UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Absorbing Advanced Digital Production Technologies to Foster Industrialization

Evidence from Case Studies in Developing Countries

INCLUSIVE AND SUSTAINABLE INDUSTRIAL DEVELOPMENT

For reference and citation, please use: United Nations Industrial Development Organization, 2019. *Absorbing Advanced Digital Production Technologies to Foster Industrialization Evidence from Case Studies in Developing Countries*. Background document prepared for the Industrial Development Report 2020. Vienna: United Nations Industrial Development Organization. Vienna.

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Acknowledgements

This document has been prepared by Elisa Calza, UNIDO consultant, and Smeeta Fokeer, UNIDO staff member, under the general guidance of Cecilia Ugaz Estrada, Director of the Policy, Research and Statistics Department, as background material for the Industrial Development Report (IDR) 2020 “Industrializing in the digital age.”

The document compiles and analyses a number of firm- and policy-level case studies collected to support the preparation of the IDR 2020. Profound appreciation goes to Ciyong Zou and to the UNIDO staff from the field offices who have made the data collection process possible, namely: Manuel Albaladejo, Nadia Aftab, Ralf Bredel, Sooksiri Chamsuk, Stein Hansen, Hanan Hanzaz, Muhammad Hammad Bashir Saeed, Lina Touri, René van Berkel, Rajeev Vijh and Süleyman Yilmaz.

The fieldwork was supported by Valeria Cantera, Nurshat Karabashov, Sebastián Pérez, Nidhi Sharma, Hongfei Yue and Azhar Zia-ur-Rehman. We are also thankful to the following institutions, which facilitated the collection of data in some of the case study countries: the Ministry of Industry and Information Technology from China, the Ministry of International Trade and Industry from Malaysia, the Turkish Industry and Business Association (TUSIAD) and the Chamber of Industries of Uruguay (CIU). Special thanks go to the firms that agreed to provide information about their experiences, making the realization of the firm-level studies possible.

UNIDO staff members Alejandro Lavopa and Fernando Santiago Rodríguez provided insightful comments on various drafts of the document. Niki Rodousakis, also UNIDO staff member, provided editorial assistance in finalizing the manuscript for publication, and Iguaraya Saavedra provided administrative support.

Part I
ADP technologies and inclusive and sustainable industrial development

Introduction

Several waves of technological advancements have reshaped the manufacturing industry since the first industrial revolution (1IR). Today, advanced digital production (ADP) technologies—artificial intelligence, big data analytics, cloud computing, Internet of Things (IoT), advanced robotics and additive manufacturing, among others—represent the latest wave of breakthroughs in production technologies.[1] These technologies have the capacity to profoundly transform production and redefine the future of manufacturing. Yet, the implications of these technological breakthroughs on industrial development are still relatively obscure, in particular for developing and emerging industrial economies.

This publication seeks to shed new light on this issue by presenting original qualitative evidence on the current engagement of developing countries with ADP technologies. It offers an original analysis of how these technologies can contribute to inclusive and sustainable industrial development (ISID) and which conditions need to be in place to exploit their potential. To do so, it takes a double-level perspective. First, it considers the experience of some technologically advanced firms in developing countries, examining the extent to which these actors have adopted ADP technologies in their operations and the impact such adoption has on their performance along several dimensions. Second, taking the main challenges associated with the absorption of ADP technologies into consideration, it looks at country-specific policy initiatives oriented towards supporting this process.

The structure of this publication reflects this double-level approach. After defining the technological domain associated with the application of ADP technologies in manufacturing, the following section introduces the main themes and threads that constitute the backbone as well as the focus of the analysis. These new technologies have multi-dimensional implications, corresponding to the ISID dimensions in terms of the firm's activity and performance: *competitiveness, environmental sustainability and social inclusiveness*. The policy initiatives that need to be taken to adapt ADP to ISID include: *setting framework conditions, fostering demand and building capabilities*. Part II contains the collection of all case studies. Firm-level case studies are presented by impact dimension; the case studies that focus on policy initiatives by area of policy action.

1 See UNIDO (2019).

Main themes

Technological focus

The technological focus corresponds to the latest wave of production technologies applied to manufacturing, ADP technologies. Following the definition proposed by the Industrial Development Report (IDR) 2020 (UNIDO 2019), ADP technologies embody the latest development of digital production technologies, which belong to one of the technological domains associated with the fourth industrial revolution (4IR), together with nanotechnology, biotechnology and new and improved materials. ADP technologies include industrial Internet of Things (IoT), big data analytics, artificial intelligence and additive manufacturing, among others (Table 1).

Table 1 ADP technologies

Advanced digital production technologies	
Industrial Internet of Things (IoT)	IoT represents the next iteration of the internet, where information and data are no longer predominantly generated and processed by humans—which has been the case for most of the data created so far—but by a network of interconnected smart objects, embedded in sensors and miniaturized computers that are able to 'sense' their environment, process data and engage in machine-to-machine communication. The term refers to the interconnection of the internet's network of devices, machinery and objects, uniquely addressable based on standard communication protocols (UNIDO 2017c).
Big data analytics	Big data are characterized by a higher volume (i.e. a vast amount of data), higher velocity (i.e. frequency or speed by which data is generated, becomes available and changes over time), larger variety (i.e. different sources and formats of complex data, either unstructured or structured), and larger granularity than has ever been previously available (OECD 2017b, Eurostat, 2017). The nature of such big data requires new forms of processing to enable their use for enhanced decision-making and process optimization. This is usually defined as BD analytics, which refers to a set of techniques and technologies that allows voluminous amounts of machine-readable data to be generated, stored, accessed, processed and analysed, with the purpose of uncovering valuable information (patterns, correlations, trends and preferences) that can help organizations make informed decisions (Schaeffer 2017).

Advanced robotics and cobots	Robots are machines that are programmed by computers, and are capable of automatically carrying out a series of more or less complex actions. Robots can be differentiated into industrial robots and service robots. Industrial robots are an automatically controlled, reprogrammable, multipurpose manipulators in three or more axes, either fixed or mobile, can can be used in industrial automation applications such as manufacturing processes (welding, painting, and cutting) or handling processes (depositing, assembling, sorting, packing processes). Service robots are machines that have a degree of autonomy and can operate in complex and dynamic environments that require interaction and coordination with individuals, objects and other devices (for example, when used for transportation, surveillance, cleaning) (Eurostat, 2017). Cobots are robots intended to physically interact with humans. They are designed to learn and adapt to new tasks. They are built with passive compliance features and integrated sensors to adapt to external forces. They tend to be cost-effective, safe, easy-to-use and are suitable for small-scale production and reduced production cycles. They are also portable and easy to configure/reconfigure to perform different tasks.
Machine learning	Machine learning is an application of artificial intelligence. Machine-learning systems use general algorithms to determine on their own how to map inputs to outputs, typically being fed by very large sample datasets (Brynjolfsson et al.. 2017). These systems can improve their performance in a given task over time by collecting experience and large volumes of data such as big data.
Cloud computing	Cloud computing enables ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. It refers to ICT services that are used over the internet to access software, computing power, storage capacity, etc., where the services have all of the following characteristics: i) are delivered from service providers' servers; ii) can be scaled up or down; iii) can be used on demand; iv) are paid for by the capacity used or are pre-paid (Eurostat 2017).
Artificial intelligence	Artificial intelligence is a branch of computer science that seeks to develop devices that simulate humans' capacity to reason and make decisions. The term usually refers to the employment of AI techniques (such as machine learning, deep learning, computer vision, natural language processing, neural networks, fuzzy logic and self-organizing maps) to provide machines and systems with human-like cognitive capabilities, such as learning, adapting, solving problems as well as in terms of perception. It can be defined as the ability to make computers intelligent and capable of mimicking and predicting human behaviour and solving problems as effective as humans or better (UNIDO 2019).

Additive manufacturing (3D printing)	Additive manufacturing, commonly known as 3D printing, refers to the use of special printers to create three-dimensional physical objects from 3D model data by adding layer-upon-layer through material extrusion, directed energy deposition, material jetting, binder jetting, sheet lamination, vat polymerization and powder bed fusion. AM contrasts subtractive manufacturing methodologies which mould or rotate milling cutters to remove material from a solid block of material (Eurostat 2017).
Computer-aided design (CAD) - Computer-aided manufacturing (CAM)	The term CAD-CAM refers to computer systems (hardware and software applications) used to design and draft technical drawings and models, as well as to control and provide instructions to machine tools and equipment to manufacture prototypes, finished products and production runs (Mayer 2018). CAD systems allow building and viewing a design in a three-dimensional space and facilitate manufacturing processes by conveying information on materials, processes, dimensions, tolerances and dimensions. CAD can be used in isolation or can be integrated with and provide inputs to other computer-aided software such as CAM, which controls the machine tool that creates and/or assembles the physical products.

Source: UNIDO (2019)

The application of ADP technologies in manufacturing and industrial activities gives rise to the concept of smart production and, at plant level, the smart factory. In smart production environments, the integration of these technologies allows workers, manufactured products, equipment and machinery to be part of an intelligent smart system along all stages of the production line. The components of this smart system interact, communicate and/or control each other's actions, take decisions and implement actions through digital networks of interconnected equipment and sensors, powered by real-time data analytics, machine learning, machine-to-machine communication and other intelligent algorithms[2]. ADP technologies are thus shaping a new paradigm in manufacturing production and increasingly blurring the boundaries between physical and digital production systems.

Firm focus: assessing the multi-dimensional impact

The firm case studies presented[3] here provide a comprehensive overview of how technologically advanced firms in developing and emerging industrial economies are adopting and using these new technologies, the impact of the technologies on firms' performance dimensions, and the main challenges firms face during this technological transition period.

The focus is placed on the effects of the application of ADP technologies along the dimensions

2 See Chukwuekwe et al. (2016).

3 On the collection of firm case studies, see Box 1.

of ISID: *competitiveness, environmental sustainability and social inclusiveness*. Each impact dimension is further divided into various sub-dimensions, corresponding to the potential and expected dividends of ADP technologies. Finally, the direct impacts on the firms are evaluated. To better understand the broader implications of new technologies, the potential spillovers to the rest of the economy, society and the environment are considered as well.

Table 2 summarizes the main dimensions and sub-dimensions covered in each firm case study[4]. The first three sections in Part II contain a brief description of each impact dimension and respective sub-dimensions, and present the individual firm case studies organized in accordance with the dimension that emerged as being the most relevant.

Box 1. Collecting primary evidence from firms engaging with ADP technologies

The qualitative firm-level evidence presented in this publication as case studies covers ten firms identified in different countries. The information about the firms' experiences in engaging with ADP technologies was collected through interviews and field visits, and complemented by available online resources and/or secondary data. The structure of the final case study follows the sequence of the topics covered during the interview, with each topic being associated with a set of questions:

- Problem/issue posed by traditional production technologies and/or opportunities associated with the application of ADP technologies (why);
- Type of ADP technology adopted and used by the firm (what);
- Description of the firm (who);
- Firm's specific application of ADP technology (how);
- Main impacts and implications of ADP technologies, along the three impact dimensions of competitiveness, environmental sustainability and social inclusiveness (which impact);
- Main challenges that constrained and/or factors that facilitated the adoption and effective use of ADP technology.

In addition to providing new insights on the firm-level mechanisms of technological learning as well as on the benefits from this technological upgrade, the case studies serve as examples of good practices that could inspire other actors operating in similar contexts.

Source: UNIDO elaboration based on Calza and Fokeer (2019).

4 Table 2 is a summary and simplification of the wealth of the collected firm case studies in terms of impacts. This summary is not exhaustive, and neither is the information on the ADP technologies actually employed by each firm or all of the potential implications in each case.

Table 2 Firm case studies examine the impact of ADP technology on competitiveness, environmental sustainability and social inclusiveness

Firm		AEDesign	Arçelik	AVS Technology AG	China Baowu Steel Group Corporation
Main activity/product		Engineering and R&D services	Washing machines	Chlorine plant	Steel
Country		Pakistan	Turkey	Uruguay	China
Main ADP technologies		Computer-aided design (CAD) and computer-aided engineering; industrial sensors; image processing and recognition; machine learning and artificial intelligence; Internet of Things	Internet of Things; industrial sensors; industrial platform; big data analytics; machine learning and artificial intelligence; augmented and virtual reality	Internet of Things; industrial sensors; big data analytics; machine learning and artificial intelligence	Machine learning and artificial intelligence; edge computing; cloud computing; augmented and virtual reality; industrial sensors; digital industrial platform
Competitiveness	Efficiency				
	Product				
	Business model				
	Endogenous innovation				
	Linkages				
Environmental sustainability	Environmental efficiency				
	Environmental goods				
Social inclusiveness	Employment conditions				
	Skills and roles				
	Relegated groups				

Source: UNIDO elaboration based on Calza and Fokeer (2019).

Genesis Bionics	Haier Group	Mahindra & Mahindra Ltd.	New-Tek LLC	Thales 3D	ZC Rubber
Bionic prostheses	Air-conditioning systems	Automotive	Solar panels	Aerospace sector	Rubber and tires
Kyrgyzstan	China	India	Kyrgyzstan	Morocco	China
Computer-aided design (CAD); 3D printing; sensors	Internet of Things; industrial sensors; digital industrial platform; big data analytics	Internet of Things; industrial sensors; digital industrial platform; cobots	Internet of Things; industrial sensors; digital industrial platform; big data analytics	Computer-aided design (CAD); 3D printing	Cloud computing; big data analytics; machine learning and artificial intelligence; digital industrial platform

Policy focus: easing challenges

The collected policy case studies[5] present a selection of initiatives carried out by several developing and emerging industrial economies to foster engagement with ADP technologies and their effective application. Without the aim of providing an exhaustive collection of policy initiatives, these case studies offer new examples of how governments can support firms in successfully integrating ADP technologies in their production processes.

