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POLICY BRIEF

THE DIGITALIZATION OF MANUFACTURING — IMPLICATIONS FOR DEVELOPING COUNTRIES

THE DIGITALIZATION OF MANUFACTURING-IMPLICATIONS FOR DEVELOPING COUNTRIES

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***Abstract**. This policy brief explores the social and technical drivers behind the ongoing process of digitalization of manufacturing, and the expected impact on current industry structures, business models, and opportunities for value creation and capture. Increased technological complexity and interdisciplinarity require countries to adopt a coordinated approach to information and communication technology (ICT) infrastructure, cyber security, and workforce development. The cases of the aviation and footwear industries are presented to illustrate how digitalization is changing existing industry practices in two very different manufacturing environments. Digital technologies present challenges and opportunities for developed and developing countries alike, and Indonesia is no exception. The policy brief concludes by suggesting that an appropriate digital implementation strategy for Indonesia is one that considers how best to employ new (and existing) digital technologies to enhance the country's existing sources of comparative advantage while recognizing sectoral differences.*

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KEY POINTS

- The global manufacturing landscape is being transformed by the convergence of technology trends in the physical, digital, and biological spaces. In particular, the convergence of digital technologies such as *cyber-physical systems*, *cloud computing, big data*, *artificial intelligence (AI)*, *machine learning*, and the *internet of things (IoT)*, among others, offers the potential to more effectively connect and integrate manufacturing systems.

- These families of digital technologies are enabling manufacturers to make factories more efficient, develop new products faster, make logistics operations more efficient, and adopt new disruptive business models. At the same time, digital technologies are allowing firms to respond to customer and societal demands such as greater personalization, higher safety, and improved energy and resource efficiency.

- Digitalization requires the development of a wide range of complementary technologies to generate, transmit, store, process, and analyse data. Networks of devices connected among them, and to the internet, are required to store and analyse the rapidly growing amounts of data. New hardware and software are needed to create such networks.

- While the impact of digitalization is expected to be crosscutting, the specific implications can vary widely from sector to sector. This policy brief illustrates this point with case studies in the aviation and footwear sectors, which were chosen because they represent sectors at distinct positions in the digitalization journey.

- For governments around the world, the digital transformation of manufacturing poses opportunities and challenges in key policy areas such as employment, productivity, competitiveness, and sustainability. Indonesia faces various policy challenges, including: identifying and addressing ICT infrastructure gaps, raising awareness of what digital technologies are and the possibilities they offer, supporting technology adoption by SMEs, and promoting R&D.

- Given the diversity of digital technologies and potential impacts, an appropriate digital implementation strategy requires effort to identify specific opportunities and challenges for different sectors. Since many digital technologies are already available, considering how best to employ them to further enhance the sources of comparative advantage in established sectors might be a good first step.

OVERVIEW OF DIGITAL MANUFACTURING

Convergence of the Physical and Digital Spaces

The global manufacturing landscape is being transformed by the convergence of technology trends in the physical, digital, and biological spaces. This convergence process is commonly known as Industry 4.0, or the Fourth Industrial Revolution. The combination of technology and market trends is expected to cause a shift in the current manufacturing paradigm, towards increased decentralization and flexibility.[1] In other words, products will increasingly be made on-demand, closer to the final consumer, and at much lower production volumes.

The development and combination of Industry 4.0 technologies promise to implement important changes in the manufacturing process along three dimensions:[2]

- the creation of "smart factories" where different machines can communicate to adapt to real-time changes in demand, increasing efficiency, and flexibility;[3]
- the real-time exchange of information among different manufacturing firms, helping to optimize global supply chains and logistics networks;[4] and
- improving the monitoring of a product along its entire life cycle, being able to predict when it will need maintenance, and allowing for a faster response when unexpected technical difficulties arise.[5]

Social and Institutional Drivers Behind the Transition to Digital Manufacturing

Technology changes are accompanied by global market trends, which may shape how the future of manufacturing looks. These trends are:[6]

- ageing of the workforce population, especially in high-income countries, which may reinforce the need for automation and highly skilled labour;
- increased demand for customized products, which forces companies to evaluate alternative means of production to capture additional market value;
- continued migration from rural to urban areas, which increases the need for technologies to improve public infrastructure and citizens' well-being; and
- increased public interest in promoting sustainability, which sees in Industry 4.0 technologies an opportunity to reduce the waste and environmental impact associated with international transportation networks.

The last decade has witnessed a revival in governments' interest in industrial policy, as there is increasing evidence that manufacturing increases innovation and economic growth.[7] As such, many governments are trying to adopt a policy for the development of national capabilities in Industry 4.0 technologies, with the hope of creating high-paid employment, attracting foreign direct investment, enhancing productivity, and creating new markets for products and services that do not yet exist (footnote 2). Digitalization also has the potential to rationalize the use of natural resources and therefore help achieve goals related to sustainability (footnote 7). The number of countries and research organizations contributing to technology innovation is also expected to increase (footnote 6). For developing countries, the digitalization of manufacturing may bring opportunities for leapfrogging some of the missing capabilities in traditional manufacturing, and adapting these emerging technologies to their particular needs, which often differ from the needs of the nations at the technological frontier.[8]

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[1] Y. Lu. 2017. Industry 4.0: A Survey on Technologies, Applications and Open Research Issues. *J. Ind. Inf. Integr*. 6. Pp. 1–10.

[2] E. O'Sullivan. 2016. *The Digitalisation of Manufacturing Economies.* Institute for Manufacturing, University of Cambridge.

