories were used: basic requirements, efficiency enhancers, and business sophistication and innovation (Schwab, 2015).

The basic requirements category comprises four sub-criteria: institutions, infrastructure, macroeconomic environment, and health and primary education. These essentially constitute the foundations upon which a nation can build a stable, productive, safe, and sustainable programme of economic development based on good governance (Schwab, 2015). The Global Competitiveness Report rates nations on each of these on a score of 1 to 7, where 7 is the maximum score attainable (Schwab, 2015).

The efficiency enhancers category refers to six sub-criteria, as follows (Schwab, 2015):

1. **Higher education and training**
   The higher education and training sub-criteria focus on the development of high-level skills and continuing education
2. **Goods market efficiency**
   Goods market efficiency refers to the level of healthy competition and customer sophistication, which will drive firms to embark on a programme of continuous improvement
3. **Labour market efficiency**
   Labour market efficiency examines the level of mobility of the workforce between economic sectors as demand for skills shift and ethical treatment of workers become based on meritocracy, gender equality, and appropriate incentives
4. **Financial market development**
   Financial market development assesses the level of development of capital markets in a nation that enables the private sector to gain effective access to such sources as loans from a sound banking sector, well-regulated securities exchanges, venture capital, and other financial products
5. **Technological readiness**
   Technological readiness measures the agility with which a nation adopts existing technologies to enhance manufacturing productivity, with specific emphasis on the adoption of ICTs for fostering production efficiency and innovation to enhance competitiveness
6. **Market size**
   Market size refers to the size of local and export markets that firms in the country have access to in today's global business setting. Here again, the Global Competitiveness Report rates nations on each of these six sub-criteria on a score of 1 to 7, where 7 is the maximum score attainable (Schwab, 2015).

The business sophistication and innovation category consists of two sub-criteria: business sophistication and innovation. The business sophistication sub-criterion assesses the quality of a country's business networks and supporting industries in terms of the quantity and quality of local suppliers, the extent of their interaction, and the level of cluster formation, all of which are needed for robust and agile business relationships. The innovation sub-criterion assesses the extent to which firms in a nation can design and develop cutting-edge products and processes to maintain a competitive edge and move toward higher value-added activities. It also evaluates the strength of the innovation ecosystem in a nation. As in the case of the earlier two categories, the Global Competitiveness Report rates these two sub-criteria on a score of 1 to 7, where 7 is the maximum score attainable (Schwab, 2015).

Tables 3(a), 3(b), and 3(c) show the overall ratings of the ASEAN nations for the three categories and sub-criteria. Since the Global Competitiveness Report 2015–2016 does not provide the ratings for Brunei Darussalam, it has not been included in the analysis. The ratings of industrially advanced nations such as Germany and Japan, and some leading economies in the Asia Pacific such as Australia, China, India, and the Republic of Korea are also shown in these tables for comparison.

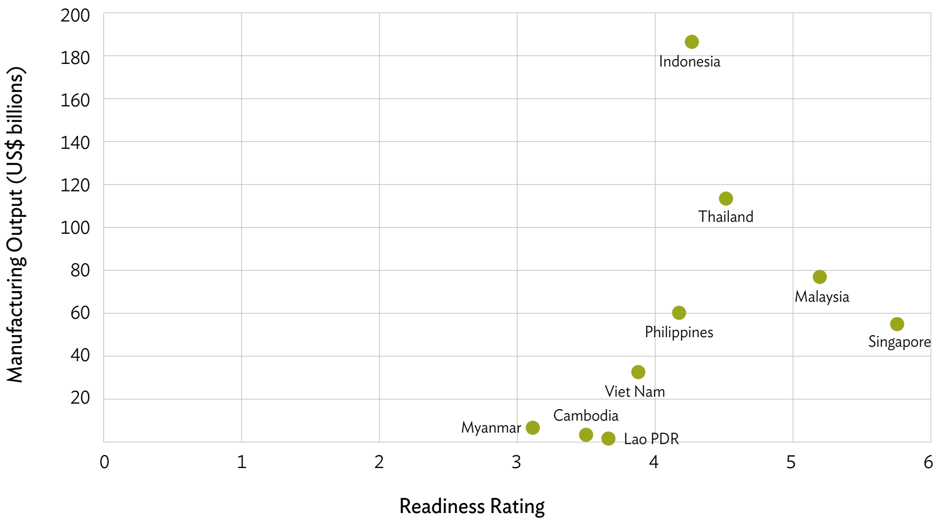
Table 4 shows an aggregate I4RI in the fifth column where the ratings of the three main categories – basic requirements, efficiency enhancers, and business sophistication and innovation – have been weighted at 20%, 50%, and 30% ratio, respectively. Similar weights have been used in the Global Competitiveness Report 2015–2016 for assessing the competitiveness index of 'innovation-driven' nations. Given that Industry 4.0 requires an innovation-driven approach, it seems reasonable to adopt the same weights to assess the I4RI of the ASEAN nations.

Table 5 shows the manufacturing output and the high-technology exports as a percentage of the manufactured exports[2] of the ASEAN nations and the comparator nations included in Tables 3, 4, and 5. These were used to develop a matrix like the ones used in the Roland Berger Readiness Index for the EU. For the sake of expository ease, these tables are presented in Appendix 1.

Figure 1 maps the I4RI and absolute manufacturing outputs of ASEAN nations. It shows that while Singapore leads in terms of I4RI, its absolute manufacturing output is less than that of Malaysia, Thailand, and Indonesia. Indonesia shows the highest level of manufacturing output followed by Thailand. The Philippines and Viet Nam rank next but with lower I4RI ratings. Myanmar, Lao PDR, and Cambodia rank low both in terms of I4RI and manufacturing output.