The focus is placed on three dimensions highlighted in the IDR 2020 as bring relevant for enhancing the readiness to adopt and exploit ADP technologies: *developing framework conditions, fostering demand and adoption, and strengthening skills and capabilities*. The areas of policy action represent a response to the challenges firms face in the process of deepening their engagement with ADP technologies. However, caution is needed when interpreting and drawing general conclusions from the presented policy responses: There are no one-size-fits all solutions and each policy initiative presented here has been tailored to addresses country-specific challenges[6].

Table 3 summarizes the areas of policy action associated with each policy initiative, highlighting the corresponding firm-level challenges. The fourth section in Part II provides a brief description of each area of policy action and presents the individual policy case studies, organized by area of relevance.

5 The policy initiative case studies are based on interviews and online resources.

6 See UNIDO (2019).

Table 3 Policy case studies examine initiatives in three main areas of policy action

Main firm-level challenge	Broad area of policy action	Specific issue addressed	Policy initiative
Access to frontier technology	Developing framework conditions	International collaboration and technology transfer	**China:** Implementing the Sino-German Smart Manufacturing Cooperation agreement: Baow and Siemens
Lack of funds and financial support Lack of linkages with other firms due to technological distance	Fostering demand and adoption	Access and affordability of ADP technologies	**China:** Fostering the adoption of cloud computing in Zhejiang Province, China
		Awareness regarding use and benefits of ADP technologies	**India:** Facilitating SMEs participation in smart manufacturing with C4i4 Lab in Pune, India **Pakistan:** Supporting technological innovation within the realm of the fourth industrial revolution in Pakistan
		Readiness of vulnerable actors, such as small and medium-sized enterprises	**Malaysia:** Supporting Malaysian manufacturing firms in embracing the fourth industrial revolution
Lack of qualified personnel Re-skilling of existing labour force Integrating new technologies with existing production equipment	Building and strengthening capabilities	Development of human resources	**Malaysia:** Facilitating firms in Penang Automation Cluster (Malaysia) in becoming regional and global players

Source: UNIDO (2019).

Part II

Case studies

Firms and ADP technologies: Pushing the frontier of manufacturing production Competitiveness

Table 4 The dimensions of competitiveness

Competitiveness				
Efficiency	**Product**	**Business model**	**Endogenous innovation**	**Linkages**
Improved capital utilization: productive/ automatic maintenance, reduction of idle time, lower inventory rate Reduced operational costs: flexible, agile and decentralized production, supply chain connectivity, logistics	Quality Variety Personalized/ customization/ smart	New and data-based services New pricing models Customers designing	User-led innovation Patents, copyright Software/ platform development	Market actors: suppliers, SMEs, business and industry associations, foreign partner Non-market actors: universities, research centres

Source: UNIDO elaboration.

Disentangling competitiveness in industrial firms

The first dimension of analysis for the firm-level impact of advanced digital production (ADP) technologies is competitiveness. Competitiveness reflects a firm's economic performance, providing the ultimate test of the firm's ability to grow and succeed in its business realm. Competitiveness also shapes the possibilities and scope of a firm's technological trajectory, defining the relative convenience of adopting and using new technologies as well as the speed of technological upgrading. Firms tend to base their decision on whether to adopt new technologies or not precisely on their expectations about the effect of new technologies on their competitiveness. Given its relevance, all firm case studies pay special attention to this dimension.

Competitiveness is rooted in different aspects of a firm's activity. To improve the scope of the analysis and to better grasp the magnitude as well as the quality of the impact of ADP technologies on firms that have adopted such technologies, competitiveness is divided into five impact sub-dimensions: *efficiency, product, business model, endogenous innovation and linkages*. The case studies presented in this section offer informative examples of the diverse effects ADP technologies can have on the five sub-dimensions of a firm's competitiveness.

Efficiency

This sub-dimension considers the impact of new technologies on a firm's efficiency. ADP technologies can optimize operations and increase production efficiency as well as drive the improvement of other indicators of a firm's economic performance, such as returns on investments, profits and revenues. The gains in efficiency are made possible through reductions in operational and production costs and improvements in capital utilization (Andreoni and Anzolin 2019). ADP technologies enable the integration of production stages and actors into an intelligent smart manufacturing system that—powered by real-time data analytics—is agile, flexible and fast in adjusting to changes in demand and production conditions. ADP technologies can also lead to improvements in the use of fixed assets, reducing idle times and increasing capacity use with automatic and predictive maintenance. This aspect is particularly relevant for firms operating in developing countries, where capital constraints can be a major barrier for upgrading technology.

Product

Competitiveness is not only boosted by enhanced efficiency; it also depends on products' quality and variety, as meeting higher quality standards may generate higher value added and access to higher markup markets. ADP technologies can significantly increase precision and accuracy along the entire production process, resulting in superior and more cost-effective products. New technologies can also enhance product-service characteristics and functionalities. For example, smart production systems enable the direct involvement of customers in production, in facilitating cost-effective customization and in the personalization of products. This aspect is related to the debate on the future of mass production systems, as the increased customization possibilities enabled by the application of ADP technologies can generate individualized products that are competitive with standard goods produced in a larger scale.

Business model

This sub-dimension examines the impact of new technologies on a firm's business model. New technologies are blurring the boundaries between digital and physical worlds as well as between manufacturing and services. The insights into customer behaviour collected and analysed by smart integrated production systems can allow firms to attach digital services in the final product, offering an integrated product-service package as well as developing new after-sales assistance services. This can lead to a new and more competitive business model, especially in the manufacturing of consumer goods.

Endogenous innovation

This sub-dimension considers the impact of ADP technologies on firm-level innovation activities and outcomes. To fully exploit their potential benefits, the integration of new technologies into the firm's production processes may require some adjustments to the firm's conditions, equipment and organization. This can lead to the development of new technological innovation. For example, the operationalization of ADP technologies in manufacturing production requires the development of an internal digital infrastructure, such as platforms and integrated software. In addition, the customization possibilities enabled by new technologies allow customers to participate in product design, thereby fostering user-led innovation.

Linkages

This sub-dimension explores the impact of ADP technologies on the firm's linkages and ties with other market and non-market actors. Given their complexity, the adoption of ADP technologies may prompt the firm to seek support from other actors to be able to fully exploit the benefits of these new technologies. Firms may need to develop ties with universities and other education institutions that can provide specific training needed to re-skill the existing labour force or to cooperate in R&D activities. At the same time, new technologies may change and increase the type of market actors the firm interacts with, for example, technologically advanced suppliers or local manufacturing firms. A firm that has adopted ADP technologies can outsource production activities for which traditional production technologies are still used to other firms. This can result in the establishment of new industrial linkages.

Key findings and lessons learnt

Increased efficiency fosters productivity and competitiveness

The firms reported improvements in efficiency, output and sales revenues as a result of reduced operational costs, optimized use of inputs and lower inventories. Owing to a new production line updated by Siemens's intelligent software, China Baowu Steel Group Corporation (commonly known as Baowu) increased its average daily output by 15 per cent to 30 per cent and reduced excess inventory in the warehouse by half, and improving labour efficiency by 10 per cent while reducing costs by 20 per cent. The new Haier air conditioning smart factory in China, which required an investment in equipment interconnections and digital systems approximately 1.2 times that of a conventional factory, registered a 60 per cent improvement in operational efficiency.

Improved competitiveness is more than just enhanced efficiency: it's also about higher quality and new products

The application of ADP technologies improve precision and minimize errors at nearly all of the interviewed firms, leading to higher product quality. ZC Rubber expects the adoption of Alibaba Cloud ET Industrial Brain, powered by artificial intelligence, edge computing and augmented reality, to reduce the factory's non-conforming product rate by 28 per cent. The major gains in terms of competitiveness are associated with the increased possibilities of product customization. The experience of the air conditioning system produced by Haier Group is prototypical: the COSMO Plat industrial platform, enabled by the industrial Internet of Things (IoT), allows for an enhanced producer-user interaction and for a high level of product customization. Additive manufacturing is another example of how ADP technologies introduce new products into the market. 3D printing technology enables the production of customized complex parts without costly tooling, eliminating the design-for-manufacturability constraints of conventional subtractive manufacturing processes. This technology allows Thales 3D to produce components for the aerospace industry that conventional manufacturing could not produce because of its complex internal structure and physical properties.

New business and organizational models emerge from ADP technologies

New production technologies go beyond improving production processes and products: They also entail new business and organizational models. With the implementation of its first smart factory for air conditioning systems, Haier Group transformed the nature of its final product from analogue to digital, i.e. smart. Through IoT, the air conditioning systems remain connected with the manufacturer even after leaving the production plant and reaching their final customer; they can thus transmit data back to the manufacturer, which are used to improve and monitor product performance as well as to develop after-sales services.

Endogenous innovation is a stepping stone for mastering new technologies

New technologies are often imported or developed outside the firm. Their adoption and application to the firm's production processes present an opportunity for technological learning. All interviewed firms experienced some degree of endogenous innovation. Thus, firms do not implement new technologies as they are, but adapt them to their specific processes and conditions. This adjustment often results in new patents and new machinery, for example, the crane developed by Baowu in cooperation with Siemens or the COSMO Plat platform by Haier Group. These innovations provide further evidence that adopting externally developed technology is a stepping stone for learning and mastering new technologies as well as for further technological upgrading.

Technologically advanced firms may generate linkages with local institutions and industries

The firms included in the case studies are not average manufacturing firms: they are technologically advanced and characterized by higher production and technological capabilities than average firms in developing and emerging economies. Yet, these technologically advanced firms generate ties with local market and non-market actors. Thales 3D actively engages with local industry associations and universities in joint trainings, student internships as well as scientific and technological research. Thales 3D also relies on local manufacturing actors using conventional technologies to finalize its high-quality products, suggesting that even the most technologically advanced firms may need the support of actors that use more traditional production technologies.

Case studies

AEDesign: Providing innovative services for engaging with ADP technologies in global manufacturing[7]

The fourth industrial revolution (4IR) opens up new scenarios for the expansion of knowledge-intensive business services (KIBS) and their integration with manufacturing (UNIDO, 2019). Engaging with advanced digital technologies in production requires increasing support from knowledge-intensive activities, such as research and development (R&D) and computer- and engineering-related services. This also calls for specialized skills and competences that are often not available within individual companies, given the sophistication and convergence of 4IR-related technologies, and thus have to be sourced outside the company. This opens up new competitive edges for advanced knowledge-intensive service providers.

Moreover, advanced digital technologies are changing how knowledge-intensive and engineering-related activities are being performed. As digital technologies allow the integration between manufacturing and services to be independent from physical proximity, engineering-related activities can be carried out globally and distributed across different countries. This could lead to a new geographical allocation of knowledge-intensive services, where service providers do not need to share the same location as their final customers. The possibility of 'horizontal integration' between service providers and industrial actors may represent a major opportunity for companies in developing and emerging economies in that they will be able to tap into global markets and become or remain competitive by offering high-quality services to global industrial actors. The Pakistan-based AEDesign exemplifies a company that successfully managed to position itself as a global high-quality service provider by taking advantage of the increasing integration between manufacturing and services brought about by 4IR, and simultaneously supporting the diffusion of advanced production technologies in global manufacturing. AEDesign was established in 2002 as an engineering consultancy company for the automotive and motorsport industry, with a focus on research and development (R&D) activities. Due to its exposure to a diverse range of projects in mechanical engineering for the automotive industry, the company has been able to refine and improve its internal practices and methodologies, enhance the skills and capabilities of its engineering team, and realize projects of increasing technological sophistication. Building on its expertise in mechanical engineering for the automotive industry, AEDesign has become a diversified company offering a comprehensive range of engineering services, including, among others, conceptual design, detailed design and computer-aided design (CAD), design validation based on "finite element methods", embedded system design, electronic circuit design, printed circuit board (PCB) design and prototyping, and computer-aided engineering for linear and non-linear static and dynamic analysis.

7 This case study has been developed with the assistance of Azhar Zia Ur Rehman.

Anticipating the potential of 4IR in manufacturing and as a result of its acquired competences in R&D and in various engineering fields, AEDesign has started diversifying its core activity into different manufacturing-related domains spanning from industrial machinery and production systems to robotics and renewable energy, and has expanded its business portfolio with innovative ADP technology-based solutions for industrial applications. This has moreover led to the development of original technological innovations, which may eventually turn into patent applications or may end up being commercialized as new business lines.

Using a combination of advanced sensors, image processing and machine learning, for example, AEDesign is developing production management and supervision systems that make automated predictive maintenance and immediate fault detection possible, which helps minimize production down time. AEDesign is also involved in developing similar smart solutions for the textile industry, a major industry in Pakistan. One application focusses on thread breakage during spinning, a common occurrence in spinning mills that produce yarn from cotton. At present, thread breakages rely on detection and intervention by humans, but this approach lacks precision and delays the recovery of the spinning process. AEDesign is developing a system based on image recognition that would immediately identify thread breakage and specify the necessary response, thus reducing machine down time as well as human involvement in the monitoring and intervention process.