[3] F. Shrouf, J. Ordieres and G. Miragliotta. 2014. *Smart Factories In Industry 4.0: A Review Of The Concept And Of Energy Management Approached In Production Based On The Internet Of Things Paradigm*. In 2014 IEEE International Conference on Industrial Engineering and Engineering Management. Pp. 697–701.

[4] D. Romero and F. Vernadat. 2016. Enterprise Information Systems State of the Art: Past, Present and Future Trends. *Comput. Ind.* 79. Pp. 3–13.

[5] J. Li, F. Tao, Y. Cheng, and L. Zhao. 2015. Big Data in Product Lifecycle Management. *Int. J. Adv. Manuf. Technol*. 81. Pp. 667–684.

[6] C. López-Gómez, D. Leal-Ayala, M. Palladino, and E. O'Sullivan. 2017. *Emerging Trends in Global Advanced Manufacturing: Challenges, Opportunities and Policy Responses*. United Nations Industrial Development Organization.

[7] K. Warwick. 2013. Beyond Industrial Policy: Emerging Issues and New Trends. *OECD Science, Technology and Industry Policy Papers, No. 2.* OECD Publishing, Paris.

[8] C. Dahlman, S. Mealy, and M. Wermelinger. 2016. Harnessing the Digital Economy for Developing Countries. *OECD Development Centre Working Papers, No. 334.* OECD Publishing, Paris,

Implementation Challenges

In an increasingly connected world, increased investment in ICT infrastructure is needed to ensure the reliability of industry communication networks.[9] In addition, the increased reliance on information technology brings significant concerns about the cyber security and reliability of industrial systems and utilities, which affects not only manufacturers but also their entire supply chain and customers.[10] Examples of areas of concern are as follows:

- Machines connected to a network might be cyber-attacked to be made inoperative at critical moments.
- Confidential information stored in the cloud might be disclosed to cause economic loss.
- Product designers may face important losses of intellectual property if communication channels are compromised.
- Digital manufacturing makes counterfeiting easier.
- Smart products may need to collect abundant data about their owners' behaviour to optimize their performance, which brings additional concerns about privacy, increasing consumers' resistance.[11]

Apart from cyber security, the other big challenge arising from the digitalization of manufacturing concerns workforce development.[12] A new generation of highly skilled workers is needed for the implementation of complex, interdisciplinary technology environments. In particular, demand for employees in computer and data sciences, mechanical and electrical engineering, and other STEM disciplines is expected to rise.[13] Existing low-skilled workers will probably need to be retrained periodically to work with a new generation of machines and respond to their potential downtimes, requiring a new mindset for lifelong learning. This problem might be exacerbated in small and medium-sized enterprises (SMEs), which represent a large share of the total employment in manufacturing, especially in traditional low- and mid-tech sectors. Small firms, when compared to large multinational corporations, have less capital to devote to labour retraining, they lack the time to perform technology surveillance activities, and in the worst cases they do not perform formal research and development (R&D) activities.[14]

To sum up, Industry 4.0 technologies may create important changes to how manufacturing is done, from product design to the aftermarket. While these changes may open up a myriad of opportunities for the creation of new businesses based on products and services that do not yet exist, the adoption of digital manufacturing technologies brings many technical and societal challenges. Hence, government efforts related to the digitalization of manufacturing should involve investment in more than just traditional mechanisms for research and innovation, such as the provision of R&D funding and tax credits. In particular, they should allocate significant resources to address market failures related to the increasing need for the coordination of a diverse pool of stakeholders, such as skills and workforce development, or the creation of reliable ICT infrastructure. Tackling these two issues requires the creation of plans to address cyber security concerns, building capacity at SMEs, developing compatibility standards, and ensuring IP rights.

[9] A. Varghese and D. Tandur. 2014. *Wireless Requirements and Challenges In Industry 4.0*. In 2014 International Conference on Contemporary Computing and Informatics (IC3I). Pp. 634–638.

[10] A. Sadeghi, C. Wachsmann, and M. Waidner. 2015. *Security and Privacy Challenges in Industrial Internet of Things.* In 2015 52nd ACM/EDAC/IEEE Design Automation Conference (DAC). Pp. 1–6.

[11] Z. Mani and I. Chouk. 2017. Drivers of Consumers' Resistance to Smart Products. *J. Mark. Manag*. 33. Pp. 76–97.

[12] N. E. Waldeck. 2000. *Advanced Manufacturing Technologies and Workforce Development*. Taylor & Francis.

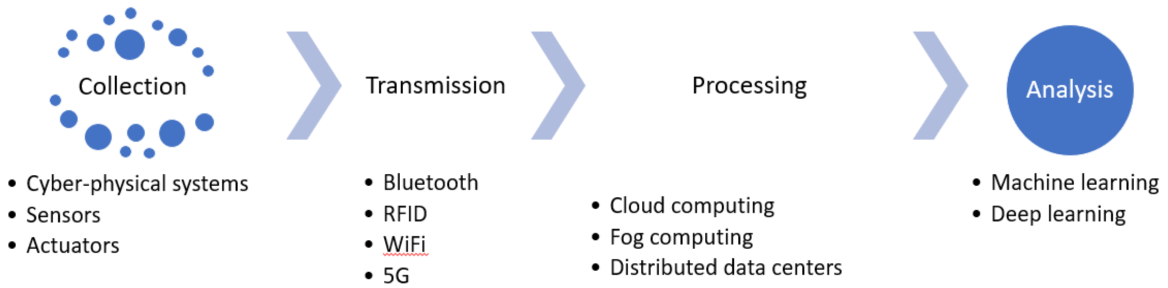
[13] J. Rothwell. 2013. The Hidden Stem Economy. Brookings Institution.