[2] The World Bank (2016) in its *World Development Report 2016* defines high-technology exports as products with high R&D intensity such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery.

Figure 1. Industry 4.0 Readiness Hierarchy for ASEAN Based on Manufacturing Output



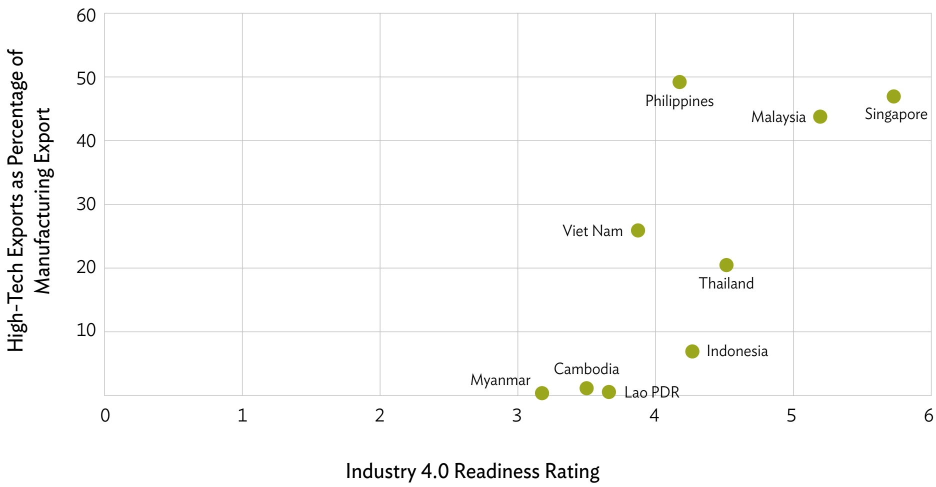
ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.

Source: Authors.

Figure 2 maps the same nations in terms of I4RI and high-technology exports as a percentage of manufactured exports. Here too, Singapore and Malaysia rank highest followed by the Philippines, Viet Nam, Thailand, and Indonesia. Myanmar, Lao PDR, and Cambodia rank low, both in terms of I4RI and percentage of high-technology exports. A striking observation is that while Indonesia has the highest level of manufacturing output amongst all the ASEAN nations, its high-technology exports as a percentage of manufactured exports is lower than that of Singapore, Malaysia, Thailand, the Philippines, and Viet Nam.

The mapping suggests that in terms of Industry 4.0 readiness, the ASEAN countries considered in this report could be grouped into four clusters. First, Singapore and Malaysia, with their high-technology export profile could be said to be 'potential innovators for Industry 4.0'. Indonesia, the Philippines, and Thailand could be considered 'efficiency seekers through Industry 4.0'. Viet Nam, due to its lower I4RI and low manufacturing output, could be a 'medium-term Industry 4.0 transitioner', while Cambodia, Lao PDR, and Myanmar may be considered 'slow movers towards Industry 4.0'.

Figure 2. Industry 4.0 Readiness Hierarchy for ASEAN Based on High-technology Exports



ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.
Source: Author.

Clearly, any action within ASEAN to promote Industry 4.0 must take into consideration the specific strengths and weaknesses of its member states from an Industry 4.0 perspective and not adopt a 'one size fits all' approach when formulating strategic initiatives.

5. A Conceptual Framework for Accelerating ASEAN Transition to Industry 4.0

To move into, compete, and survive, an Industry 4.0 ecosystem requires much more than machines and finance. In an Industry 4.0 setting, the key source for sustainable competitive advantage is knowledge, which may be regarded as intellectual capital (Murray et al., 2016). The three main components of intellectual capital are human capital, relational capital, and structural capital (Murray et al., 2016). As defined by Murray et al. (2016):

- Human capital refers to the set of knowledge, skills, and capacities of the workforce in an organisation aimed at achieving company objectives.

- Relational capital represents the working links and arrangements that a firm creates with its customers, employees, suppliers, universities, research and development (R&D) institutions, financing institutions, government agencies, the community, and other stakeholders.
- Structural capital refers to technologies, data, publications, procedures, and other relevant coded and non-coded knowledge owned by the company, which may or may not be protected through intellectual property laws.

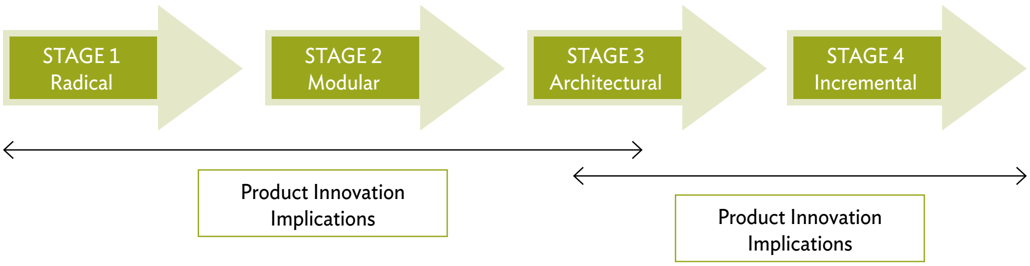
From the earlier discussion in this chapter, it is evident that IoT can play a critical role in building and sustaining these three components of intellectual capital. Murray et al. (2016) show empirically how the introduction of IoT had enhanced the intellectual capital owned by a company, named Cisco Systems Inc.