Industrial robots also play an important role for the company. With the surge of self-driving and autonomous vehicles, the need for test tools in complex city scenarios and without any supervision or intervention from humans is increasing. Capitalizing on its experience in the automotive industry as well as on its increasing competence in ADP technologies, AEDesign developed AVCASS (Autonomous Vehicle for Certification of Active Safety System), a robotic platform for testing active safety systems for the automotive industry, which includes high-quality services such as crash safety, durability simulation and vehicle dynamics. The AVCASS has been designed to be fully connected as an Internet of Things device, and can thus connect and integrate with all simulated road users, while simultaneously providing and analysing real-time data from the various sensors on the tested vehicle. AEDesign is thereby supporting manufacturing enterprises' transition towards a smarter and more connected industry. All of these new 4IR-based services can deliver significant competitive advantages to AEDesign's clients, who gain access to high-quality tailored solutions to exploit the potentials of advanced digital technologies by increasing flexibility and tapping into specialized skills, ultimately reducing operational costs and enhancing both efficiency and competitiveness. Engaging with ADP technologies and focussing on high-value added smart services for manufacturing has led to an increase in AEDesign's competitiveness and it has now become a global player in knowledge-intensive and high-quality engineering services. Consequently, AEDesign established a subsidiary in Frankfurt, Germany, with the aim of leveraging the value addition provided by a global supply chain and achieving new business and learning opportunities that would not have been possible in Pakistan.

AEDesign's engagement with ADP technologies also has implications on environmental sustainability. The company has in fact prioritized advanced digital technologies that generate environmental benefits and sustainability. Reductions in greenhouse gas emissions and sustainable energy production was the primary driver behind the development of innovative solar power technology systems. These do not only produce electric power but can also provide heat for industrial processes derived from solar energy. Improving the cost and water efficiency of solar plants was the driver behind the deployment of cleaning robots for solar PV (photovoltaics) plants, which are already being employed in Pakistan and in the Middle East. In addition, by integrating a host of data and performance factors, AEDesign's cleaning robots are able to autonomously decide when and how to clean a PV solar plant to maintain optimum performance, reducing the costs of operating and maintaining solar plants and water consumption for the cleaning process by 90 per cent. By using AEDesign cleaning robots, a 100MW solar PV plant cleaned once a week could save approximately 21.6 million m3 of water annually. AEDesign patented its concentrated solar power technology and cleaning robots, and established ZED Solar, a spin-off company in charge of their production and commercialization.

AEDesign offers competitive work conditions for its employees. By providing a compensation package that is 10 per cent to 50 per cent above the rate for equivalent positions in the market, the company counts on a diversified team of 65 engineers, most of who are qualified engineers holding Pakistani and international qualifications. As a knowledge-based company, AEDesign greatly values its team and consequently invests heavily to ensure that its employees remain content, motivated and challenged: the company offers many benefits, including trainings, to reward its team members for their contribution in increasing the value added of the company's services. An equal opportunity employer from its inception, AEDesign also believes in the importance of keeping the work place diversified, overcoming the traditional lack of female engineers. The company recruits and retains the best engineers in the market, regardless of gender, and its female staff currently represents about 10 per cent of total employees.

Based in the ancient city of Lahore, AEDesign's experience demonstrates how a Pakistani company can compete and succeed in global markets. The company faces various challenges, however. Even if being located in Pakistan is associated with advantages in terms of relatively lower costs for qualified human capital, these are less relevant for a company like AEDesign, whose competitiveness is based not on cost but on high quality and the wide range of advanced services it offers. These do not compensate for the scarcity of support facilities for prototyping and the lack of public support, this usually being limited to subsidies for participation in global exhibitions. On the other hand, the company has recognized that self-reliance also represents an opportunity for further learning, turning into a competitive advantage against competitors who have matured in more protected environments.

China Baowu Steel Group Corporation: Introducing smart production into the steel industry[8]

Enhancing efficiency through improved capital utilization and reduced operational costs is allegedly one of the major benefits of deploying advanced digital production (ADP) technologies in manufacturing (UNIDO 2019). Production modes in capital-intensive industries are often associated with machinery characterized by high energy consumption, low efficiency and high emissions. This holds particularly true for the steel industry, which could benefit significantly from reducing redundancies and improving efficiency, and from eliminating high-risk activities in its production process. Rapid advances in technology are now making it possible to employ precise and intelligent production processes in the steel industry as well, potentially transforming this traditionally heavy industry into one exemplified by technological development, international cooperation and global partnership.

China Baowu Steel Group Corporation (commonly known as Baowu) is one of the main actors in China's steel production. The company has used digital technology for 30 years: for instance, as early as the 1990s, Baowu began using the enterprise resource planning system (ERP) and the manufacturing execution system (MES) for automatic production. Yet, the company lags behind international leaders, especially in areas such as system operation and maintenance, logistics management and integration of the stages of production. In other words, there is room for improvement, mostly in terms of labour productivity and energy efficiency. Baowu has consequently taken steps towards adopting advanced digital production (ADP) technologies to create smart steel plants to improve production efficiency and competitiveness as well as working conditions.

With the endorsement of both the Chinese and German governments[9], a strategic agreement was signed between Baowu and Siemens in 2016 to foster the use of smart manufacturing in the steel industry. Building on Baowu's existing automation equipment, Siemens has made targeted improvements to the previously employed digital systems. Siemens primarily used the factory engineering design and management software COMOS to establish a digital platform connecting the entire production line using the existing production equipment. As Baowu's existing production equipment did not have to be replaced, the costs of this technological upgrade were contained considerably. Other ADP technologies, such as artificial intelligence, edge computing, augmented and virtual reality and industrial cloud, are being applied with the aim of optimizing operations and improving maintenance activities in production processes.

Baowu's transition towards smart production has provided it with a number of benefits, mostly in terms of competitiveness and performance. ADP technologies have indeed resulted

8 This case study has been conducted with the assistance of Hongfei Yue and in collaboration with the Ministry of Industry and Information Technology (MITT) of China

9 See case study "Implementing the Sino-German Smart Manufacturing Cooperation agreement: Baowu and Siemens."

in enhanced production efficiency owing to reduced operational costs and improved capital utilization, but also in higher quality and precision.

The application of Siemens's smart software to the hot steel production line in the Baoshan plant, for instance, led to a 6 per cent increase in the automation rate, reaching a total automation rate of 98.5 per cent. This, in turn, has resulted in a 10 per cent increase in labour efficiency and a 20 per cent decline in operational costs. Once the implementation of the new technologies is completed, the average daily output of the Baoshan plant is expected to increase by 15 per cent to 30 per cent, while any excess inventory in warehouses will be reduced by half. Additional benefits may also arise from reducing idle time and faster responses to production faults as a result of improvements in automatic and predictive maintenance. In this respect, Siemens applied innovative industrial software solutions such as COMOS and Walkinside to help Baowu establish a virtual operation and maintenance platform across different production plants in Baoshan, Shanghai, Wuhan, ZhanJiang, Nanjing, Urumqi, Shaoguan and other production plants to conduct remote intelligent monitoring, mechanical diagnoses, fault warnings as well as predicting the equipment's end-of-life. Together with increased engagement with other ADP technologies, this technological upgrade is expected to significantly improve the speed, precision and quality of steel production by extending the equipment's effective operation time by 35 per cent, thereby reducing the factory's nonconforming product rate by 28 per cent and increasing its operational efficiency by 30 per cent.

Innovation is recognized as playing an important role in terms of competitiveness and performance. The collaboration between Baowu and Siemens has introduced technological novelties into steel production. For instance, Siemens worked together with Taiyuan Heavy Industries to design the first smart running crane carrying molten metal for Baowu, which has been in operation since March 2018. Under the intellectual property cooperation and sharing mechanism established between Siemens and Baowu as part of their agreement, the intellectual property and patents of innovations developed during the project's duration—such as the smart running crane—are shared by both parties. Nine patent applications have been submitted since the beginning of the collaboration.

Aside from fostering competitiveness through enhanced performance, capital utilization and innovation, ADP technologies can contribute to inclusive and sustainable industrial development by improving environmental sustainability as well as the social dimension of manufacturing production (UNIDO, 2019). In this regard, the application of Siemens's intelligent software to Baowu's hot steel production line increased its energy utilization rate by 5 per cent. In addition to reducing the company's energy costs, such gains in energy efficiency also entail positive environmental spillovers.

Despite Baowu's increased automation rate in steel production, the company's transition towards smart production does not seem to have led to a significant rise in unemployment. On the contrary, the number of employees in Baowu increased by 40 per cent between 2015 and 2017.


Source: China Baowu Steel Group Corporation

In addition, smart production has brought about better working conditions for employees, as new technologies can create a safer work environment compared with traditional methods of steel production. Lifting molten metal is the most dangerous task in the steel industry: one slight mistake causes irreparable damage. While this procedure in the past relied on workers' experience, the introduction of smart technological solutions—such as the smart crane carrying molten metal developed in collaboration with Siemens—significantly decreases the risks for workers. Similarly, the integration of controllers and radio frequency identification technology has created a "smart brain" for operations in the plant, leading to significant improvements in the accuracy and efficiency of refuelling activities and to the elimination of safety hazards related to manual operations. As heavy physical work is increasingly being replaced by automated smart machinery, steel production no longer involves many physically demanding tasks and the majority of workers now sit in the central control room and manage production processes instead of moving on the plant floor. Today, over 2,500 workers at Baowu are involved in management and monitoring. The elimination of physically demanding work has also opened up more employment opportunities for women in the steel industry, an industry from which women tended to be excluded: The share of female employees at Baowu increased by 38 per cent between 2015 and 2017.

Two factors that have significantly contributed to Baowu's successful exploration of smart production and that have facilitated the adoption and absorption of ADP technologies are first, the role both the Chinese and German governments have played in supporting the Baowu-Siemens cooperation, ensuring its effectiveness; and second, Baowu's pre-existing capabilities and in-depth knowledge of steel production. Baowu's workers had a high level of professionalism and experience with the previous digital production line and management system, which enabled them to master the new software in a short period of time, facilitating a smooth technological upgrade. Furthermore, as the establishment of advanced digital production systems still requires information about the basic parameters used in traditional processes, Baowu, owing to its long experience in the steel industry, was able to provide Siemens a wealth of comprehensive and accurate data to set up and feed the new digital system.

Although the cooperation agreement with Siemens did not encounter any major roadblocks and proceeded smoothly, Baowu worries about the uncertain future of steel markets. Given the large-scale compression of global steel production capacity and the competition from new materials, it is difficult to assess how long it could take to recover the cost of this technological upgrade.

Haier: Reinventing products and business models with the Internet of Things[10]

The debate surrounding the fourth industrial revolution (4IR) focuses mostly on its implications in terms of increased capital utilization, process optimization and production efficiency, or put simply, on the reduction of associated costs (Andreoni and Anzolin 2019). Such improvements can be associated with increases in labour productivity and a decline in unit prices, thereby expanding demand and opening consumption to the mass market (UNIDO 2019). In the case of consumer goods, the implications of 4IR may go one step further: new technologies shift the source of competitiveness from mass production and low unit cost to cost-effective customization by transforming consumer goods into smart product-service packages, whose overall physical and digital performance—and not only their physical characteristics—can generate both higher value added and revenue. For consumer goods, customization is becoming the new, if not the only, competitive production mode. The transformation of traditional goods into customized physical-digital solutions has been made possible by the development of new digital and interconnected technologies, such as the Internet of Things (IoT), and their application in industrial production.

The IoT represents the next iteration of the internet: it relies on interconnections through the internet's network of devices, machines and objects that communicate and exchange information among each other and with the environment through sensors and miniaturized computers, and process and analyse data in real-time (UNIDO 2017c). One main feature of IoT is its vast range of possible applications, from everyday objects, such as watches, cars, refrigerators or washing machines, to production machinery and equipment, including robots. IoT opens up new scenarios for industrial processes.

The Chinese Haier Group (commonly known as Haier) is a good example of a company that is leading the transition of consumer goods manufacturing in the face of the fourth industrial revolution (4IR). Established in 1984 as a small white electronics factory, Haier has become a global leader in providing better-life solutions that go beyond physical goods and comprise an entire ecosystem of services, such as home living and interactive entertainment, to meet the increasing demand for fully customized solutions aimed at improving everyday life. This transformation has been made possible by engaging with advanced digital and interconnected technologies such as IoT.

10 This case study has been conducted with the assistance of Hongfei Yue and in collaboration with the Ministry of Industry and Information Technology (MITT) of China.

Source: Haier smart factory in Qingdao (Shandong China)

Haier officially launched COSMO Plat in 2017, an industrial IoT platform based on an operating system called COSMO, which was developed entirely by Haier. COSMO Plat represents a new generation of industrial platforms and is expected to lead the trend of mass customization in future manufacturing. Enabling real-time interconnection with users and other actors in the production process, such platforms turn production facilities into smart plants and produce smart goods. Since its launch, COSMO Plat has been implemented in eight of the Haier Group's factories, including the central air conditioning interconnected factory located in Qingdao (China).

Haier's central air conditioning interconnected factory produces air conditioning equipment for individual customers as well as for large-scale businesses, the latter representing the majority of its clients. The production line employs advanced robotics technologies, which have been designed by well-known robotics companies, such as, for example, KUKA, to embed and operate the COSMO Plat in a smart environment. Although Haier's previous technological system served as the foundation, the implementation of the smart interconnected factory required an investment in physical capital of around 1.2 times the amount invested in traditional factories.