[14] R. Rajkumar, I. Lee, L. Sha, and J. Stankovic. 2010. *Cyber-Physical Systems: The Next Computing Revolution*. In Design Automation Conference. Pp. 731–736; P. Leitão, A. W. Colombo, and S. Karnouskos. 2016. Industrial Automation Based on Cyber-Physical Systems Technologies: Prototype Implementations and Challenges. *Comput. Ind.* 81. Pp. 11–25.

TECHNOLOGY TRENDS IN DIGITAL MANUFACTURING

For societies to take full advantage of the opportunities offered by the emerging manufacturing technologies, they need to be able to create networks of physical objects (devices, vehicles, buildings, equipment, etc.). These networks are commonly known as the internet of things, and, in the context of manufacturing, the industrial internet of things (IIoT), which incorporates automated production technologies.[15] Implementing IIoT requires the development of a wide range of different technologies and systems that allow improved generation, transmission, storage, processing, and application of the data (footnote 6), which are summarized in (Figure 1)

Figure 1: Summary of the Different Data Technologies That Need to Be Integrated to Create the Industrial Internet of Things



Source: Adapted from C. López-Gómez, D. Leal-Ayala, M. Palladino, and E. O'Sullivan. 2017. *Emerging Trends in Global Advanced Manufacturing: Challenges, Opportunities and Policy Responses*. United Nations Industrial Development Organization.

Data Collection

Generating data requires the creation of "cyber-physical systems", a combination of existing machinery with embedded hardware such as sensors, actuators, and control software, so that operations are supervised, coordinated, and optimized by a computer system.[16] Examples of these systems can be:

- machines equipped with sensors to check in real time the accuracy of their operations and a potential need for maintenance;
- industrial robots to manipulate the product along the production line;
- machines that can be monitored and operated remotely; and
- machines that learn from experience about how best to perform an operation.

Embedded sensors enable improved quality control, the reduction of process uncertainty, and better process modelling. The capability of sensors is expected to widen in scope in the near future, with the addition of wireless connectivity, real-time data analysis, and further integration with the physical systems to help in the calibration of equipment and health evaluation of the cyber-physical system.[17] However, there are still some limitations to the integration of these embedded systems. Major barriers are the difficulties processing the large amounts of data created in real time, concerns about cyber security, and the absence of external tools to validate software tools and offer system maintenance.[18] The cost of sensors and actuators is still high. Similarly, their size and power consumption need to be reduced to enable future miniaturization.[19]

Data Transmission

[15] S. Jeschke, C., Brecher, T. Meisen, D. Özdemir, and T. Eschert. 2017. Industrial Internet of Things and Cyber Manufacturing Systems. In S. Jeschke, C. Brecher, H. Song, and D. B. Rawat, eds. *Industrial Internet of Things: Cybermanufacturing Systems*. Springer International Publishing. Pp. 3–19.

[16] R. Rajkumar, I. Lee, L. Sha, and J. Stankovic. 2010. *Cyber-Physical Systems: The Next Computing Revolution*. In Design Automation Conference. Pp. 731–736.

[17] NSF. 2015. *Workshop on Research Needs in Advanced Sensors, Controls, Platforms, And Modelling (ASCPM) For Smart Manufacturing.*

[18] P. Leitão, A. W. Colombo, and S. Karnouskos. 2016. Industrial Automation Based on Cyber-Physical Systems Technologies: Prototype Implementations and Challenges. *Comput. Ind.* 81. Pp. 11–25.

[19] NSF. 2015. Workshop on Advanced Manufacturing for Smart Goods.

Data collected by the cyber-physical systems may need to be transmitted to other pieces of equipment, which can be either inside or outside (e.g. suppliers, consumers, maintenance facilities) the factory. This communication is usually performed through wireless networks. The most widely used wireless transmission technologies are:

- RFID and Bluetooth, when the distance to cover and amount of data are small;[20]
- WiFi and Wimax, cheap options for high-speed communication over short distances;[21]
- mobile platforms, for long distances (the next generation of mobile communication technology, 5G, is expected to offer speeds that are up to 1,000 times faster than the current 4G networks with ultra-low latency);[22]
- non-IP network protocols such as NetBEUI, AppleTalk, and IPX, which might allow the connection of devices within one organization without exposing it to the risks associated with being connected to the internet.[23]

These transmission technologies, when combined with the latest internet protocol, Ipv6, create the opportunity to monitor and reconfigure the manufacturing floor at any time, from a distance, although concerns about the reliability of such wireless networks remain unsolved.[24] In addition, the community lacks the public standards, protocols, and interfaces needed to ensure the universal compatibility of any device and allow the integration of different types of cyber-physical systems across the entire supply chain.[25]

Data Processing

The large-scale deployment of cyber-physical systems will result in the growth of data volume and traffic, something that is often referred to as big data. Although there is no standard definition of big data, there are five characteristics that usually define big data:[26]

- large volume of data,
- variety of types of data to store,
- high speed of data generation,
- large commercial value of data generated, and
- the veracity of the data can be checked.

Traditional information technology infrastructure and methods for data management and analysis are unfit for the rapid growth of big data, as they are usually limited in their ability to process data and verify its correctness, and they cannot easily be scaled.[27] To meet the stringent demands of big data, new technology developments are required, such as the creation of larger, more efficient data centres and applications to process and analyse the data; the implementation of data tools to clean, validate, and filter the incoming data; distributed data storage centres to handle the large amounts of data; and appropriate human–machine interfaces to facilitate visualization of the most important aspects of the data (footnote 25).