From an ASEAN perspective, intellectual capital has strategic implications. Unless firms in the manufacturing sector in ASEAN can steadily build up their intellectual capital, moving into an Industry 4.0 setting would be extremely difficult. The question is: What approach should be adopted to steadily build up the three components of intellectual capital?

A possible approach could be to adopt the model proposed by Caputo, Marzi, and Pellegrini, (2016). In their model of innovation, with specific reference to an Industry 4.0 and IoT setting, innovation in the manufacturing industry can evolve into four stages from product innovation through to process innovation as shown in Figure 3.

In Stage 1, a firm produces revolutionary and breakthrough products that have the potential to create new markets, make existing products obsolete, and change the currently prevailing paradigm that governs competition. This requires a very high level of intellectual capital within the firm, especially human and structural capital. Technology leaders are the ones that can engage in this type of innovation.

Figure 3. Evolutionary Phases of Innovation



Source: Adapted from Murray et al., 2016.

In Stage 2, the radical products are improved by improving the sub-technologies in the product and/or the linkages between them so that performance is further enhanced. This can be carried out by firms that may be called 'fast followers'. They, too, have a high level of intellectual capital. In Stage 3, architectural innovations focus on further strengthening performance by changing the nature of the interactions between the sub-technologies. This can be carried out by firms that have adaptive R&D capabilities and a substantial level of production capability. Incremental innovation in Stage 4 involves making small changes to improve both the product and the process used to make the product.

Murray et al. (2016) illustrate the model through the case of 3D printing. The four stages that they describe are summarised below.

Stage 1: An RFID tag is directly embedded in the product
This requires technologies and skills to design products with embedded readable unique identifier codes.

Stage 2: Product and printers are constantly connected
This requires considerable skills and know-how in designing, equipping, managing, and linking sensors into the manufacturing information network.

Stage 3: Products and 3D printers produce a constant flow of data
Here, the know-how gained in Stage 2 is leveraged to manage the two-way flow of data for creating a networked manufacturing system that will lead to the realisation of a 'smart factory'.

Stage 4: Produced data is used for product tracking, production planning, and strategic decision-making
Here, the emphasis is on managing the 'smart factory' and engaging in '*kaizen*' ('*kaizen*' is usually a tagline that used in the most of japanese manufacturing industry to motivate the employee to work at the best effort) to ensure that manufacturing objectives are achieved with a focus on continuous improvement. The above example suggests that, to enter an Industry 4.0 ecosystem, a firm could start by building its production capability (production planning and control, quality management, supply/procurement management, amongst others) to use additive manufacturing technology. Once this has been mastered, the firm could then move backwards to create greater value through process and product innovation. This approach is nothing new. As far back as the 1980s, Amsden (1989), in her study of the rise of the Korean steel industry, pointed out that learners do not innovate and must compete initially based on low wages, state support, high quality, and productivity. The route that must thus be pursued should

be based on transfer, absorption, and adaptation of technology. Habibie (1990), the architect of the highly publicised Indonesian aircraft industry in the 1980s and 1990s, stated that, 'technology receivers must be prepared to implement manufacturing plans on a step-by-step basis, with the ultimate objective of eventually matching the added-value percentage obtained by the technology transferring firm'. He referred to such an approach as 'progressive manufacturing' and popularised the slogan, 'begin at the end and end at the beginning', implying that a transferee firm should start with production and move backwards to cutting-edge research.

Based on the above conceptualisation, one possible approach for the four clusters of ASEAN nations to enter the Industry 4.0 ecosystem would be as follows:

Table 6. Possible Longitudinal Entry Approaches to Industry 4.0

Clusters	Strengthening Production and Maintenance Capabilities, and Supply Chain Management	Partnering Industry 4.0 Leaders in Production and Incremental Innovation	Partnering Industry 4.0 Leaders in Architectural and Modular Innovation	Assuming Industry 4.0 Leadership
Potential Innovators (Singapore, Malaysia)	Exists at high level. Strengthen further	High priority area	Short-term priority area	Medium-term priority area
Efficiency Seekers (Indonesia, Philippines, Thailand)	Exists. Strengthen further as a matter of high priority	Short-term priority area	Medium-term priority area	Long-term priority area
Transitioner (Viet Nam)	High priority area	Medium-term priority area	Long-term priority area	Long-term priority area
Slow Movers (Cambodia, Lao PDR, Myanmar)	High priority area	Long-term priority area	Long-term priority area	Long-term priority area

Lao PDR = Lao People's Democratic Republic.
Source: Author.

6. Discussion: Enhancing the Regional Architecture for Accelerating ASEAN Transition to Industry 4.0

The fourth wave of technological advancement in manufacturing, referred to as Industry 4.0, has the potential to confer the following substantial benefits to nations:

- Firstly, from a circular economy perspective, it can lead to waste reduction and a lower carbon footprint.
- Secondly, it can enhance the productivity of firms by reducing material and transformation costs, and through the accruing of higher value by enabling greater customisation of products.
- Thirdly, suppliers and industry partners involved in supplying machinery, sensors, materials, application software, and data services will also derive greater revenue.
- Fourthly, in high labour cost nations, reshoring of previously offshored manufacturing could enhance employment, but it is not clear how this will impact low labour cost nations with a relatively unskilled workforce. If a nation has a workforce skilled in automation, application software development, analytics and the like, new employment opportunities will become available.

However, all these will mean that enterprises will have to invest heavily to modify and modernise their production systems. Rüßmann et al. (2015) estimate that over the next 10 years, German firms will have to spend about €250 billion to incorporate Industry 4.0. In the ASEAN region, it will be necessary to invest heavily. Developing mechanisms to provide funding will be a major challenge. There is also a concern that SMEs could well become victims instead of beneficiaries of the Industry 4.0 revolution (Sommer, 2015). This could be a major concern for developing ASEAN country governments.