The Haier Group's experience with its central air conditioning interconnected factory distinctly exemplifies the tremendous changes that have taken place in the manufacturing of consumer goods initiated by the adoption of industrial IoT and other ADP technologies. First, it allows the full customization of central air conditioning systems, changing the business model from 'manufacturer's design' to 'customer's design'. While customers could only purchase products from standard production lines in the past, they can now choose the product's functions, model, size and even colour in accordance with their needs and preferences. Over 10,000 sensors along the entire production line connect the product equipment, factory workers and clients with one another, achieving real-time optimization of production design and allowing final users to participate in all production stages – from ordering to product design, manufacturing, logistics and distribution. By embedding their individual needs in the final product, COSMO Plat elevates user-producer interaction to a higher level.

Second, it changes the nature of products from analogue to digital, making them interconnected and smart, increasingly blurring the boundaries between manufacturing and services. Smart products transmit data to manufacturers through IoT, who, in turn, analyse and use them to monitor products' performance, improve processes, and provide customized after-sales services. Accordingly, Haier offers a real-time monitoring service: each air conditioning system can automatically analyse data in real-time, and report any potential faults to the after-sales service team, leading to significant reductions in costs and in response times compared with tradition inspection and customer assistance methods.

Finally, COSMO Plat provides a good example of how ADP technologies can foster the generation of linkages with both market as well as non-market actors, leading to more knowledge sharing and technological innovation. By acting as a space of interaction, COSMO Plat facilitates the involvement of external actors in production, such as raw material suppliers, service providers, equipment suppliers, as well as other non-market actors including design institutes, universities and research and development (R&D). When customers submit their request via COSMO Plat, the company's workers assess its feasibility based on internally available knowledge, skills and resources. If the request can be served and a certain demand size achieved, it will directly enter in production; if this is not the case, Haier can turn to technology providers and other similar actors on COSMO Plat and find a provider that can create solutions to meet customers' demands. That is, the platform also fosters technological cooperation and innovation.

Within one year since it went into operation at the end of 2016, the output of Haier's central air conditioning interconnected factory had increased by 300,000 units per year. The increase in operation efficiency by more than 60 per cent compensated the relatively larger investments in equipment interconnection and digital systems required for the establishment of the smart factory. Inventory turnover increased due to product customization.

By transitioning to a smart factory, labour costs have dropped by around 50 per cent. This has partly been driven by the decrease in the number of employees, namely from a total of 550 to 248. Not only the number, but also the workers' skills, roles and tasks have changed to meet the requirements of a smart interconnected factory. Instead of traditional, mechanical, repetitive manual tasks, workers' duties now involve direct interaction with clients and coordination with other actors on the COSMO Plat to meet customers' demand. Factory workers have been transformed into platform and business managers, with their income now in part being determined by their ability to satisfy users' demands and by the actual cash-flow generated. Consistent with the transformation of workers' roles, the new remuneration model aims at incentivizing workers' independence and innovation, establishing a new relationship between the enterprise and employees. New roles entail new negotiation and coordination

Source: Haier smart factory in Qingdao (Shandong China) tasks that require soft skills as opposed to physical and manual skills, i.e. applications of digital operating systems and robotics technologies are taking over physically demanding tasks. Although women already represent nearly 40 per cent of the total employees of Haier's central air conditioning interconnected factory, these changes may open even more opportunities for female workers, further promoting gender inclusion.

When new technologies favour the introduction of greener goods, they contribute to improving the environmental sustainability of industrial production. On account of the customized after-sales monitoring services, the magnetic levitation central air conditioning system produced at Haier's smart factory reduces energy consumption by up to 50 per cent compared with traditional central air conditioning.

The Chinese government has played an important role in supporting Haier's transition towards a smart interconnected factory. Haier's central air conditioning interconnected factory is located in the Sino-German industrial park in Qingdao (Shandong, China), which is a joint project between the Chinese and the German governments. The park creates a favourable environment for engaging with foreign companies and sharing knowledge about the COSMO operating system. This transition has not, however, been without challenges. The biggest challenge seems to be related to workers' new roles and duties. Although workshops and trainings were offered to help employees adjust to their new roles within the smart interconnected production mode, it was not an easy task getting workers to adopt the new business model and a new business mindset.

Thales 3D: Shaping the future of aerospace manufacturing with 3D printing[11]

The fourth industrial revolution (4IR) is transforming manufacturing, both in terms of processes and products. Propelled by the technological breakthroughs, manufacturing actors are looking for new strategies and business models to increase value added and satisfy consumers who have become more demanding in terms of customization and responsiveness. Technologies such as additive manufacturing (also known as 3D printing) are opening up new opportunities for product personalization and customization, especially in industries, such as aerospace, that require sophisticated and uniquely-designed components with a complex geometry and specific physical properties.

3D printing technology enables the production of complex metal parts with superior mechanical properties without the need for costly tooling, and eliminates the design-for-manufacturability constraints of conventional subtractive manufacturing processes. Developed in the 1990s, this process is the reverse of subtractive manufacturing: when using conventional subtractive

11 This case study has been conducted with the assistance of Lina Touri form UNIDO Morocco.

manufacturing methods, objects are constructed by successively cutting and removing material from a solid block to achieve the desired shape: when using 3D printing, a 3D computer-aided design (CAD) model is converted into a physical object by assembling successive layers of material. 3D printing allows for the design and realization of geometrically complex parts, which could previously not be built. Designers can now create designs that mimic natural structure, thus enabling product personalization and resulting in a significant change in production and time-to-market. Most additive manufacturing has so far been conducted using plastic materials, but considerable efforts are now focussed on developing technologies that use metals. Additive manufacturing is therefore gaining momentum, particularly in the aerospace industry. Thales Group (formerly Thomson-CSF) is a French multinational company with over 65,000 employees operating in 56 countries, specialized in producing equipment for the aerospace, defence, security and transportation industries. The Group has been operating in the Moroccan defence, aerospace, transportation and security market for more than 40 years and in 2009, established industrial activities in the country through Thales Holding Morocco. In 2011, the Group signed a strategic cooperation agreement with the Kingdom of Morocco, with the aim of supporting technological innovation through training, research and the implementation of industrial development projects focussing on advanced technologies. Under this agreement, the Group established an industrial competence centre in the MidParc Casablanca Free Zone in 2017, Thales 3D, which specializes in metal additive manufacturing.

Thales 3D uses a special 3D printing technique—selective laser melting (SLM)—that utilizes a high power density laser to melt and fuse metallic powders to produce near net-shaped parts with near full density. Through this method, data about the component are first processed and transmitted from a CAD model. The metal part is then printed out flat and iteratively by a 3D printer: shaping the piece after adding material layer by layer, a 30 micron thick layer of metal powder is spread across the previous layer. The laser beam subsequently melts the first layer, the machine adds a second layer, and so on. Parts manufactured using the SLM technique also undergo heat treatment to eliminate internal stress and reduce porosity. The plant to date has been using aluminium and titanium, which are common in aviation. The use of a secure digital platform provides Thales 3D with the latest innovations in smart production. The plant is 100 per cent interconnected and integrates the most advanced digital technologies. It currently operates with three 3D printing systems (ProX DMP 300) that use the SLM technique, but another seven metal 3D printers will be added in the near future. The plant's physical space has also

Source: Thales Group

Source: Thales Group

been specifically designed to accommodate the activity of a fully digital and smart factory: office rooms are equipped with computers, three secure rooms have been designed to host the 3D printers, and from an open space, control screens display the process parameters in real-time, so employees have the possibility to intervene in the process to refine the parts' digital model, control the degree of machine utilization and monitor dust, the plant's air quality and temperature. Overall (including building and specific trainings for the engineers that operate the machines), the investment required to establish the Thales 3D industrial competence centre was in the range of EUR 15 million to 20 million. The return on this large investment is expected to be relatively long at around 10 years or more. Thales Group is primarily interested in using the centre for developing technological innovation. The plant is the only one among the Group's subsidiaries in over 50 countries around the world involved in this type of production.

The application of additive manufacturing significantly increases the possibilities of cost-effective product personalization and customization in the aerospace industry. By making it possible to easily model complex parts without using costly tooling and without having to produce expensive moulds to generate a small number of specific components, it considerably improves the competitiveness of the solutions offered to final customers.

In addition, the experience of Thales 3D exemplifies how advanced digital production (ADP) technologies can foster linkages with market as well as non-market actors. Thales 3D aims to improve the country's competences in metal 3D printing, which will benefit local industries and strengthen cooperation with the regional ecosystem, and ultimately have a positive impact on the local economy. In this regard, even if over 50 per cent of the final products' value added is generated within the plant, Thales 3D still relies on support from the local industrial ecosystem, such as SMEs and industrial actors, to finalize its products based on conventional technologies—from traditional crafts to various types of activities (non-destructive, testing, surface treatment, heat treatment)—which Thales 3D prefers to outsource due to its small size. In addition, Thales 3D has developed close ties with local universities (e.g. the Universities of Fes, Tangiers and Meknes) to provide training activities and to conduct scientific and technical research, R&D on additive manufacturing, etc.

Aside from fostering competitiveness, the personalization of products and innovation, ADP technologies such as additive manufacturing can contribute to inclusive and sustainable industrial development by improving the social dimension of manufacturing production as well as environmental sustainability (UNIDO 2019). In terms of energy efficiency, the SLM additive manufacturing technique used at the Thales 3D industrial competence centre does not consume much energy compared to a conventional machine. What is more energy demanding is the need to maintain a controlled atmosphere, air quality and temperature, which requires the deployment of air conditioning and not the 3D printing technique *per se*. Moreover, as parts and components are not obtained by material removal, 3D printing reduces the amount of waste produced.

The Thales Group hired a multidisciplinary team of three technicians and eight highly qualified engineers specialized in mechanics and computer training to establish the Thales 3D industrial competence centre. The number of engineers working at the plant is expected to grow to 20 in total. Even though this is not a particularly large labour force, Thales 3D's highly qualified staff enjoys good working conditions and benefits from advanced training, allowing workers to further refine their skills. Even though qualified engineers can be found in Morocco due to the quality of the country's academic education, the engineers employed by Thales 3D participated in a one-year training course at the facility of a partner company in Belgium before mastering the new technology and adapting it to the company's specific production requirements.

The Moroccan authorities, such as the Ministry of Industry, have played a relevant role in facilitating the establishment of the Thales 3D industrial competence centre. The company also benefitted from the collaboration of the local association for aerospace industry (Groupement des Industries Marocaines Aéronautiques et Spatiales (GIMAS)). Thales Group's strong digital culture is another factor that positively affected the adoption of advanced additive manufacturing technology. Despite this, the process of technological upgrading still poses various challenges. The deployed additive manufacturing techniques are new, still being developed and very complex, thus implementation requires a solid academic background as well as precision and personal dedication to be able to adequately master the new technology. As the digital dimension permeates advanced production technologies, all activities require a profound knowledge of digital technologies. In this regard, another major challenge Thales 3D faces is the lack of education programmes associated with this particular discipline or special training courses offered in the country, meaning the engineers' training had to be provided abroad in collaboration with a foreign partner.

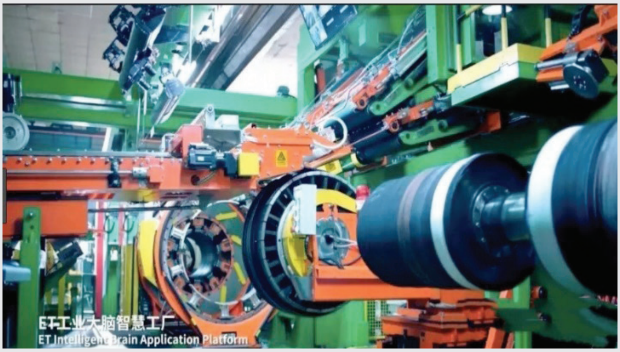
ZC Rubber: Improving rubber production with cloud computing and big data analytics[12]

Improving efficiency and reducing operational costs is one of the major advantages of adopting advanced digital production (ADP) technologies in manufacturing (UNIDO 2019). Industrial actors in capital-intensive sectors, in particular, whose production modes still tend to be arduous and associated with low efficiency, high energy consumption and a high environmental impact, may largely benefit from reducing redundancies and optimizing processes. The rubber industry is no exception. The traditional rubber production line includes the manual sorting of rubber blocks: before the raw material enters the production line, workers have to classify the blocks according to production area, processing factory and batch. Each mistake has implications on the quality of both the production process and the product, as it affects the rubber making process's efficiency as well as the characteristics of the final product, such as rubber compound and tires. [12]

Recent technological advances have made it possible to implement more precise and smart production processes in this medium low-tech industry, opening up new opportunities for improvements in competitiveness and environmental sustainability. In this respect, cloud computing has become a symbol of the fourth industrial revolution (4IR) and its applications in terms of smart production for manufacturing.

Cloud technology is a general term for information sharing, management platforms and other application technologies based on cloud computing. Relying on a shared pool of configurable computing resources, cloud technology allows users to conveniently share and utilize resources on-demand, including computing, storage, application software, services as well as networks. With the support of big data analytics and artificial intelligence, cloud technology can help companies optimize their operations and information processing. For example, cloud computing makes it easier to record and use produced data, test processes, strengthen security protection and coordinate various business functions such as management, communication, marketing, customer services as well as research and development (R&D). In manufacturing, cloud technology is being increasingly used to record and analyse production parameters to optimize production processes and increase efficiency. Moreover, by enabling industrial equipment to perceive, transmit and self-diagnose problems, the application of these new technologies can reduce production costs for certain industries. In 2017, the Chinese digital company Alibaba Cloud officially released its computing-based service for industrial customers, ET Industrial Brain. Already operating in various manufacturing fields, from energy to environmental protection to light and heavy industry, Alibaba Cloud's cloud technology has also been applied in the rubber and tire industry through collaboration with ZC Rubber.