To date, industry has tackled these issues through cloud computing, which has experienced a market explosion in recent years. Cloud computing can be defined as using, remotely and on-demand, a pool of computing resources hosted on the internet, to store, manage, and process data with little interaction with the service provider.[28] A market forecast by Gartner predicts that the revenue from public cloud services will almost double between 2017 and 2021.[29] Private cloud services, which offer higher privacy levels, are also offered for use by a single enterprise. However, technical challenges remain in relation to handling the amount of data that the IIoT will produce. Cloud computing is expected to evolve into “fog computing”, which allows the cloud to communicate with local devices such as routers, multiplexers, or local area networks, which may provide support to store, transmit, and analyse the data before sending them to the internet.[30]

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[20] Z. Bi, L. D. Xu, and C. Wang. 2014. Internet of Things for Enterprise Systems of Modern Manufacturing. *IEEE Trans. Ind. Inform.* 10. Pp. 1537–1546.
[21] Ibid.
[22] Q. Wu, G. Y. Li, W. Chen, D. W. K. Ng, and R. Schober. 2017. An Overview of Sustainable Green 5G Networks. *IEEE Wirel. Commun*. 24. Pp. 72–80.
[23] E. D. Zwicky and B. Chapman. 1995. *Building Internet Firewalls*. O’Reilly Media.
[24] D. Dujovne, T. Watteyne, X. Vilajosana, and P. Thubert. 2014. 6TiSCH: Deterministic IP-Enabled Industrial Internet (Of Things*). IEEE Commun. Mag.* 52. Pp. 36–41.
[25] W. Tian and Y. Zhao. 2014. *Optimized Cloud Resource Management and Scheduling: Theories and Practices*. Morgan Kaufmann.
[26] K. Gordon. 2013. What is Big Data? *ITNOW 55*. Pp. 12–13.
[27] European Commission. 2010. *Factories of The Future PPP: Strategic Multi-Annual Roadmap*. Publications Office.
[28] P. Mell and T. Grance. 2011. *The NIST Definition of Cloud Computing* 7.
[29] Gartner. 2018. *Gartner Forecasts Worldwide Public Cloud Revenue to Grow 21.4 Percent in 2018.*
[30] A. V. Dastjerdi and R. Buyya. 2016. Fog Computing: Helping the Internet of Things Realize Its Potential. *Computer.* 49. Pp. 112–116.

Data Analysis

Analysis of the data stored and generated by the IIoT is, because of their size and complexity, only feasible with the use of artificial intelligence (AI).[31] AI refers to computer systems that are able to perform tasks such as visual perception, speech recognition, and decision-making that have traditionally required human intervention, or which have been impossible to perform.[32] Some of these problems might not have a right or wrong answer and the appropriate outcome may depend on firms' preferences.[33] In a manufacturing environment, AI applications include:[34]

- machine vision tools to detect, as they are produced, microdefects that would go unnoticed by the human eye;
- optimization of new product designs according to the materials, available process, and cost targets;
- prediction of problems on the shop floor to avoid factory downtimes; and
- prediction of the best time to perform maintenance of the production equipment.

However, several barriers to the further implementation of AI remain, namely, the technical complexity of the field, the lack of skilled labour to apply AI to manufacturing problems, the lack of high-quality data, and the difficulties ensuring that the AI is performing the tasks as desired and diagnosing the source of failure.[35]

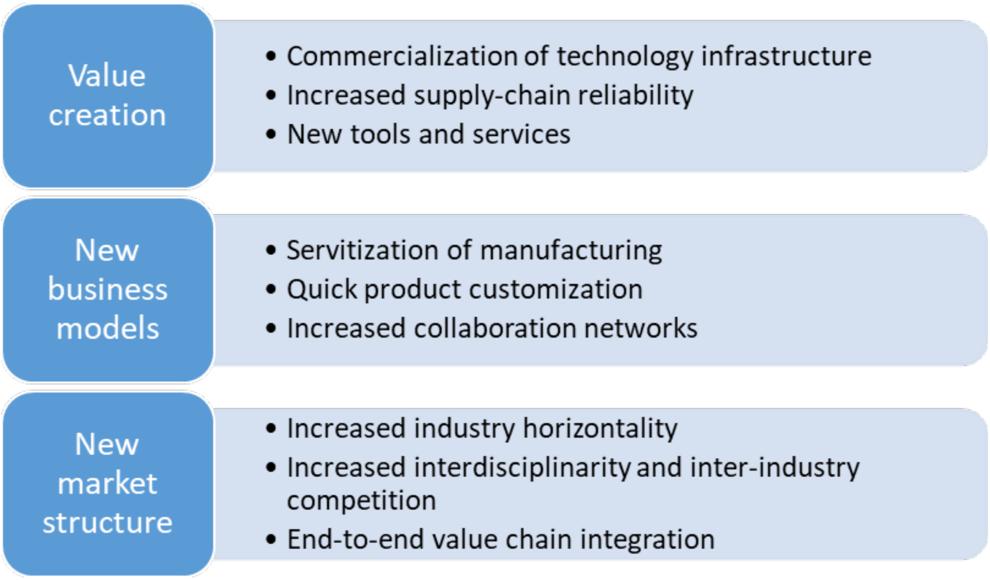
Expected Impact of Technology Trends on Businesses

The diversity and complexity of all the technologies involved in the digitalization of manufacturing opens up many opportunities for value creation, novel business models, and emerging market structures.

A group of firms may want to commercialize key technology components such as electronic devices, software, and cloud services. Industry adopters of these digital technologies may increase their competitiveness by improving the responsiveness, reliability, and overall efficiency of their supply chain, while being able to offer new products customized to the particular needs of their clients. Other firms may capture value from selling tools or services that do not yet exist.