6.1 Intervention Needed at the Corporate and National Levels

Against this background, it would be useful to develop a preliminary set of interventions that would be needed by ASEAN nations to create an Industry 4.0 ecosystem. As explained in section 2.1 of this chapter, the four main characteristics of Industry 4.0 are the following:

- vertical networking of smart production systems;
- horizontal integration of global value chain systems;
- through-engineering across the entire value chain; and
- adoption of exponential technologies for individualised solutions, flexibility, and cost savings.

It will therefore be useful to examine the interventions that will be needed to enable the realisation of each of these attributes, and others, based on the work of Deloitte (2015), Li Xu, and Zhao, (2015), Li ,Tryfonas, and Li, (2014), Rüßmann et al. (2015), and Trequattrini et al. (2016).

Vertical networking of smart production systems

1. Strengthen networking by reducing the fragmentation of existing IT networks through the development of new solutions in partnership with suppliers of sensors, modules, control systems, communication networks, business applications, and customer-facing applications.
2. Develop specialist skills in analytics and efficient data management to generate new insights and strengthen evidence-based decision-making that will become possible due to 'big data' that will become available.
3. Develop skills in using cloud-based solutions so that decentralised networked smart-production systems can gain any time access to key data.
4. Strengthen operational efficiency (improving production processes, production planning and control, quality management, safety, total productive maintenance, and servicing) on a continuing basis.

Horizontal integration of global value chain systems

5. Develop a new business model at the edge of current businesses that will create new ways of working and utilise new skills so that, eventually, their success will lead to the model gradually extending to the rest of the business. Such an approach will reduce resistance amongst employees and avoid resentment of those who may initially be less engaged.
6. Work closely with supply chain partners, starting not just from raw material suppliers but also R&D, to gradually build a smarter and transparent supply chain that will facilitate coordination and collaboration by using data and information from a common database.
7. Smart supply chains also require the development of smart logistics arrangements across global value chain networks where autonomous technologies, flexible logistics systems, warehousing, distribution, and value-added services are seamlessly integrated. Partnering closely with logistics service providers is imperative.
8. The high levels of data sharing across entities will make it imperative to enhance data security. A service-oriented architecture for IoT requires security protection at four layers: sensing layer, network layer, service layer, and application interfaces layer (Li, Xu, and Zhao, 2015; Li, Tryfonas, and Li, 2014). This will require firms to develop a tailored risk management system and a security strategy to improve operational efficiency and security across the entire value chain.
9. Firms must develop new ways of protecting their intellectual property so that data, routines, products, and systems are protected against misappropriation and misuse.

Through-engineering across the entire value chain

10. As discussed in section 5, firms will need to develop the capacity to progressively engage in incremental, architectural, modular, and radical innovation. This needs to flow through the entire value chain, starting from customer-facing functions through to distribution, logistics, manufacturing, procurement, and design and development. The power of IT in enhancing innovative capability needs to be fully explored. For instance, data flowing from products and processes will enable innovative possibilities to be explored throughout the life cycle of a product.

Adoption of exponential technologies for individualised solutions, flexibility, and cost savings

11. This requires firms to develop horizontal and vertical technology transfer capabilities. Horizontal technology transfer refers to inter-firm commercial transfer of technologies through popular mechanisms such as purchase of plant and equipment, licensing, joint ventures, and so on. Vertical technology transfer is intra-firm and refers to commercialising technologies developed through R&D. Furthermore, firms also need to develop the ability to invest in start-ups and acquire the technologies thus developed.

Measures to be taken by governments

In addition to these interventions at the corporate level, governments in the ASEAN nations need short- and medium-term actions to strengthen the analogue complements of digital investments (World Bank, 2016). These include the following measures (World Bank, 2016; Li, Xu, and Zhao, 2015):

- Lower the barriers to digital adoption by reforming taxation and tariff regimes.
- Foster IoT standardisation with respect to security standards, communication standards, and identification standards.
- Increase competitiveness through effective regulation and enforcement, and encourage greater use of digital technologies by gradually reducing market distortions.
- Tailor 'new economy' regulations to ensure 'fair' competition (for instance, is Uber a software firm or taxi business?) and new taxation models (for instance, how to enforce value-added tax and customs regulations for 3D printing of products across countries when there is no physical crossing of national borders).
- Upgrade and continually revise education systems holistically, from foundational to tertiary education through to continuing education, to ensure the continued availability of a relevant stream of skills for the digital economy.
- Develop robust and enforceable digital safeguards and privacy policies.

6.2 Possible Regional Cooperation Mechanisms for Industry 4.0 Transformation

Section 5 outlined the possible paths that ASEAN member states could follow to build up and sustain a productive Industry 4.0 ecosystem. In this context, section 6.1 elaborated on specific interventions needed at both the national and corporate levels. Realising these, however, would pose many challenges since it requires access to knowledge (know-why, know-what, know-how, and show-how) and funds. This would require cooperation amongst many entities within the ASEAN region, supplemented by partnerships with external entities.