12 This case study has been conducted with the assistance of Hongfei Yue and in collaboration with the Ministry of Industry and Information Technology (MITT) from China.



Source: ZC Rubber

ZC Rubber, a Chinese company located in the Hangzhou Economic and Technological Development Zone in Zhejiang Province, is one of the largest tire manufacturers in China. Engaged in the production of automobile tires and rubber products since its establishment in 1958, the company adopted Alibaba Cloud ET Industrial Brain in 2017, within the framework of Zhejiang Province's cloud computing initiative[13]. The cooperation with Alibaba Cloud ET Industrial Brain marked the starting point of ZC Rubber's engagement with ADP technologies.

At the end of 2016, Alibaba Cloud entered ZC Rubber's production factory to conduct an in-depth study on all types of data produced in all stages of production. Using cloud computing and big data analytics, the ET Industrial Brain collected, analysed, mined, modelled, re-associated and reconstructed industry data to explore and exploit the information, helping ZC Rubber optimize its production processes. For example, based on artificial intelligence algorithms and the decision tree model based on dynamic industrial data, ET Industrial Brain can rapidly analyse each piece of rubber information, obtain and analyse real-time data to match the optimal synthesis programmes and parameters, such as rubber-discharging time and temperature, and monitor the final outcome in terms of the rubber compound's quality.

The application of Alibaba Cloud's ET Industrial Brain has contributed to enhancing ZC Rubber's competitiveness and performance, mostly by increasing production efficiency and quality. The use of new technologies has led to reduced standard deviations of key parameters in the rubber mixing process, such as time and temperature, by 10 per cent and 6 per cent, respectively. In addition to reducing production costs, the improved stability of the parameters during the mixing process results in a higher quality rubber compound, as the increase in the rate of quality products by 3 per cent to 5 per cent during the first six months demonstrates. Owing to the significant improvements in product quality and production efficiency, ZC Rubber registered an increase in the overall value of sales one year after adopting the ET Industrial Brain: in 2018, sales revenues rose by 5.31 per cent compared with the same period in 2017.

ADP technologies can also play a role in supporting environmental sustainability and fostering social inclusiveness and shared prosperity. The improvements in the stability of rubber production parameters of ZC Rubber represented a significant enhancement in terms of energy efficiency, increasing by more than 10 per cent. At the same time, the adoption of ET

13 This case study has been conducted with the assistance of Sebastian Perez and Valeria Cantera form the Chamber of Industries of Uruguay (CIU).

Source: ZC Rubber

Industrial Brain has not affected the number of employees, thus posing no real threat for ZC Rubber's workforce. The technological upgrade has raised the level of required digital skills, which may compel the company to look beyond its borders for adequate competences or to re-skill its existing labour force. Pre-existing capabilities and ZC Rubber's knowledge in rubber and tires production played an important role in facilitating the adoption and absorption of ADP technologies such as cloud computing. The design of functions and algorithms of ET Industrial Brain benefitted from the company's production experience, especially in terms of the definition of parameters, such as temperature and time.

Although the application of ET Industrial Brain was connected with a number of benefits for ZC Rubber, the company continues to face challenges along its path towards technological upgrading. First, the company is facing a serious lack of qualified staff and adequate talent, who are familiar with both the rubber industry and advanced digital technologies. This greatly limits the speed of digital transformation. Second, as a company operating in a traditional and medium low-tech industry, ZC rubber's experience with digital technologies has not been very extensive, thus delaying the rate of absorption of new technologies as well as their effective use. Finally, the rapid development of 4IR is forcing companies to continuously update their knowledge and applications of ADP technologies, causing some confusion and uncertainty about technology standards. This may lead to frustration and weaken the enthusiasm of even the most motivated and competitive company.

Environmental sustainability

Table 5 The dimensions of environmental sustainability

Environmental sustainability	
Environmental efficiency	**Environmental goods**
Energy efficiency Input efficiency Emissions and waste reduction	Eco-friendly materials/components Product energy efficiency Recyclability, circularity

Source: UNIDO elaboration

A road towards sustainable industrial development

The second dimension of analysis of the firm-level impact of advanced digital production (ADP) technologies is environmental sustainability. The environmental issues associated with the production model based on traditional technologies have turned the attention to alternative modes of industrial development. The environmental sustainability of manufacturing production starts at the firm level, and advanced digital production (ADP) technologies are opening up opportunities for significant improvements in firms' environmental performance without jeopardizing their efficiency and cost optimization. In fact, the application of these technologies may even increase the economic convenience of transitioning towards more sustainable industrial development. Thus, ADP technologies can have a positive impact on environmental sustainability which, in turn, can also generate economic dividends, such as improving capital use.

There are two main channels through which ADP technologies can impact environmental sustainability at firm level: *environmental efficiency and environmental goods*. The case studies presented in this section clearly illustrate how these sub-dimensions are affected by new technologies.

Environmental efficiency

This sub-dimension explores the impact of ADP technologies on firms' environmental performance, looking in particular at improvements in inputs and energy efficiency. By optimizing fixed asset utilization and production parameters, ADP technologies can increase the accuracy and precision of production processes, thereby minimizing redundancies and the waste of inputs. ADP technologies also allow for the replacement of energy-intensive production modes with more energy-efficient ones. For example, the use of software tools that optimize energy consumption may reduce carbon emissions as well as production costs.

Environmental goods

This sub-dimension covers the impact of ADP technologies on the introduction of *green* and environmental manufacturing goods. Environmental goods can be defined as goods that improve the quality of life while minimizing the use of resources and inputs (including energy) and the emissions of pollutants and waste (including CO_2 emissions and toxic materials) over the product's life cycle (UNIDO 2017b). Similar to what takes place in production, embedding new technologies into products can optimize their functions and increase their energy efficiency. For example, towing to the transformation of physical products into an integrated product-service package, manufacturers can control and improve a product's overall performance, including its energy consumption. Thus, the digital nature of a physical product can be exploited to enhance its environmental performance.

Key findings and lessons learnt

Enhancing efficiency goes along with improving environmental sustainability

The firm case studies provide evidence of ADP technologies' effects on firms' environmental performance. This mostly occurs by improving energy efficiency and reducing waste and pollution, thus leading to positive environmental spillovers. The smart modular plants for producing chlor-alkali directly at the water treatment plant developed by Uruguayan AVS Technology AG eliminate the need to store or transport chlorine in liquefied gas form, whose leakages could harm both human health and the environment. This implies a significant reduction of hazardous and polluting processes in water treatment. Moreover, the advanced technology developed by AVS Technology AG also leads to a significant reduction in energy consumption.

ADP technologies not only introduce new products, they also make products greener

ADP technologies improve the environmental performance and energy efficiency of manufactured goods, ultimately contributing to a reduction of carbon emissions associated with the product's functionalities. In the case of New-Tek LLC, the application of ADP technologies to its production line has increased the quality and performance of its produced solar modules. This has a double impact on environmental sustainability: it improves the solar panels' energy efficiency—thus optimizing the use of resources—which in turn increases the competitiveness of solar power as a reliable and cost-effective source of energy.

Case studies

AVS Technology AG: Improving the environmental sustainability of water treatment plants with the Internet of Things[6]

Traditional manufacturing is at the centre of the debate about the environmental sustainability of industrial production. Addressing today's major global challenges, such as climate change and lack of access to clean energy, calls for a transformation of industrial production towards *greener* production modes and products, and towards more circular economic processes. In this regard, the surge of the fourth industrial revolution (4IR) and the diffusion of advanced digital production (ADP) technologies are raising hopes about the possibility of entering a new sustainable and circular industrial era. By allowing for energy savings and a reduction of CO_2 and other pollutant emissions per product, the application of technologies such as the Internet of Things (IoT) can indeed open up new possibilities for optimizing the use of inputs in industrial production.[14]

IoT represents the next iteration of the internet: it relies on interconnections through the internet's network of devices, machinery and objects that can communicate and exchange information between each other and with the environment through the use of sensors and miniaturized computers, and process and analyse data in real-time (UNIDO 2017c). The range of applications of this technology is vast, from everyday objects—like connected watches, washing machines or refrigerators—to specific applications in industrial production. One area in which the IoT may lead to more sustainable industrial scenarios is water treatment.

Treatment plants in traditional water treatment models are located far from the chlor-alkali production plants. Consequently, large volumes of chlorine, a key input of water treatment plants, have to be stored, handled and transported in a liquid state, with a high risk of gases leaking through cracks and the ensuing damage to human health and the environment. Today, IoT and other ADP technologies make it possible to operate small-scale chlor-alkali production plants located on the same premises of water treatment plants: direct injection of gaseous chlorine into the water streams eliminates the need for manipulation, storage and transportation of chlorine, minimizing related environmental and health risks. The Uruguayan company AVS Technology AG exemplifies how a more sustainable model of chlorine production and distribution can be implemented by combining IoT solutions with other ADP technologies.

AVS Technology AG was founded in 2009 as an industrial engineering consulting company for the chlor-alkali industry, offering specialized services to international companies located in diverse international markets, such as the United States, Australia and Argentina. The company's core activity was providing customized technological solutions to optimize

14 This case study has been conducted with the assistance of Sebastian Perez and Valeria Cantera form the Chamber of Industries of Uruguay (CIU).

processes in large chlorine production plants, including assistance in the design of equipment. Due to its specialized knowledge and experience in the sector, AVS Technology AG moved from being a service provider to designing and manufacturing its first small-scale plant for the production of chlorine in 2012.

The adoption of ADP technologies makes the-small-scale plants produced by AVS Technology AG competitive in terms of performance, efficiency and costs against larger scale production facilities. One of their main features is that they are designed to be remotely controlled from Uruguay using IoT. Embedded in the plant, smart sensors collect real-time data on process parameters (temperature, pressure, pH levels and cell voltage, among other things) and transfer them to a control system that communicates with the company's team through a human-machine interface. The team can thus monitor and assist the production process remotely, with no need to be physically present at the plant site, allowing for a rapid identification and solution of detected problems directly from company headquarters. Moreover, by providing feedback about plant performance, the analysis of collected data delivers proposals for operational improvements, thus upgrading the structural design and functionalities of newly established plants.

AVS Technology AG developed this control system in collaboration with an Argentinean partner, who realized and programmed the software according to the specifications defined by AVS Technology AG. The sensors and instruments embedded in the plants are acquired in the international market, but the company modifies and adapts them to each plant's needs and characteristics. The realization of the control system and the acquisition of field sensors and instruments in the international market account for approximately 10 per cent to 15 per cent of the final cost of a small-scale chlorine production plant, whose realization is financed with the company's own funds and with funding from private investors. To reduce costs, AVS Technology AG has begun considering the adoption of 3D printing technology for the realization of some components that are currently being purchased abroad.

The innovative application of new technologies to water treatment developed by AVS Technology AG represents a more sustainable and competitive solution for chlorine production and distribution. First, it has positive implications for health and environmental protection on account of the transformation of traditional water management models and the consequent elimination of the need to handle, transport and store chlorine, which reduces the risks related to leakages. Second, the application of IoT and other ADP technologies in chlorine production plants delivers significant benefits in terms of efficiency in the use of chemical inputs and energy. Chlor-alkali production is characterized by high levels of energy consumption, which accounts for approximately 40 per cent of production costs. AVS Technology AG has developed a new system of membrane electrolyzers, whose power consumption is comparable to those of larger scale chlorine production plants. Owing to real-time monitoring, analysis of the voltage of each cell in this membrane system makes it possible to carry out energy efficiency tests that can detect deviations and solve these immediately, thereby significantly improving the plant’s energy efficiency. In addition, having records of each plant’s energy consumption and related faults represents a valuable asset for AVS, which can use this information to improve the quality of the membrane electrolyzers.

Aside from the positive impact on environmental sustainability, the application of ADP technologies has increased AVS Technology AG’s competitiveness. This, on one hand, is due to the fact that new technologies enable the collection of performance data from the plants, which in turn allow for significant improvements in plant design and performance, ultimately increasing quality and value added. On the other hand, analysis of the performance data creates new possibilities for developing technical assistance services as well as alert systems for the existing plants. In this regard, AVS Technology AG is already taking steps towards offering after-sales technical assistance services. This represents a good example of how the application of ADP technologies can transform a company’s business model: originally focussing on providing engineering services, AVS Technology AG is moving from the production of chlorine plants to offering an integrated product-service package.

The chlorine production plant developed by AVS Technology AG also represents a relevant technological innovation in the field of water treatment. The company decided not to register the patent of the plant’s design and, instead, to keep it an industrial secret. Consequently, various actors have expressed interest in acquiring the company and its innovative technological solution.

The adoption of ADP technologies can have an impact on employment and working conditions (UNIDO 2019). Starting with only five founders in 2009, AVS Technology AG today has 15 employees. Due to its specialized and innovative activity, the company employs mostly highly-qualified professionals, such as engineers (chemical, civil, industrial), architects, designers and assemblers. The company offers good working conditions and career opportunities independently of gender: Among the 20 people currently employed by AVS, five are women, the CEO being one of them.