[31] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami. 2013. Internet of Things (IoT): A Vision, Architectural Elements, and Future Directions. *Future Gener. Comput. Syst*. 29. Pp. 1645–1660.
[32] S. Russell and P. Norvig. 1998. Artificial Intelligence: A Modern Approach. Pearson; M. Copeland. 2016. The Difference Between AI, Machine Learning, and Deep Learning? *The Official NVIDIA Blog.*
[33] I. Salian. 2018. Supervised Vs. Unsupervised Learning. *The Official NVIDIA Blog*.
[34] Forbes. 2018. *How AI Builds A Better Manufacturing Process.*
[35] The Royal Society. 2015. *Machine learning*. Conference Report.

Figure 2: Expected Impact of Digital Manufacturing on Business Operations



Source: Author's elaboration

Manufacturing is increasingly seen as a service, where local shops may respond, on demand, to the requirements and taste of each customer. In addition, businesses can collaborate in new ways to share equipment and optimize their production capacity, scheduling, and response to supply chain disruptions. Within these networks, a manufacturer may use the resources of another member of the network to perform activities for which it may have not developed capabilities, such as running software simulations or creating a new product design. Consumer goods industries where customization is more valued, such as shoes, jewellery, or furniture, and industries that make the tools to make them (e.g. moulds or casts), are likely to be the most sensitive to these changes. However, it is still unclear whether this demand for higher customization will become widespread or remain concentrated in a small segment of the market.

New business models based on analysis of the data gathered by the IIoT are likely to appear. This could, for instance, reduce the waiting time in the maintenance and repair segment. Similarly, manufacturers of industrial equipment would be able to predict when a certain machine will require maintenance, providing them with incentives to switch their focus from the sale of machinery towards its lease, which is already happening with equipment such as machine tools or jet engines. Moreover, digital technologies facilitate the implementation of business models based on the concept of circular economy,[36] helping to reduce material and energy usage in the production process, reduce inventory, inform "repair or buy" decisions, and improve the logistics of waste management.

Finally, the adoption of flexible manufacturing technologies creates opportunities for new entrants who may decide to serve different market segments as a way to reach economies of scale, potentially increasing price competition.[37] Collaborative business models may incentivize the introduction of horizontal business structures where tasks have traditionally been separated. The technical base and skills required to serve each industry may become less differentiated, as the new workforce may become increasingly interdisciplinary and more frequently retrained. As the preferences of customers are prevalent in a market of customized goods, businesses need to find ways to integrate their entire value chain, from initial design to aftermarket, so that they can respond quickly to changes in demand.
In the following boxes, examples are provided of how digital technologies are transforming manufacturing industries. The case studies are from the aviation and the shoe industries. The cases were chosen to represent two very distinct technology contexts. The aviation industry produces high-value products, and although current capabilities in Indonesia are limited, it represents a natural evolution for a country with a large pool of suppliers in complementary industries such as automotive, following the examples of countries such as South Korea, Malaysia, or Portugal, and driven by a strong growth in air traffic demand. In fact, the maintenance,

[36] W. R. Stahel. 2016. The Circular Economy. *Nat. News.* 531. P. 435.
[37] C. Weller, R. Kleer, and F. T. Piller. 2015. Economic Implications of 3D Printing: Market Structure Models in Light of Additive Manufacturing Revisited. *Int. J. Prod. Econ*. 164. Pp. 43–56.

repair, and operations (MRO) industry has called Indonesia "one of Asia's MRO Hotspots".[38] In contrast, the shoe industry is a traditional industry where products typically have much lower value, but they represent an important source of revenue for the Indonesian economy.

Box 1: Case Study – Supporting the Rise of the Aviation Industry in Southeast Asia

A forecast by the International Air Transport Association (IATA) suggests that world air traffic could double between 2016 and 2036, driven by increasing demand in Southeast Asia.[a] In this forecast, IATA predicts that domestic air traffic in Indonesia could almost triple and reach a total of more than 350 million passengers per year in 2036.[b] This increase in air traffic should translate to an increase in market demand for maintenance, repair, and operations (MRO), which could become an engine of growth for the Indonesian manufacturing sector.

Increased Importance of Additive Manufacturing in Aviation

One of the technologies that is expected to lead performance improvements in aviation is additive manufacturing. Additive manufacturing (AM) is a family of near net shape manufacturing processes whereby digitally created three-dimensional objects can be built up by depositing material layer by layer. Different AM techniques allow for the use of an increasing variety of materials, including polymers, metals, ceramics, and even composites.[c] AM allows for the creation of complex geometries that would be hard to build using traditional manufacturing processes. AM can be used by designers to reduce the weight of components, which translates into important fuel savings and lower emissions, or to increase manufacturing flexibility and reduce lead time.[d] In addition, using AM may save assembly costs by integrating different components. For instance, GE redesigned a fuel nozzle by integrating approximately twenty different parts into a single one, which reduced weight, improved the efficiency of the engine, and increased the power supplied by the engine by 10%.[e] The complexity and criticality of the components manufactured with AM are also increasing, and in 2018 GE started to test its application for turbine blades.[f] Airbus, meanwhile, is making more than a thousand components of its newest aircraft A350 with AM, mostly polymers.[g]

Additive Manufacturing (AM)

Additive manufacturing is a family of processes which can produce a component, layer-by-layer, from a digital design. Available materials include an increasing variety of polymers, metals and ceramics

Advantages:
- Very complex geometries
- Less material waste
- More durable parts
- Manufacturing flexibility
- Shorter lead times