In 2011, the Organisation for Economic Co-operation and Development (OECD) Task Team on South–South Cooperation pointed out that, '[t]he global landscape of development cooperation has changed drastically in recent years. The era of one-way cooperation has become outdated, as countries of the South are engaging in collaborative learning models to share innovative, adaptable and cost-efficient solutions to address their development challenges' (OCED, 2011, pp.00). Knowledge sharing, which is a critical and dynamic element of South–South cooperation, is now regarded as the third pillar of development cooperation, complementing finance and technical assistance (OECD, 2011). However, when South–South cooperation is expanded creatively to include industrially advanced wealthy countries (the traditional north) through what is popularly termed the 'triangular cooperation', then greater effectiveness can be achieved (United Nations ECOSOC, 2008). This mode of cooperation could be a path that ASEAN could adopt in accelerating the region's Industry 4.0 transformation.

However, the South–South cooperation and triangular cooperation initiatives need to be implemented in a climate of cooperation based on equity, trust, mutual benefit, and long-term relations. An examination of ASEAN cooperation initiatives in the past suggests that its member nations have, over the years, worked hard to create such a climate. The ASEAN Economic Community Blueprint 2025 (AEC 2025) has three significant objectives that are of relevance to the longitudinal entry approaches to Industry 4.0 as outlined in Table 6. These are (ASEAN 2015a):

- Foster robust productivity growth through innovation, technology, and human resource development, and intensified regional R&D that is designed for commercial application to increase ASEAN's competitive edge in moving the region up the global value chains to higher technology and knowledge-intensive manufacturing and services industries.
- Promote the principles of good governance, transparency, and responsive regulatory regimes through active engagement with the private sector, community-based organisations, and other stakeholders of ASEAN.

- Widen ASEAN people-to-people, institutional, and infrastructure connectivity through ASEAN and sub-regional cooperation projects that facilitate movement of capital as well as skilled labour and talents.

Over the years, ASEAN has developed several plans of action to foster inclusive development within the region. These complement the plans developed to achieve the objectives outlined in AEC 2025. An examination of these plans suggests that there is flexibility within some of the proposed action plans to incorporate explicit efforts to foster ASEAN transition towards Industry 4.0. These efforts can be implemented through South-South cooperation and triangular cooperation with appropriate dialogue partners. In this section, some suggestions will be made based on three plans that are of most relevance to Industry 4.0.

Leveraging the ASEAN ICT Master Plan 2015

In 2015, under the auspices of the ASEAN Telecommunications and Information Technology Ministers, an ASEAN ICT Master Plan 2015 was formulated to harness ICT potential in establishing AEC (Nam et al., 2015). The specific objectives of this master plan during the period 2015–2020 are (Nam, Cham, and Halili, 2015):

- Develop ICT as an engine of growth for ASEAN countries.
- Gain recognition for ASEAN as a global ICT hub.
- Enhance the quality of life for the peoples of ASEAN.
- Contribute towards ASEAN integration.

As elaborated by Nam, Cham, and Halili, (2015), to achieve these objectives, the plan formulates three foundations supporting three pillars. The foundations are infrastructure development, human capital development, and bridging the digital divide. The pillars are economic transformation, people empowerment and engagement, and innovation.

The ASEAN ICT Master Plan thus provides a platform that can be used to promote cooperation amongst the ASEAN member nations to implement some of the interventions that have been elaborated in section 6.1. Tabor and Yoon (2015) highlight the measures taken by Indonesia and its experience in strengthening its ICT infrastructure. Similar information would be available in Singapore, Malaysia, the Philippines, Thailand, and Viet Nam, all of which would be invaluable to Cambodia, Lao PDR, and Myanmar. The exchange of ICT infrastructure building experiences and providing expertise well versed in the workings of the ASEAN region could be carried out under South–South cooperation programmes.

Leveraging the ASEAN Strategic Action Plan for SME Development

The ASEAN Strategic Action Plan for SME Development 2016–2025 (ASAPSMED 2016–2025) has five strategic goals (ASEAN, 2015b):

1. promote productivity, technology, and innovation;
2. increase access to finance;
3. enhance market access and internationalisation;
4. enhance the policy and regulatory environment; and
5. promote entrepreneurship and human capital development.

For each strategic goal, desired outcomes have been identified, and actions to achieve these have been delineated. While all five goals are important, Table 7 lists the related actions under three goals that are of higher priority from an Industry 4.0 transformation perspective.

For each identified action, a sequence of action lines should be developed to enable enterprises that are at different levels of manufacturing sophistication to choose an appropriate action line to move upwards. Referring to Table 7 – Action A-3-3, enhancing business and academia collaboration – could have sequential action lines ranging from basic to advanced, as follows:

1. Create awareness/develop skills to improve production and quality management practices.
2. Collaborate to improve manufacturing performance through low-cost automation.
3. Develop skills to improve supply chain performance and evaluate performance through approaches such as the supply chain operations eference model.
4. Set up programmes to promote collaboration amongst multinational corporations (MNCs)/large enterprises, SMEs, and academia to improve supply chain performance through IT-based initiatives.
5. Establish cooperative research programmes between MNCs, local large enterprises, SMEs, R&D centres, and academe for promoting commercial technology transfer and introduction of advanced technology from an Industry 4.0 perspective.