To date, AVS Technology AG has produced and implemented its small-scale chlorine plants in various countries including Brazil, Spain and Uruguay. AVS is planning to expand and establish an operation centre in Spain from where it could reach African markets. In fact, as small-scale chlor-alkali water treatment plants with remote monitoring may represent a solution for water treatment in isolated areas and with no access to clean water, AVS Technology AG is starting to explore the African market, where the proposed technological solution could become a game changer for producing potable water at competitive costs. With this new unit in Spain, AVS expects to double its current staff.

Accumulated over decades of assisting world leading companies in the chlor-alkali industry in designing, the realization and operation of electrolysis plants, AVS Technology AG’s capabilities and knowledge were fundamental in enabling the development of small-scale production plants and the integration of ADP technologies into chlorine production processes. In pursuing technological upgrading, the company has also benefitted from being located in the free zone of Parque de las Ciencias (Uruguay). Activities in free zones are exempt from national taxes and profit from additional fiscal and financial benefits.

New-Tek LLC: Fostering the use of renewable energy with high-tech solar panels[15]

Since the first, second and third industrial revolutions, steam power and electricity have been driving an increasing range of production equipment, from simple single-task tools to assembly lines, mass production systems and flexile automation. Despite having driven economic development, the traditional industrial model has had a negative environmental impact. Major global challenges today such as climate change call for a fundamental transformation of industrial production systems, starting with a reduction of reliance on fossil fuels and an improvement in energy efficiency to decrease total carbon emissions. In this scenario, renewable energy has attracted increasing attention as a main factor in facilitating the transition towards a more sustainable industry. Although there is still a long way to go, a number of countries is promoting the diffusion of green energy by adopting measures to incentivize the use of solar energy.

The surge of new advanced digital production (ADP) technologies is also opening up new avenues for more inclusive and sustainable industrial development (ISID). Recent technological breakthroughs associated with the fourth industrial revolution (4IR) pledge increased deployment of renewable energy in manufacturing, optimized energy use and reduced carbon emissions at an unprecedented scale (UNIDO 2017a). More specifically, ADP technologies are expected to decouple natural resource use from environmental impacts by replacing energy-intensive technologies and products with more energy-efficient ones on account of the introduction of software tools that optimize energy use or of smart *green* and environmental goods, thus ultimately contributing to environmental sustainability. The Kyrgyz-based New-Tek LLC exemplifies how ADP technologies can foster the diffusion of renewable energies by improving the quality and efficiency of solar panels and of their production processes.

New-Tek LLC is a joint Kyrgyz-German company that produces photovoltaic (PV) solar modules and develops and implements innovative projects in the field of solar energy. New-Tek LLC was established in 2015, when two partners from Kyrgyzstan (Babek Ltd) and Germany (Schmid Group) agreed to build a plant to produce the latest generation of PV solar modules. The decision to establish the plant in Kyrgyzstan was based on the country's convenient geographical location, its favourable investment climate and optimal conditions in terms of legislation, taxes and customs duties. In 2017, the newly established New-Tek LLC began producing class

15 This case study has been conducted with the assistance of Nurshat Karabashov.

Source: New-Tek LLC

A solar modules in its modern plant located in an area of over 10,000 square metres. The plant's total productive capacity is around 50 MW annually, which corresponds to 200,000 units of PV solar panels. The company's entire production is designed for export to CIS countries (mostly Kazakhstan and Russia), the Middle East and Europe (Germany)[16]. The company is currently receiving requests from the United States, Iran, Afghanistan and Mongolia, which they plan to supply in the near future.

New-Tek LLC deploys the fully automated production line 'Montrak' to assembly the solar modules. Realized jointly with Schmid Group, a world leader in equipment for the production of solar panels, the 'Montrak' production line integrates the most advanced digital production technologies, such as industrial robots equipped with material control sensors connected through a control system software. At each stage of production, the sensors transmit real-time information about the movement of materials and parts; if there is any material shift or fault, robots that are also connected to the sensor through the control system stop working. The production line employs a monorail instead of a belt conveyor, which prevents vibrations during the movement of material along the conveyor, making production as accurate as possible. The automated line is operated by specialized workers, who were trained and certified in the German facilities of Schmid Group. However, given the possibility to remotely connect to the plant using the application of ADP technologies, the equipment and operations can be monitored remotely by Schmid Group's experts based in Germany, who can react quickly and provide immediate assistance if any faults are detected. This significantly facilitates equipment maintenance and reduces idle times, thereby improving the plant's efficiency. The initial investment required for the realization of the plant amounted to approximatively USD 15 million. This amount is fully warranted compared with the expected value of annual production, which is expected to be around USD 20 million per year at maximum capacity. Since the plant's construction, the price for solar panels has declined by nearly half, thus extending the expected time for recovering the investment to five years from the start of production.

Despite the advanced production line, the remaining business functions of New-Tek LLC are less automated and rely to a lesser degree on the application of ADP technologies. For instance,

16 These final markets are related to trade agreements that favour export from Kyrgyzstan. In 2015, Kyrgyzstan joined the Eurasian Economic Union (EEU), which opened up the possibility to tap into a potential market of over 180 million people and a GDP of more than USD 1.8 trillion. In addition, state programmes to support renewable energy have appeared in neighbouring countries such as Kazakhstan, where the government guarantees 15 years to buy back the generated electricity, driving a rise in demand of solar panels. The same programmes have been established in the Russian Federation, Qatar and the United Arab Emirates.

purchase orders are manually received by e-mail, the design of the product uses non-integrated 3D modelling programmes, customer relations are recorded manually in spreadsheets, and non-integrated information systems are used in personnel management.

The application of ADP technologies to the production of solar panels positively affects environmental sustainability by increasing the quality and performance of solar modules, thus improving the competitiveness of solar power as a reliable and convenient energy source. New-Tek LLC produces its solar modules with the best raw materials, such as the highest quality silicon cells available on the market, and only uses components from certified suppliers approved by Schmid Group. To maintain high-quality standards throughout the entire production process, the fully automated production line is equipped with three posts of quality control testing that collect product information in real-time and store it in a centralized database to perform quality tests. The adoption of advanced technologies allows New-Tek LLC to minimize inaccuracies and errors and to obtain class A solar PV panels of premium quality, the highest quality currently available on the market. Aside from representing a competitive edge for the company, the superior quality of its products is also reflected in their performance: New-Tek LLC's solar modules have an energy efficiency of over 18 per cent. New-Tek LLC's products can thus be classified as environmental products, not only because they generate energy from a renewable source, but also because they do so in the most efficient way possible. Moreover, the entire production process is sustainable and environmentally friendly. In fact, New-Tek LLC relies on the power generated by its own solar panels, which ensures uninterrupted power supply during production processes with almost zero CO_2 emissions. Due to their superior quality and performance and their sustainable production process, the company's solar modules have been certified by TÜVRheinland[17], a quality mark in Europe, and received UL certification[18] in May 2019, the latter opening up the possibility to enter the U.S. market.

In addition to fostering the diffusion of renewable energy and contributing to environmental sustainability, the industrial application of ADP technologies has implications on competitiveness and employment. The quality and reliability of its products allows New-Tek LLC to position itself as a leader in PV solar modules in its main target markets, CIS countries and the Middle East. Even if the company faces competition from Chinese and Russian producers, New-Tek LLC can maintain its competitive edge by offering products of superior quality[19] that still fall within a price range that is comparable to that offered by competitors.

New-Tek LLC's experience also provides a good example of how the adoption of new technologies can contribute to innovation. The company realized that in the process of baking glass sheets for solar panels, the polymerization of the film is non-linear. This was an important discovery in the realm of solar module production, leading to the development of new tests

17 https://www.tuv.com/world/en/index.html

18 https://www.ul.com/

19 For example, New-Tek LLC offers a 10-year warranty on its solar module, while its direct competitors offer a 2.5 year warranty.

Source: New-Tek LLC

for the non-linearity of film polymerization. In addition, New-Tek LLC has also identified several parameters in film production, the improvements leading to an increase in the power of solar panels by several percentage points.

In terms of employment, 35 people currently work at New-Tek LLC's plant in Kyrgyzstan. The company offers advantageous working conditions, offering a salary of around USD 500 per month, well above the country's average salary of USD 250 in 2018. The fully automated production does not involve any physically demanding tasks, i.e. no duties are performed that could limit the involvement of women in the manufacturing process. Currently, the company employs three female workers. This low number is explained by the fact that there tend to be less women among electricians and information technology (IT) specialists in the Kyrgyz Republic, which are the main qualifications needed to work for New-Tek LLC. In pursuing its technological upgrading, New-Tek LLC has benefitted from its location in a Free Economic Zone (FEZ). This entails significant tax breaks, including exemption from most taxes and a flat tax of 2 per cent on revenues. Moreover, international agreements allow duty-free delivery of solar panels from the FEZ, not only to EU countries, but also to other European countries and the U.S. Since the start of operations, the company has not received any additional government subsidy, or any other forms of financial support from other institutions.

Despite the advantages of the production location and the technical support provided by the German partner (Schmid Group), New-Tek LLC still faces challenges in further deepening the integration of ADP technologies in its production processes. The main issue is the lack of staff with adequate qualifications. As employees need to have skills at the junction of two professions—IT and electronic engineering—no professionals with such qualifications were available in Kyrgyzstan when New-Tek LLC established its business. This meant that all staff had to undergo special training, partly in Germany offered by Schmid Group, before the production equipment was installed, and partly in Kyrgyzstan once the production line was ready.

Social inclusiveness

Table 6 The dimensions of social inclusiveness

Social inclusiveness		
Employment conditions	**Skills and roles**	**Relegated groups**
Change in labour force (quantity) Work conditions and safety Wages and incentives	New skills New roles, task-efficiency	Marginalized customers Female workers

Source: UNIDO elaboration

Social inclusiveness for shared prosperity

The third dimension of analysis of the firm-level impact of advanced digital production (ADP) technologies is social inclusiveness. At firm level, this dimension is often interpreted as the impact of integrating advanced digital production (ADP) technologies in manufacturing processes on the firm's total number of employees. However, achieving inclusive and sustainable industrial development (ISID) entails more than simply sustaining employment levels, as the path leading from industrial development to shared prosperity also encompasses qualitative aspects of employment and social inclusion. ADP technologies can affect the social dimension of manufacturing production in a broader and more complex way.

To improve the scope of the analysis and to better understand the qualitative aspects of the impact of ADP technologies on firms' social inclusiveness, this dimension is divided into three sub-dimensions: *employment conditions, skills and roles and relegated groups*. The case studies presented in this section represent informative examples of the possible effects of ADP technologies on the different facets of social inclusiveness.

Employment conditions

This sub-dimension investigates the impact of new technologies on the firm's employment level. The net impact of ADP technologies on the size of the manufacturing labour force is still being debated. New technologies upgrade automation and the production machinery with artificial intelligence (e.g. interconnected robots can exchange and process information, recognize images or take actions autonomously), which can potentially replace human intervention in an increasingly complex range of tasks. At the same time, the application of ADP technologies increases the quest for specialized staff, which may imply new employment and career opportunities. In addition to changes to the size of the labour force, new technologies can also impact employment in terms of working conditions and new opportunities. For example, advanced automation solutions and collaborative robots (cobots) in manufacturing plants can improve safety by taking over hazardous and physically heavy tasks.

Skills and roles

This sub-dimension explores the impact of new technologies on employees' skills and roles in manufacturing firms. Exploiting the potential of ADP technologies requires new skills and capabilities. Skills that complement new technologies are likely to be favoured, including analytical, technology-related and soft skills (Kupfer et al. 2019). In terms of technology-related abilities, digital skills are playing an increasingly important role, thus fostering demand for specialized training and education programmes. Moreover, the application of ADP technologies in manufacturing can lead to a reorganization of production tasks and a redefinition of workers' roles along the production line.

Relegated groups

This sub-dimension focusses on the impact of new technologies on the inclusion of specific groups and individuals, who tend to be marginalized in the industrial model based on traditional production technologies. ADP technologies can promote social inclusion by providing innovative solutions to the needs of vulnerable individuals, such as people with specific health conditions and disabilities, whose needs are typically overlooked by manufacturing systems based on mass and lean production technologies characterized by large volumes to lower unit costs. For example, personalized medical devices can be designed and commercialized, as the diffusion of 3D printing offers a cost-effective option for low volumes of manufacturing. The implications of ADP technologies for female employment also deserve special attention, as it is still unclear whether new technologies would exacerbate or alleviate gender biases in manufacturing. By replacing workers in physically arduous tasks, ADP technologies can open up new employment opportunities for women, thus promoting gender inclusion.

Key findings and lessons learnt

Cobots remove workers from arduous and hazardous tasks

The application of ADP technologies improves working conditions. At Mahindra & Mahindra Ltd., the introduction of cobots has reduced the amount of physically demanding tasks and increased workers' safety, because they eliminate the need for safety fencing and reduce the risk of human contact with hazardous materials, such as the sealant used in gear production. Hence, the increased collaboration between humans and robots is creating a blended workforce. The elimination of physically arduous tasks is also opening up new opportunities to expand female employment in traditionally male-dominated industries such as automotive.

Smart factories create new roles and skills that require specialized training

New technologies are leading to a profound redefinition of workers' skills and roles throughout production. To work in Arçelik's smart washing machine factory, workers need to have advanced digital skills to understand and integrate new technologies into their production tasks. In addition, workers increasingly need soft skills, such as the ability to learn and communicate. The rising importance of soft skills is partially being driven by the change in workers' roles: instead of performing manual repetitive tasks, production workers are increasingly functioning as platform managers who have to coordinate customers' requests and interact with suppliers. These new roles require additional negotiation and coordination skills. As the lack of qualified staff is a major challenge, firms have to develop internal training programmes to re-skill existing workers or rely on a foreign partner.