Applications in aviation:
- Aircraft interiors
- Non-structural supports
- Ducts
- Combustors
- Rapid tooling

Digital needs for AM:
- User-friendly design tools
- Reduce manual intervention
- Real-time in-built sensors
- Damage evaluation
- Encrypted communication

Despite the potential advantages of using AM, important challenges remain regarding its implementation.[h] Most importantly, AM materials and products need to undergo extensive qualification programmes to prove that AM products are safe to use, as databases with publicly available information about material properties do not exist, and the performance of the products under real-life conditions is uncertain.[i] As such, companies need to perform lengthy and expensive R&D programmes to control potential variability in their production configuration. AM products are usually subject to multiple post-processing steps, and overall there are more than a hundred parameters that need to be controlled to ensure that the product is consistent. Related to this issue, there is a lack of appropriate non-destructive testing techniques that would allow manufacturers to know whether a part is good or not, quickly and inexpensively. In addition, there is an undersupply of skilled labour to work with these technologies, creating an important barrier to entry for new players.

All these technical and contextual limitations have contributed to creating a fear within the aviation industry that the misuse of AM technology could lead to the production of components that perform adequately in a one-off test but do not conform to the original specifications, in terms of longevity.[l] It is still unclear how manufacturers of aircraft and engines may introduce AM in their supply chains, and how aviation authorities will regulate the market for spare parts and repairs. Firms entering the aviation market often establish strategic partnerships with original equipment manufacturers (OEMs). A noteworthy example is Norsk Titanium, a Norwegian company that developed its own AM machine, which was recently qualified by Boeing to produce titanium components for the B787 aircraft.[m]

Overcoming Implementation Challenges Through Further Digitalization

The further integration of digital technologies into AM systems is expected to overcome some of the aforementioned challenges. Machine learning algorithms may accelerate R&D efforts to optimize the production parameters to build a certain component, saving considerable amounts of time and financial resources devoted

[38] MRO Network. 2017. Indonesia Emerges As One Of Asia's MRO Hotspots. https://www.mro-network.com/airframes/indonesia-emerges-one-asia-s-mro-hotspots.

to testing and data collection.[n] In addition, the introduction of sensors in machines, which allow the real-time monitoring of the production process, may help to decrease variability in the properties of AM components and the need for testing after production.[o] The first machines with embedded sensors and software tools to analyse their data output are already being commercialized. These embedded systems could then be integrated into the IIoT through the creation of wireless networks and cloud computing infrastructure to minimize the response time.[p] Some manufacturers of AM equipment have recently commercialized machines that combine the fabrication of the component with AM, and tools for its post-processing, which reduces the need for human intervention and speeds up the manufacturing process, making it more suitable for mass production.[q] To solve the issues related to training, the European Union has funded several initiatives to create frameworks for workforce development in the field of AM.[r] In the US, higher education institutions have already introduced AM-related courses in their engineering degrees.

[a] IATA. 2017. 2036 Forecast Reveals Air Passengers Will Nearly Double to $7.8 Billion.
[b] Ibid.
[c] W. E. Frazier. 2014. Metal Additive Manufacturing: A Review. *J. Mater. Eng. Perform*. 23. Pp. 1917–1928.
[d] R. Huang, M. Riddle, D. Graziano, J. Warren, S. Das, S. Nimbalkar, J. Cresko, and E. Masanet, 2016. Energy And Emissions Saving Potential of Additive Manufacturing: The Case of Lightweight Aircraft Components. *Journal of Cleaner Production.* 135. Pp. 1559–1570,
[e] T. Kellner. 2017. How 3D Printing Will Change Manufacturing. GE Reports.
[f] T. Kellner. 2018. The Blade Runners: This Factory is 3D Printing Turbine Parts For The World's Largest Jet Engine. GE Reports.
[g] D. Simmons. 2015. Plane Has 1,000 3D Printed Parts. BBC News.
[h] J. Bonnín Roca, P. Vaishnav, J. Mendonça, and G. Morgan. 2017. Getting Past the Hype About 3-D Printing. *MIT Sloan Manag. Rev. Camb*. 58. Pp. 57–62.
[i] J. Bonnín Roca, P. Vaishnav, E. R. H. Fuchs, and M. G. Morgan. 2016. Policy Needed For Additive Manufacturing. *Nat. Mater*. 15. Pp. 815–818.
[l] J. Bonnín Roca, P. Vaishnav, M. G. Morgan, J. Mendonça, and E. Fuchs. 2017. When risks cannot be seen: Regulating uncertainty in emerging technologies. *Res. Policy* 46. Pp. 1215–1233.
[m] J. Wynbrandt. 2018. Norsk Earns Boeing Approval for Titanium Parts. Aviation International News.
[n] B. Kappes, S. Moorthy, D. Drake, H. Geerlings, and A. Stebner. 2018. Machine Learning to Optimize Additive Manufacturing Parameters for Laser Powder Bed Fusion of Inconel 718. In E. Ott et al., eds. Proceedings of the 9th International Symposium on Superalloy 718 & Derivatives: Energy, Aerospace, and Industrial Applications. Springer International Publishing. Pp. 595–610.
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[r] E. G. Assunçao, E. R. Silva, and E. Pei. 2019. Professional Training of AM at the European Level. In E. Pei, M. Monzón, and A. Bernard, eds. Additive Manufacturing – Developments in Training and Education. Springer International Publishing. Pp. 211–217.