Table 7. **Actions Under ASAPSMED 2016–2025 to Foster Industry 4.0 Transformation**

Desired Outcomes		Actions
A-1	Productivity will be enhanced	A-1-3: Improve production management skills
A-2	Industry clusters will be enhanced	A-2-1: Enhance industrial linkages amongst SMEs and large enterprises including MNCs
		A-2-2: Promote technology and build capabilities to foster industrial clustering
A-3	Innovation will be promoted as a key competitive advantage	A-3-1: Promote key technology usage and its application to business for innovation
		A-3-2: Enhance information on innovation support services
		A-3-3: Enhance business and academia collaboration
B-1	Institutional framework for access to finance will be developed and enhanced	B-1-1: Improve understanding and strengthen traditional financing infrastructure
		B-1-2: Improve policy environment and measures to foster alternative and non-traditional financing through increasing availability of diversified sources of private financing
		B-1-3: Strengthen export financing facilities
C-1	Support schemes for market access and integration into the global supply chain will be further developed	C-1-1: Increase information on regional and global market access and opportunities
		C-1-2: Promote partnerships with MNCs/large enterprises to increase market access and opportunities
		C-1-3: Enhance the use of e-commerce
		C-1-4: Promote adoption of international standards of quality to facilitate market access
C-2	Export capacity will be promoted	C-2-1: Establish mechanisms to assist in increasing exports

ASAPSMED 2016–2025 = ASEAN Strategic Plan for SME Development 2016–2025, MNCs = multinational corporations, SMEs = small and medium-sized enterprises.

Source: ASEAN (2015b).

Enterprises in high-income Singapore may commence action lines 4 and 5, whereas firms in low-income or lower middle-income ASEAN nations may even have to start at action line 1.

While this is meant as an illustrative example for comprehensive capacity building under ASAPSMED, it would be more appropriate to form a consortium of leading universities and R&D institutes within the ASEAN region that could deliver training programmes in specific areas of Industry 4.0, with emphasis on interventions 1 through 11 described in section 6.1 above. This consortium should work with business associations and chambers of commerce in the ASEAN region so that industry practitioners from member countries could be trained. Initially, leading universities and R&D institutes from Indonesia, Malaysia, the Philippines, Singapore, and Thailand could be used as a core in this initiative, and this can be expanded over time with the inclusion of institutions from industrially advanced nations under a triangular cooperation initiative. The emphasis in all these capacity-building initiatives should be the 'training of trainers' to ensure a multiplier effect. How this consortium would function and be funded needs to be worked out.

Leveraging the ASEAN Plan of Action on Science, Technology, and Innovation 2016–2025 (APASTI 2016–2025)

The vision of APASTI 2016–2025 is, 'A Science, Technology, and Innovation-enabled ASEAN which is innovative, competitive, vibrant, sustainable, and economically integrated' (ASEAN, 2015c). The four major thrust areas under APASTI 2016–2025 (APASTI 2016–2025) are:

- Thrust 1: Strengthen strategic collaboration amongst academia, research institutions, networks of centres of excellence, and the private sector to create an effective ecosystem for capability development, technology transfer, and commercialisation.
- Thrust 2: Enhance mobility of scientists and researchers, people-to-people connectivity, and strengthen engagement of women and youth in science, technology, and innovation (STI).
- Thrust 3: Establish innovative system and smart partnership with dialogue and other partners to nurture STI enterprises to support micro, small, and medium-sized enterprises in knowledge creation and STI applications to raise competitiveness.
- Thrust 4: Raise public awareness and strengthen STI enculturation to enhance ASEAN science and technology cooperation.

Here again, as in the case of ASAPSMED 2016–2025, while all four areas are important, thrust areas 1 and 3 are directly relevant to regional cooperation to facilitate Industry 4.0 transformation. The actions envisaged under thrust areas 1 and 3 are as follows (APASTI 2016–2025):

Thrust 1

Action 1.1: Intensify the engagement of academe, private sector, and relevant partners in the planning, implementation, and assessment of joint undertakings in human resource development, and R&D.

Action 1.2: Enhance and sustain the utilisation of the ASEAN Science and Technology Network and strengthen other science and technology networks to facilitate information sharing.

Action 1.3: Establish policy frameworks, including intellectual property rightsprotection, risk, and benefit-sharing mechanisms for collaboration and technology transfer amongst centres of excellence.

Action 1.4: Strengthen existing regional STI initiatives in priority areas including Sustainable Development Goals.

Thrust 3

Action 3.1: Establish support mechanisms such as mentorship and incentive programmes to support and nurture STI enterprises from start-up to the next competitive level of development.

Action 3.2: Engage dialogue and other strategic partners in joint undertakings on appropriate and commercially viable STI initiatives.

All these actions will, as in the case of ASAPSMED 2016–2025, require an action line hierarchy to enable inclusive Industry 4.0 capacity strengthening of ASEAN member states that are at different levels of development.

From an Industry 4.0 perspective, the Sub-Committee on Microelectronics and Information Technology (SCMIT) will have an important role to play. APASTI 2016–2025 states that 'The SCMIT seeks to develop and enhance the capabilities of ASEAN member countries' microelectronics and ICT, and its related areas from downstream to upstream technologies. The sub-committee aims to undertake research, development, capacity building, and demonstration projects in microelectronics and ICT and related areas according to the strategic thrusts' (ASEAN, 2015c). The specific objectives of SCMIT are to:

- undertake capacity building for less developed ASEAN member states;
- promote and carry out R&D technology transfer in microelectronics, ICT, and other related areas;
- foster and strengthen intra-ASEAN activities in the priority areas;
- strengthen information network/database for exchange and dissemination within and outside ASEAN; and
- strengthen institutions and centres of excellence.

The work of SCMIT is therefore critical from an Industry 4.0 perspective due to the role that it is expected to play in strengthening the IT infrastructure of ASEAN member states, which is a prerequisite for Industry 4.0 transformation.

Yet, it must be acknowledged that ASEAN firms are not yet world leaders in Industry 4.0-related technologies. Companies in Germany (for example, Siemens) and Japan (for example, NEC) are often cited as trail blazers in Industry 4.0. It would be of great value if the governments of Germany and Japan could establish centres in the ASEAN region to provide advanced training and act as a focal point for promoting business relationships between ASEAN firms and those in Germany and Japan. Both ASAPSMED 2016–2025 and APASTI 2016–2025 have sufficient flexibility to incorporate triangular cooperation in association with dialogue partners from industrially advanced nations.