ADP technologies offer new competitive solutions for individuals with specific needs

ADP technologies provide personalized cost-effective solutions for individuals with specific needs. The production of high-quality prosthetic limbs at an affordable price is a paradigmatic example. Using 3D printing technology and computer-aided design (CAD) programmes, Genesis Bionics manufactures personalized bionic prostheses at a more affordable price (between USD 1,000 and USD 2,000) than standard prostheses, which can cost ten times more. The possibility of affordable prosthetic limbs that are mechanically closer to the functional limb of a healthy person is an immense contribution to the quality of life of people with disabilities as well as to their social inclusion.

Case studies

Arçelik: Smart factories and skills for future manufacturing

Smart factories represent the latest advancements in the application of advanced digital production (ADP) technologies at the plant level. In smart factories, workers, products, equipment and machinery are part of a smart production system, whose components interact, exchange information, take decisions and implement actions through digital networks of sensors powered by real-time data analytics and artificial intelligence-based algorithms. Smart factories also use augmented and virtual reality to simulate real-world environments and optimize manufacturing and maintenance processes before they are actually carried out. This overlap of physical and digital infrastructure—the so-called cyber-physical system (CPS)—makes manufacturing operations faster and more efficient, and result in the production of a new generation of smart products of higher value added and a higher level of serviceability for customers. Due to the high level of interconnectivity and the intensive use of data in decision-making, operating a smart factory requires a very different set of skills than traditional manufacturing plants. According to Arçelik, an international consumer goods producer, building the right set of skills to work in a smart manufacturing environment represents the biggest challenge of the current digital transformation.

Arçelik is a Turkish company with decades of experience in durable consumer goods production. The company owns various brands (e.g. Beko, Grundig) and offers a wide range of products, from white goods to built-in products, electronic products, small home appliances, fitted kitchens, air conditioning systems as well as after-sales services. In 2002, Arçelik acquired Arctic, a long-established brand and market leader of domestic white goods in Romania. Building on the country's accumulated production experience and on the proximity with one of Arctic's refrigerator plant, which facilitated insertion in the existing supply chain, Arçelik opened its first smart factory for the production of washing machines in Romania in early 2019.

Arçelik smart factory produces washing machines with a new generation of ADP technologies. To optimize plant efficiency, the smart factory was first modelled and tested in a virtual environment, where technical infrastructure and processes could be simulated and optimized before being carried out in reality. Then, the digital infrastructure was designed to overlap with the physical one, with the goal of recoding the data of processes as well as human-machine-product and environment data, analysing them with the support of big data analytics, artificial intelligence and machine learning algorithms, and enforcing real-time decision-making to improve production processes and product performance through self-learning and automatic optimization. For instance, the production line was designed to embed various machine learning applications or smart processes, which automatically adjust process parameters according to quality control results.

The investment needed for the realization of such a smart factory was a bit higher, albeit not even double, of that required for traditional production plants. Since new technologies were mostly developed internally or in collaboration with partners (e.g. suppliers, satellite companies, universities, research centres) that helped generate new technological solutions, the company was able to experiment with the technology prior to making a final investment decision, thereby not having to purchase externally developed technology. This smart factory serves as pilot project: in future, all of Arçelik's production plants are to be converted into smart factories, and the first smart factory provides valuable learning experiences that will allow an optimization of the investment amount needed for the smart transformation of other plants, i.e. their realization may end up being even cheaper.

In addition to the necessary physical, digital and technological changes, the most important factor in terms of enforcing and achieving the digital transformation of production is related to work culture and skills. Workers need to be able to understand and apply ADP technologies if they are to properly integrate them in the production processes. As 90 per cent of the tasks require digital competences, employees need to possess a complex set of technical and digital skills, such as automation, coding, data management and analytics, network and data security, writing intelligent algorithms and integrating them into physical production processes and data-based decision-making. These 'hard skills' must be matched with a set of advanced 'soft skills', such as problem solving and learning abilities, teamwork, communication and negotiation skills. Soft skills are in fact crucial for smart factory operations, because the connectivity among all parts of the smart system—from suppliers to products to final customers—requires workers to coordinate with different actors, ultimately acting as platform managers.

The transformation from 'traditional' blue collar, mechanical and repetitive tasks to 'digital manager' type duties requires negotiation and coordination skills, and at the same time frees workers from laborious and hazardous activities. In this regard, although Arçelik has already introduced gender policies to promote the employment of women in all types of functions, the reduction of physically demanding tasks in smart factories could open up more opportunities for female workers. In addition to focussing on hiring qualified individuals, Arçelik also provides on-the-job training for its existing staff to re-skill them towards the required set of abilities, also in collaboration with local higher education institutions.

The application of ADP technologies contributes to enhancing efficiency and labour productivity, ultimately improving competitiveness (UNIDO 2019). In Arçelik's smart factory, all processes have been redesigned to become lean and more efficient; new technologies also allow enforcement of an agile and decentralized production system, where all processes are digitalized to enable end-to-end traceability of a product from the moment it is created in accordance with the customer's preferences up to delivery. This fully integrated digital infrastructure involves all actors, from suppliers to customers. Smart production thus relies on a close and real-time connection with suppliers. Arçelik's smart factory shares its production plans and quality information with suppliers in real-time through the use of an internally developed industrial digital platform. In future, the goal is to send predictive feedback directly to suppliers' production facilities, enabling them to take immediate actions and to adapt the process parameters. Arçelik also transfers ADP technologies to its direct suppliers so they can adapt to new technologies and avoid eventual inefficiencies due to the different skill requirements compared to traditional manufacturing systems; in addition, it incentivizes its crucial suppliers to move geographically closer to the smart factory with a co-investing model.

Competitiveness may also be affected by the changes in product characteristics. With the application of ADP technologies, the washing machines produced have become smart and differ fundamentally from traditional consumer goods. Being a digitally connected device, the washing machine can now communicate back to the manufacturer, improving performance and providing data for the development of customized after-sale assistance services.

Finally, aside from shaping future demand for skills and fostering competitiveness through production optimization and innovative products, ADP technologies can contribute to inclusive and sustainable industrial development by improving the environmental sustainability of industrial production (UNIDO 2019). In this regard, the smart factory's achievements are in line with Arçelik's green and innovative spirit, as new technologies allow for more efficient use of inputs and energy. With the use of interconnected sensors, compressed air usage and water and energy consumption can be automatically regulated according to changes in the production line's parameters; the continuous monitoring of flow rate and pressure in the compressed air system allows savings in energy consumption of up to 12 per cent. The smart factory also relies on a photovoltaic panel field with a capacity of 1 MW (equivalent to 1-year electricity consumption of approximately 350 houses), while a 700 kW thermal solar panel is used to support the plant's heating and cooling needs. This implies that 487 tonnes of CO_2 annually are not emitted into the atmosphere. Moreover, compared to other plants, the per product water consumption has been reduced by 84 per cent due to the fact that 54 per cent of the smart factory's annual water need is provided by rainwater and that the plant's water recovery capacity is around 70 per cent.

Genesis Bionics: Using 3D printing to provide innovative solutions for marginalized customers[20]

Artificial devices to address specific medical needs, such as prosthetic limbs, have been available for a long time. Today, as a result of the diffusion of digital technologies, bionic prostheses have become the most advanced solution for artificial prosthetic limbs, being mechanically closer to the functional limb of a healthy person. Various companies at the global level have been involved in the development of advanced bionic prostheses; the price

20 This case study has been conducted with the assistance of Nurshat Karabashov.

of such devices can reach USD 20,000 or more, and even the most affordable options still cost between USD 7,000 and USD 10,000. This price range is out of reach for people living in countries where the average monthly salary is around USD 300 and USD 500, i.e. in developing and low-income countries. Hence, even if demand for bionic prostheses is relatively high in some developing countries, no high quality, cost effective and competitive solutions are yet available in the market for this group of potential users. The development and diffusion of advanced digital production (ADP) technologies such as additive manufacturing (commonly known as 3D printing) allows for the manufacturing of such medical devices more quickly and at more affordable prices, even if they are highly customized and produced in relatively small batches.

3D printing technology allows for the production of small batches of parts and components without the need for costly tooling. Developed in the 1990s, this process contradicts traditional subtractive manufacturing: using conventional subtractive manufacturing methods, objects are constructed by successively cutting and removing material from a solid block or by pouring liquid raw material—such as plastic—in a mould. Using 3D printing, a 3D computer-aided design (CAD) model is converted into a physical object by assembling successive layers of material, usually plastic. Designers are now able to create designs that mimic natural structures that meet individual customers' needs. In addition to the production process's cost effectiveness, 3D printing of complex and unique parts allows for a new level of personalization and customization, at the same time significantly improving production times, customer satisfaction and competitiveness. Due to the development and more widespread use of 3D printing technology, bionic prostheses can now be manufactured within a short period of time at more affordable prices, with the possibility of customizing their functions according to the users' individual needs.

Kyrgyzstan-based Genesis Bionics is an example of how these new technologies can improve people's lives in developing countries. Genesis Bionics uses CAD programmes and 3D printing to manufacture customized bionic prostheses. Genesis Bionics is a start-up company that originated from an ENACTUS[21] project, involving students of the Kyrgyz State Medical Academy (KSMA) together with a surgeon specializing in hand surgery, who was also the main investor, and a robot programmer. In 2016, the team developed the first bionic prosthetic hand prototype. The team presented its project at the national competition "ENACTUS – 2018" in June 2018, during which a bionic prosthetic arm developed for a ten-year old girl was presented. That same year, the company was officially established and registered as Genesis Bionics. At the onset, the company relied on funds provided by the founder (USD 1,600) and USD 1,000 donated by U.S. citizens. These resources were used to purchase equipment and material from China and Russia, including the first 3D printer.

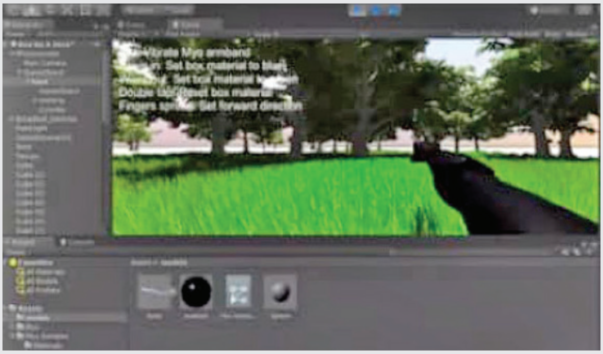
21 ENACTUS is the world's largest experiential learning platform, connecting students, academics and business leaders. Guided by educators and supported by business leaders, teams of students identify complex issues in their communities, elaborate potential solutions and are supported in the development of community-based projects.

The company possesses two 3D printers: a three axes 3D printer and a DLP 3D printer, which allows printing small parts with high accuracy. To design the individual parts of the prosthesis, the Genesis Bionics team uses the software 'Blender 3D', a CAD system that is free of charge, and the 'Simplify 3D' software to print the designed parts using the 3D printers. The team learned how to use the software and operate the 3D printers from online tutorials. Electromyography (EMG) is used for human interaction with the prosthesis. EMG is a method for analysing muscle activity: in practice, prostheses' microcircuits receive impulses from a chip implanted into the individual's arm and through the muscle, the prosthesis seizes the neuro-impulse and begins to perform the corresponding function. The use of a control system tailored to the individual's patterns of movement allows Genesis Bionics to create a natural interface between the person and the prosthesis. In addition to being non-invasive, the EMG developed by Genesis Bionics has impressive functionality, can be rapidly configured and is resistant to external influences.

By focussing on marginalized groups such as people with disabilities, whose needs are often disregarded and not adequately addressed by market solutions, Genesis Bionics significantly contributes to social inclusion and the sharing of prosperity and benefits associated with new technologies (UNIDO 2019). Using additive manufacturing, Genesis Bionics produces high-tech bionic prostheses at affordable prices: while the price for such advanced prostheses usually ranges between USD 10,000 and USD 20,000, Genesis Bionics's solutions cost between USD 1,500 and USD 2,000. This has had a considerable impact in Kyrgyzstan, a small developing country where the average monthly salary was around USD 250 in 2018. Moreover, Genesis Bionics produces bionic prostheses that are individually customized for each client, thereby adapting the prosthesis to the client's limb and not the other way around. Since it started its activities, Genesis Bionics has manufactured ten personalized bionic prosthetic hands. The company's experience provides an example of how additive manufacturing allows cost-effective production of small batches of personalized goods.

Genesis Bionics is a small enterprise. Aside from its founders, a surgeon and a robot programmer, the company employs two programmers/designers and two experts in medical sciences. Having originated within the scope of the ENACTUS project, the company has maintained close relationships with local universities and education institutions since its inception. Genesis Bionics regularly hosts students from the Kyrgyz State Technical University (KSTU) as interns, providing them training and practical experience. The collaboration with universities also encompasses research and development (R&D) activities; for instance, Genesis Bionics collaborates with academics at KSMA to further develop and refine the EMG.