Box 2: Case Study – The Digitalization of the Footwear Industry: Increased Automation and Simulation

Although it might seem that the digitalization of manufacturing is led by applications in high-tech industries, Industry 4.0 technologies are increasingly being applied to traditional sectors, where developing countries have built capabilities for mass production, as they have the advantage of much lower labour costs than high-income countries. One of these traditional industries is the footwear industry, where much of the world's demand is manufactured in countries such as Vietnam, China, or Indonesia. According to the United Nations' Comtrade database, in 2016 Indonesia's exports of leather, textile, and rubber footwear accounted for more than $6 billion. More than three-quarters of those exports were destined for high-income countries. However, the size of these exports might change, as leading brands such as Nike and Adidas are investing heavily in automating their manufacturing processes and relocating part of their production closer to their customers in Europe and North America, which would allow for higher product customization and shorter lead times.[a]

The Case of Adidas' Speedfactory

One of the most advertised corporate investments in the digitalization of manufacturing involves Adidas. In late 2015 Adidas opened a new type of factory in Germany, the Speedfactory, to increase the level of automation in shoe manufacturing, and to implement digital technologies along all stages of production, from conceptual design to production.[b] In 2017 a new Speedfactory opened in Atlanta, the United States.[c] The factories are expected to jointly produce a million pairs of shoes annually by 2020, mostly for limited-series and customized shoes adapted for the needs of each client.[d] This is still a small fraction of Adidas' annual production, which surpassed 400 million pairs of shoes in 2017 but is expected to increase in the future.[e]
To speed up the development process and shorten the lead time, the design process is done digitally with three-dimensional modelling and rapid prototyping tools, and the factory has developed a "digital twin", a virtual model to simulate the production conditions for the newly designed shoes.[f] New materials are created inside the factory

from raw plastic pellets, and the introduction of robotic arms has allowed Adidas to combine manufacturing and assembly operations into a single step, making the production process much more efficient, to the point that they can produce customized products at a price that is competitive with the specialized shoe market.[g] In 2018 Adidas started the commercialization of customized shoes using additive manufacturing, with the goal of producing hundreds of thousands of pairs with this technology in the coming years.[h]
The adoption of all these technologies brings several advantages to the German company. It decreases logistics risks, as producing shoes closer to customers makes the supply chain less sensitive to disruptions. The adoption of digital technologies has helped drive down the time between order and delivery from months to days.[i] Production batches have been reduced from tens of thousands to hundreds, which facilitates the control of inventory and increases the flexibility to react to sudden changes in product demand.[l] Furthermore, data from custom orders can be used to analyse which features are demanded the most and to incorporate them into their future mass-produced series, which has the potential to increase revenue.[m]

Potential Impact on Developing Countries

The direct impact of these investments on the production capacity in developing countries is still unclear. So far, Adidas' investments in the Speedfactory are seen as a complement, instead of a competitor, to existing capabilities in developing countries.[n] Production costs are still high, to be able to sell to the mass market, although future advances may bring costs down. Footwear suppliers in developing countries such as Vietnam have already started to invest in automation technologies, to be able to cope with increasingly stringent quality standards, rising wages, and shortened lead times.[o] The introduction of robots on the shop floor may reduce the need for low-wage workers, but human intervention is still needed for tasks that are hard to automate, such as shoe-lacing.[p] In addition, newly trained, highly skilled employees will be needed to configure the production equipment and perform troubleshooting operations.

[a] M. Bain. 2017. *A Revolution Is Coming In The Way Your Sneakers Are Designed And Manufactured*. Quartz.
[b] A. Wiener. 2017. *Inside Adidas' Robot-Powered, On-Demand Sneaker Factory*. Wired.
[c] Reuters. 2016. *Adidas to Open Shoe Factory In Atlanta In 2017*. Reuters.
[d] D. Green. 2018. Adidas Just Opened A Futuristic New Factory – And It Will Dramatically Change How Shoes Are Sold. *Business Insider*.
[e] Ibid.
[f] *The Economist*. 2017. *Adidas's High-Tech Factory Brings Production Back to Germany*.
[g] R. Manthorpe. 2017. *To Make A New Kind of Shoe, Adidas Had To Change Everything*. Wired UK.
[h] B. Heater. 2018. *Adidas Joins Carbon's Board as Its 3D Printed Shoes Finally Drop*. TechCrunch.
[i] M. A. Bain. 2017. *German Company Built a "Speedfactory" To Produce Sneakers in The Most Efficient Way*. Quartz.
[l] S. Pandolph. 2017. Adidas uses Speedfactory to localize shoe designs. *Business Insider*.
[m] M. S. Sodhi and C. S. Tang. 2017. Supply Chains Built for Speed and Customization. *MIT Sloan Management Review*.
[n] *The Economist*. 2017. Adidas's High-Tech Factory Brings Production Back to Germany.
[o] J. Hofer. 2018. Robots transforming Asian Adidas suppliers. *Handelsblatt Global Edition*.
[p] M. Bain. 2017. *One Very Basic Job In Sneaker Manufacturing Is Testing the Limits of Automation*. Quartz.

IMPLICATIONS FOR DEVELOPING COUNTRIES

For governments around the world, the digital transformation of manufacturing poses opportunities and challenges in key policy areas such as employment, productivity, competitiveness, and sustainability. The ongoing process of manufacturing digitalization is expected to have a crosscutting effect in manufacturing, with implications for firms across sectors and levels of technological sophistication. This is because technologies underpinning the digitalization of manufacturing are highly diverse in nature and applicability. Digitalization is permeating many different sectors simultaneously.

Thus far, however, there is significant uncertainty about the size and shape of the impact across sectors. Much of the available evidence is anecdotal, and most policy efforts and advice have focused on high-income countries.

Nonetheless, analysts agree that the digitalization of manufacturing can represent an opportunity to foster economic growth in countries such as Indonesia.[39] However, responses accounting for the country's particular context are required.