A precedent case in Thailand can be cited, even though it occurred 2 decades ago. A study carried out by Cuyvers and Ramanathan (1991) shows that, in the 1970s and 1980s, the Japanese government played an important role in upgrading technical skills in Thailand by providing vocational training centres, training equipment, and fellowships. This helped the Japanese investors in Thailand since these initiatives led to the availability of a skilled pool of labour who were already influenced by the 'Japanese way of working'. The Japanese government also funded the Technological Promotion Association (Thailand–Japan) in the 1980s and 1990s, which provided advanced training in selected technical fields and in areas such as quality management for apprentices and those already employed in Japanese–Thai joint ventures.

Establishing such specialised Industry 4.0 promotion centres in ASEAN by Japan and Germany could play a very useful role in accelerating the accomplishment of the interventions outlined in section 6.1 above.

In summary, this section has essentially outlined three major cooperation mechanisms for Industry 4.0 transformation in the ASEAN region. These are:

- South–South cooperation and triangular cooperation initiatives for accelerating Industry 4.0 transformation.
- Leveraging the ASEAN ICT Master Plan 2015, the ASAPSMED 2016–2025, and the APASTI 2016–2025 to create explicit action lines to enable the inclusive incorporation of ASEAN member states in Industry 4.0 transformation.
- Establishment of advanced Industry 4.0 training and business promotion centres by leading Industry 4.0 nations such as Germany and Japan.

These recommendations need to be examined in the context of currently existing cooperation mechanisms. Such study is beyond the scope of this study. It is recommended that a detailed study of institutional mechanisms currently existing in the ASEAN be examined to assess their potential for incorporation into the Industry 4.0 regional cooperation mechanism.

7. Concluding Remarks

This chapter attempts to examine the Industry 4.0 readiness of ASEAN member countries. Basic concepts of Industry 4.0 and IoT were initially examined to establish the context within which the analysis of Industry 4.0 readiness could be carried out. As part of the examination of the basic concepts, it was also shown through literature-based case studies how Industry 4.0 could contribute towards the creation of a circular economy.

A conceptual framework was then developed for assessing the Industry 4.0 readiness of the ASEAN nations and the Industry 4.0 Readiness Index (I4RI) was computed for each ASEAN nation (except Brunei Darussalam for which comparable data were not readily available). This was then used in conjunction with manufacturing output data and high-technology exports as a percentage of manufactured exports to map the level of Industry 4.0 readiness of each ASEAN nation. The mapping showed that the ASEAN countries could be grouped into four clusters. First, Singapore and Malaysia, with their high-technology export profile, could be considered as 'potential innovators for Industry 4.0'. Indonesia, the Philippines, and Thailand could be considered as 'efficiency seekers through Industry 4.0'. Viet Nam, due to its lower I4RI and low manufacturing output, could be a 'medium-term Industry 4.0 transitioner', while Cambodia, Lao PDR, and Myanmar may be considered as 'slow movers towards Industry 4.0'.

This finding showed that any action within ASEAN to promote Industry 4.0 must take into consideration the specific strengths and weaknesses of its member states from an Industry 4.0 perspective and not adopt a 'one size fits all' approach when formulating strategic initiatives. Further analysis based on an intellectual capital framework suggested that ASEAN nations could progress towards comprehensive Industry 4.0 transition through four levels:

- Strengthening production and maintenance capabilities and supply chain management.
- Partnering Industry 4.0 leaders in production and incremental innovation.
- Partnering Industry 4.0 leaders in architectural and modular innovation.
- Assuming Industry 4.0 leadership.

Interventions needed at both the corporate and government levels to move through these four levels were then identified.

Having identified the interventions needed, three major cooperation mechanisms for Industry 4.0 transformation in the ASEAN region were proposed. These are:

- South–South cooperation and triangular cooperation initiatives for accelerating Industry 4.0 transformation.
- Leveraging the ASEAN ICT Master Plan 2015, ASAPSMED 2016–2025, and APASTI 2016–2025 to create explicit action lines to enable the inclusive incorporation of ASEAN member states in Industry 4.0 transformation.
- Establishment of advanced Industry 4.0 training and business promotion centres by leading Industry 4.0 nations such as Germany and Japan.

The modalities for implementing these cooperation mechanisms need to be examined in the context of currently existing arrangements.

A major limitation of this study is that the entire analysis is based on published information. Discussions with ASEAN experts in the field of Industry 4.0 and visits to firms in the ASEAN region that have already commenced Industry 4.0 initiatives could have substantially strengthened the content. Also, the I4RI was computed using published data. While the analysis does provide a useful start, it may be useful to conduct a survey in the ASEAN region, along the lines of the Roland Berger (2015) study carried out in Europe, to obtain more accurate insights into the Industry 4.0 readiness of the ASEAN member countries.