Interestingly, evidence suggests that developing countries can maintain a competitive position by performing strategic incremental improvements to existing production methods, even when developing countries adopt

[39] A. V. Bogoviz, V. S. Osipov, M. K. Chistyakova, and M. Y. Borisov. 2019. Comparative Analysis of Formation of Industry 4.0 in Developed and Developing Countries. In E. G. Popkova, Y. V. Ragulina, and A. V. Bogoviz, eds. *Industry 4.0: Industrial Revolution of the 21st Century*. Springer International Publishing. Pp. 155–164.

emerging technologies, given the differences in labour costs and other production inputs.[40] Macroeconomic data suggest that Indonesian productivity is lower than that of its regional competitors; and digital technologies could help to accelerate the improvement of management practices.[41]

The level of penetration of ICT technologies in Indonesia is lower than in other ASEAN countries, and thus additional resources might be needed to ensure that the existing “digital divides” are progressively closed.[42] This is likely to be a slow process that requires long-term commitments to infrastructure investment. Overall, Indonesia faces various policy challenges, including: identifying and addressing ICT infrastructure gaps; raising awareness of what digital technologies are, and the possibilities they offer; supporting technology adoption by SMEs; and promoting R&D.

While existing trends towards globalization and the liberalization of trade in key specific sectors might benefit the process of international technology diffusion, achieving the successful diffusion of those technologies requires fostering indigenous innovation efforts and governance structures.[43] Public efforts are needed to develop appropriate institutions and mechanisms for the acquisition of technology; platforms for knowledge exchange between foreign and local companies; comprehensive workforce development programmes; and incentives for local companies to increase their engagement in R&D and innovation.

Developments in firms in high-income countries may require those in developing countries to adopt new digital technologies, in order to keep their systems compatible with those of their international partners. A failure to promote the diffusion of digital technologies might therefore affect international competitiveness, exports, and opportunities for diversification. As digital technologies evolve rapidly, it is important for Indonesia that long-term investment plans are periodically revised to incorporate the latest information about technology trends and forecasts.

A common option to promote international technology diffusion is foreign direct investment (FDI), as multinational enterprises may import advanced technologies and equipment, offer training to local employees and suppliers, and incentivize competition among local firms.[44] For those positive effects to take place, it is important that laws and rules concerning trade and intellectual property rights create a favourable environment for foreign firms to bring core technology.[45] However, foreign firms might lack incentives to share the technology, and technology spillovers to local firms might be low, even when FDI may appear to have a positive impact on employment and economic growth.[46]

Larger firms might have an important enabling role, by providing support to smaller local enterprises with limited knowledge of digital technologies and scarce resources to invest in them. Indonesia’s state-owned enterprises, which represent a significant part of Indonesia’s economy, might also have a role to play. Financial incentives for large firms could be combined with incentives towards entrepreneurship such as dedicated venture capital pools or financial incentives to high-tech firms.[47]

Although the wider application of digital technologies increases the number of opportunities for value creation, trying to tackle the needs of all the sectors at the same time might be “spreading too thin” and diluting the already scarce financial resources of developing countries. Hence, it would seem advisable, first, to focus on those sectors and applications where a country holds a position of global competitiveness, and, once those initial efforts start to bear fruit, to start developing inter-industry linkages to increase knowledge spillovers across sectors.

[40] E. Fuchs and R. Kirchain. 2013. Design for Location? The Impact of Manufacturing Offshore on Technology Competitiveness in the Optoelectronics Industry. *Manag. Sci*. 56. Pp. 2323–2349.

[41] N. Bloom, A. Mahajan, D. McKenzie, and J. Roberts. 2010. Why Do Firms in Developing Countries Have Low Productivity? *Am. Econ. Rev.* 100. Pp. 619–623.

[42] McKinsey. 2016. Unlocking Indonesia’s Digital Opportunity; L. Puspitasari and K. Ishii. 2016. Digital divides and mobile Internet in Indonesia: Impact of smartphones. *Telemat. Inform.* 33. Pp. 472–483.

[43] X. Fu, C., Pietrobelli, and L. Soete, L. 2011. The Role of Foreign Technology and Indigenous Innovation in the Emerging Economies: Technological Change and Catching-up. *World Dev*. 39. Pp. 1204–1212.

[44] P. J. Buckley and F. Ruane. 2006. Foreign Direct Investment in Ireland: Policy Implications for Emerging Economies. *World Econ.* 29. Pp. 1611–1628.; J. E. Haskel, S. C. Pereira, and M. J. Slaughter. 2007. Does Inward Foreign Direct Investment Boost the Productivity of Domestic Firms? *Rev. Econ. Stat*. 89. Pp. 482–496.

[45] B. J. Aitken and A. E. Harrison. 1999. Do Domestic Firms Benefit from Direct Foreign Investment? Evidence from Venezuela. *Am. Econ. Rev*. 89. Pp. 605–618.

[46] A, Reis, M. Heitor, M. Amaral, and J. Mendonça. 2016. Revisiting industrial policy: Lessons learned from the establishment of an automotive OEM in Portugal. *Technol. Forecast. Soc. Change*.

[47] D. Breznitz. 2007. *Innovation and the State: Political Choice and Strategies for Growth in Israel, Taiwan, and Ireland.* Yale University Press.

Given the diversity of digital technologies and potential impacts, an appropriate digital implementation strategy requires efforts to identify specific opportunities and challenges for different sectors. Since many digital technologies are already available, considering how best to employ them to further enhance the sources of comparative advantage in established sectors might be a good first step.