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Appendix 1: Basic Requirements, Efficiency Enhancers, and Business Sophistication and Innovation Ratings of ASEAN Countries

Table 3(a). Basic Requirements Ratings

Country	Institutions	Infrastructure	Macroeconomic Environment	Health and Primary Education	Overall Rating
Australia	5.3	5.7	5.6	6.6	**5.8**
China	4.1	4.7	6.5	6.1	**5.4**
Germany	5.2	6.1	6.0	6.5	**6.0**
India	4.1	3.7	4.4	5.5	**4.4**
Japan	5.5	6.2	3.7	6.7	**5.5**
Republic of Korea	3.9	5.8	6.6	6.3	**5.7**
ASEAN Countries					
Cambodia	3.3	3.2	4.8	5.4	**4.2**
Indonesia	4.1	4.2	5.5	5.6	**4.8**
Lao PDR	3.9	3.2	4.7	5.4	**4.3**
Malaysia	5.1	5.5	5.4	6.3	**5.6**
Myanmar	2.9	2.1	4.2	4.6	**3.5**
Philippines	3.8	3.4	5.7	5.5	**4.6**
Singapore	6.0	6.5	6.2	6.7	**6.4**
Thailand	3.7	4.6	5.7	5.8	**4.9**
Viet Nam	3.7	3.8	4.7	5.9	**4.5**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.

The ratings are from 1 to 7, with 7 being the highest.

Brunei Darussalam is not included due to lack of data.

Source: Schwab, 2015.

Table 3(b). Efficiency Enhancers Ratings

Country	Higher Education and Training	Goods Market Efficiency	Labour Market Efficiency	Financial Market Develop ment	Technologi cal Readiness	Market Size	Overall Rating
Australia	5.8	4.8	4.5	5.4	5.6	5.1	**5.2**
China	4.3	4.4	4.5	4.1	3.7	7.0	**4.7**
Germany	5.6	4.9	4.6	4.7	6.0	6.0	**5.3**
India	3.9	4.2	3.9	4.1	2.7	6.4	**4.2**
Japan	5.4	5.2	4.8	4.7	5.7	6.1	**5.3**
Republic of Korea	5.4	4.8	4.1	3.6	5.5	5.6	**4.8**
ASEAN Countries							
Cambodia	2.8	4.2	4.5	3.9	3.0	3.0	**3.6**
Indonesia	4.5	4.4	3.7	4.2	3.5	5.7	**4.3**
Lao PDR	3.2	4.3	4.5	3.8	2.8	2.9	**3.6**
Malaysia	5.0	5.4	4.9	5.2	4.6	5.0	**5.0**
Myanmar	2.5	3.6	4.2	2.4	2.2	4.2	**3.2**
Philippines	4.5	4.2	4.1	4.2	3.9	4.9	**4.3**
Singapore	6.2	5.7	5.7	5.6	6.2	4.8	**5.7**
Thailand	4.6	4.7	4.2	4.4	4.2	5.2	**4.6**
Viet Nam	3.8	4.2	4.4	3.7	3.3	4.8	**4.0**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.
The ratings are from 1 to 7, with 7 being the highest.
Brunei Darussalam is not included due to lack of data

Source: Schwab, 2015.

Table 3(c). Innovation and Business Sophistication Ratings

Country	Business Sophistication	Innovation	Overall Rating
Australia	4.7	4.5	**4.6**
China	4.3	3.9	**4.1**
Germany	5.7	5.5	**5.6**
India	4.2	3.6	**3.9**
Japan	5.8	5.5	**5.7**
Republic of Korea	4.8	4.8	**4.8**
ASEAN Countries			
Cambodia	3.4	2.7	**3.0**
Indonesia	4.3	3.9	**4.1**
Lao PDR	3.7	3.0	**3.3**
Malaysia	5.3	4.8	**5.1**
Myanmar	2.9	2.5	**2.7**
Philippines	4.3	3.5	**3.9**
Singapore	5.1	5.2	**5.2**
Thailand	4.4	3.4	**3.9**
Viet Nam	3.6	3.2	**3.4**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.
Brunei Darussalam is not included due to lack of data.

Source: Schwab, 2015.

Table 4. Readiness Ratings

Country	Basic Requirements	Efficiency Enhancers	Business Sophistication and Innovation Factors	Readiness Rating 20-50-30
Australia	5.8	5.2	4.6	**5.1**
China	5.4	4.7	4.1	**4.7**
Germany	6.0	5.3	5.6	**5.5**
India	4.4	4.2	3.9	**4.2**
Japan	5.5	5.3	5.7	**5.5**
Republic of Korea	5.7	4.8	4.8	**5.0**
ASEAN Countries				
Cambodia	4.2	3.6	3.0	**3.5**
Indonesia	4.8	4.3	4.1	**4.3**
Lao PDR	4.3	3.6	3.3	**3.7**
Malaysia	5.6	5.0	5.1	**5.2**
Myanmar	3.5	3.2	2.7	**3.1**
Philippines	4.6	4.3	3.9	**4.2**
Singapore	6.4	5.7	5.2	**5.7**
Thailand	4.9	4.6	3.9	**4.5**
Viet Nam	4.5	4.0	3.4	**3.9**

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.
Brunei Darussalam is not included due to lack of data.

Source: Schwab, 2015.

Table 5. Profile of the Manufacturing Sector

Country	Manufacturing Output in 2014 (US$ billions)	High-Technology Exports as Percentage of Manufactured Exports
Australia	101.8	13.6
China	3,106.4	25.4
Germany	889.7	16.0
India	348.2	8.6
Japan	874.3	16.7
Republic of Korea	423.1	26.9
ASEAN Countries		
Cambodia	2.7	0.2
Indonesia	186.6	7.0
Lao PDR	1.1	-
Malaysia	77.8	43.9
Myanmar	4.5	-
Philippines	59.8	49.0
Singapore	55.4	47.2
Thailand	113.3	20.4
Viet Nam	31.7	26.9

ASEAN = Association of Southeast Asian Nations, Lao PDR = Lao People's Democratic Republic.
Brunei Darussalam is not included due to lack of data.

Source: The World Bank, 2016.