The application of 3D printing technology not only allows for reductions in production costs and the final price of customized bionic prostheses, but also guarantees high quality and functionality. Far from being inferior to other, more expensive solutions offered by competitors, Genesis Bionics's prostheses have a number of advantages, such as a larger battery capacity (2200 milliamps compared to 550 milliamps of a competitor) that can be charged 'on the go' without removing it from the limb or using ordinary power plugs, and a lighter weight (around



Source: Genesis Bionics

1 kg compared to 2 kg of a competitor's product), as they are made of a photopolymer which is very light and strong. Moreover, eco-friendly materials are used to build the prostheses; they are manufactured using 3D printing technology from lightweight and PLA plastic based on sugarcane and corn.

As is the case of other applications of ADP technologies, the adoption of 3D printing may foster the development of further technological innovation. For instance, a unique firmware (control code) and prosthesis control chips were developed by the company internally, obtaining the copyrights. Genesis Bionics also provides its customers with an internally developed virtual reality game to train the muscles and improve comfort and precision in the use of the prosthetic hand.Genesis Bionics is currently working to improve its products, with the goal of expanding the functions of the bionic prosthesis and introducing machine learning algorithms to avoid false triggers when using the prosthesis as well as compression force control. Additionally, the company aims to improve the aesthetic appeal of its prostheses based on basic templates for the design of prosthesis parts for different age groups and body sizes, and to develop prosthetic legs. To achieve these improvements, the founder of the company has invested USD 6,500. The expected time to recover the cost of the investment is about three months after the launch of the new and improved bionic prostheses.

Access to a reliable digital infrastructure base was a necessary precondition for establishing and developing Genesis Bionics's activities. Due to high-speed (between 4 MB to 50 MB) and affordable internet in the Kyrgyz Republic, the company can use the internet without delays and learn how to use 3D modelling software and 3D printers online. The main challenge Genesis Bionics faces is the lack of qualified staff in the country. Since the curricula of the universities in the Kyrgyz Republic do not offer robotics and additive manufacturing courses, and there is a huge shortage of specialists in this technological domain.

Mahindra & Mahindra Ltd: Introducing cobots for a blended manufacturing workforce[22]

The latest wave of technological advancements associated with the fourth industrial revolution (4IR) is reshaping the manufacturing industry. Advanced digital production (ADP) technologies are creating unprecedented opportunities to increase efficiency and generate more value added, but the transformative scope of the 4IR in manufacturing goes beyond those benefits. As was the case of major technological revolutions in the past, ADP technologies also have a far-reaching impact on firms' business functions, activities and governance: new technologies have reached the point at which they can transform the way machines and humans interact in manufacturing plants. This can lead to significant changes of shop floor operations in the manufacturing sector which largely uses automation and machinery, such as in the automotive industry. Automotive manufacturing firms are becoming increasingly aware of the benefits associated with the integration of new production technologies with human work.

The automotive industry has traditionally been employing a large number of robots to automatize standard and repetitive tasks, or which required the use of manual labour. Despite this, traditional assembly lines still required human intervention to complete non-routine or specific tasks requiring high concentration. Aside from increasing the risk of errors affecting the quality of the final product, this often implied unsafe work conditions. The development of ADP technologies such as collaborative robots (commonly known as cobots) represents an innovative solution for both of these issues.

Cobots physically interact with humans in a shared workspace. They are designed to collaborate with workers to carry out tasks that ensure greater accuracy and precision in production. One key advantage is the technical features designed to ensure that they do not cause harm when a worker comes into direct contact with them, whether deliberately or by accident (IFR, 2018). These features include “skins” (padding with embedded sensors) and sensors at the robot base or joints that measure and control force and speed and ensure that they do not exceed defined thresholds if contact occurs. The experience of the Indian group Mahindra & Mahindra Ltd. (M&M), a dominant player in the tractor and automobile industry, exemplifies how the introduction of cobots can significantly improve working conditions and simultaneously provide various benefits, from productivity and quality gains to input optimization and cost reduction.

M&M is a USD 20.7 billion multinational group and a market leader in the Indian sport utility and multi-utility vehicle sector, and it is the world's largest tractor company in terms of volume. It has manufacturing firms at various locations in India and abroad. The M&M plant located in Kadndivali (India) has been leading the introduction of a number of initiatives in the area of digital manufacturing, including the integration of cobots to its assembly line for ring gears and vehicles.

22 This case study has been collected with the assistance of Rajeev Vijh form UNIDO India.

One specific example of the use of cobots is their integration in sealant application operations in the ring gear assembly line. Previously, the application of loctite sealant was carried out manually, which raised two types of challenges: not only manual operations were more prone to errors and inaccuracies, these obstructing the quality of the final product, but also workers' safety conditions were endangered by the risk of direct skin contact with hazardous materials such as sealants. Designing and installing traditional industrial robots to perform this task would have required a rearrangement of the entire production line to obtain the necessary physical space. Instead, M&M developed the innovative solution of employing cobots.

The application of cobots led to significant improvements in terms of safety and working conditions for line workers. Facilitating the partnership between robots and humans is indeed one of the greatest advantages of introducing cobots. The cobots employed in sealant application had to be integrated into the existing production line to not interfere with other activities and to optimize coordination with the workers' duties, who continued carrying out the remaining activities as they did earlier and monitor the process. As cobots are relatively easy to use and programme, their introduction did not require extensive training for workers to be able to interact with them. On account of their design, the use of cobots instead of traditional industrial robots also eliminates the need of safety fencing and barriers to protect workers from being injured by robots during production activities. This implied a more comfortable organization of the workspace and improved workers' freedom of movement. In addition, employing cobots in sealant application significantly increased the safety of operations by reducing the risk that workers come into direct skin contact with hazardous materials, such as sealant. Finally, ergonomic working conditions also make work easier for employees. Thus, cobots significantly improved the overall working conditions on the shop floor.

The introduction of cobots also led to multiple benefits in terms of increased quality and productivity, thus contributing to fostering the competitive performance of the M&M plant in Kadndivali (India). The cobots considerably improved the efficiency and quality of sealant application. The sensor mounted on the cobot's arm ensures precise location of part holes. The quantity of sealant dispensed in each hole of the ring gear is pre-programmed, thus ensuring accuracy as well as optimal use of this input, leading to significant cost savings. Moreover, the replacement of small sealant bottles previously used by workers with larger 20 kg bottles also allowed for the reduction of hazardous wastes. A new technology of vision system integration was also applied, with embedded cameras checking and recording task quality, allowing for real-time monitoring of performance. Together with the use of

Loctite sealant application: manual versus cobot
Source: Mahindra & Mahindra

a digital checklist between the individual process steps, this resulted in a significant decrease in the frequency of errors and an increase in efficiency. Since their introduction, it has been estimated that the cobots led to productivity improvements in the ring gear assembly line of around 8.4 per cent. With these performance results, the time in operation required to recover the initial investment was 1.5 years. Involved in various dimensions of a firm's activity and performance, cobots seem to entail significant multi-dimensional benefits. This represents a case for traditional automotive manufacturing to adopt new technologies to create value and foster competitiveness. In the case of M&M, the successful implementation of the project set the stage for a fully-fledged implementation of the use of cobots in M&M manufacturing plants. Consequently, additional 10 cobots will be integrated in the production operations at the Kandivli plant, in addition to another 15, which will be installed at other M&M plants.

The application of cobots is, however, not free of challenges. As a new industrial technology that is still being developed, the integration of cobots in the production line is still characterized by trials and errors. Most criticalities derive from the technological difference between new technologies and existing production equipment into which cobots need to be to fully integrated. Moreover, to be able to fully exploit the advantages of their collaborative design, cobots' way of operating needs to be understood by workers. As a new technology for the company, the introduction of cobots initially posed new challenges in terms of facilitating the collaboration of humans and cobots on the shop floor.

From challenges to policy responses: Setting conditions for engaging with ADP technologies

Areas of policy action to adapt ADP to ISID

Developing framework conditions

Developing framework conditions	International collaboration and technology transfer

The adoption of ADP technologies requires significant efforts to develop the necessary framework conditions. These framework conditions include regulations, digital infrastructure and the institutionalization of multi-stakeholder approaches to industrial policy formulation. A clear emphasis should be placed on the institutional setting for policy, which is particularly important to adapt advanced digital production (ADP) technologies to inclusive and sustainable industrial development (ISID). A new industrial policy formulation in this context should be based on close collaboration between the private and public sector. In this respect, policies should promote the establishment of connections with international initiatives and foreign partners. The opening of channels for international collaboration allows firms in developing and emerging economies to tap into global knowledge and benefit from technology transfers.

Case study

Implementing the Sino-German Smart Manufacturing Cooperation agreement: Siemens and Baowu[23]

With the Memorandum of Understanding (MoU) linking the countries' national strategies—Made in China 2025 and Industrie 4.0—China and Germany agreed in 2015 to promote the readiness of their respective economies to adopt advanced digital production (ADP) technologies associated with the fourth industrial revolution (4IR). The MoU was signed by the China Ministry of Industry and Information Technology (MIIT) and the German Ministry of Economy and Energy. Standing out among the proposed activities is the promotion of networks of Chinese and German enterprises collaborating in the implementation of smart manufacturing projects. This collaboration is already bearing fruits through a Sino-German Industrial Park jointly established as a platform to connect Chinese enterprises and German technology.[23]

Under the Sino-German Smart Manufacturing Cooperation agreement, the Chinese MIIT selected pilot projects among Chinese firms in 2016, which had submitted proposals for a development strategy. The MIIT promoted the establishment of a commission of Sino-German experts to evaluate projects and identify the first batch of 14 pilot demonstration projects. This first batch included the project for the application of ADP technologies in the iron and steel industry involving the China Baowu Steel Group Corporation[24] (commonly known as Baowu) and Siemens. In 2016, with the endorsement of both the Chinese and German governments, Baowu and Siemens signed a strategic agreement.

Based on Baowu's existing automation equipment, Siemens carried out targeted improvements of previously deployed digital systems. For example, Siemens used the factory engineering design and management software COMOS to establish a digital platform connecting the entire production line using existing production equipment. Siemens supported Baowu's upgrading to smart production by adopting COMOS in several production plants, an engineering and management software that enables remote intelligent monitoring, mechanical diagnosis, fault warning and equipment end-of-service prediction.

The cooperation between Baowu and Siemens is already generating positive outcomes. First, a joint working group was set up to focus on the diagnostic of criticalities in the Chinese steel companies and compare them with features of Siemens products. After considering a wide range of issues such as blueprint, feasibility studies, project implementation and intellectual property rights, 12 research areas were identified. The most relevant for transitioning towards

23 This case study has been conducted with the assistance of Hongfei Yue.

24 See the firm case study "China Baowu Steel Group Corporation: Introducing smart production into the steel industry."

a smart manufacturing production model were digital factories, simulation, industrial big data, industrial networks, security architecture and smart logistics.

Second, the project implementation plan was formulated with short-term, medium-term as well as long-term goals, representing the schedule for the cooperation between the two companies.

Third, an intellectual property cooperation and sharing mechanism was also defined. It established that the intellectual property or patents derived from technological novelties in steel production developed during the project are shared by both sides. An example is the first smart running crane carrying molten metal designed by Siemens for Baowu in cooperation with Taiyuan Heavy Industries, which has been in operation in Baowu's facilities since March 2018. Since the beginning of the collaboration, nine patent applications have been submitted.

Last but not least, the scope of project cooperation was expanded from the project itself to product life cycle management, supply chain, technology innovation, intellectual property, corporate culture, personnel training, legal and regulatory research.

Fostering demand and adoption

Fostering demand and adoption	Access and affordability of ADP technologies
	Awareness of use and benefits of ADP technologies
	Readiness of vulnerable actors, such as small- and medium-sized enterprises

Countries need to foster the demand and adoption of new technologies. This requires concentrated policy efforts to raise awareness of firms of the potential use and benefits of such technologies, together with facilitation of funding for their adoption. Policy initiatives should include targeted support for actors (for instance, small- and medium-sized enterprises, (SMEs)) that are lagging behind from a technological perspective.

Case studies

Fostering the adoption of cloud computing in Zhejiang Province, China

Cloud technology is a general term for information sharing, management platforms and other application technologies based on cloud computing. Relying on a shared pool of configurable computing resources, this technology enables users to conveniently share and utilize resources on-demand, including computing, storage, application software, services as well as networks.

For industrial enterprises, the adoption of cloud computing can be a game changer in terms of competitiveness and performance. Cloud technology makes it easier to record and use produced data, strengthen security protection, coordinate business functions and reduce production costs by enabling industrial equipment to perceive, transmit and self-diagnose problems in real-time. In manufacturing production, cloud technology is also increasingly involved in recording and analysing production parameters to test processes and improve efficiency. Thus, supported by big data analytics and artificial intelligence, this new technology may indeed help manufacturing companies optimize their operations.

Cloud computing has become the symbol of the potential benefits associated with the fourth industrial revolution (4IR). Given its potentials, fostering the diffusion and adoption of cloud computing among industrial actors has become the object of policy initiatives around the world. In China, the local government of Zhejiang Province has promoted an effective action plan to raise awareness about cloud technology and the benefits of its application, and to encourage firms to integrate this technology in their industrial production processes.

In April 2017, the local government of the Zhejiang Province launched an action plan to promote the adoption of cloud computing, entitled ‘Enterprises Deploying the Cloud.’ The initial target was to assist 100,000 firms between 2018 and 2020. Within one year from the action plan’s launch, over 218,000 firms in Zhejiang Province had deployed cloud computing, bringing the total number of adopters by the end of 2018 to 268,000.

To implement the action plan, the Zhejiang government first established a coordinated mechanism involving the province-, city- as well as county-level governments, with the aim of mobilizing public awareness about cloud computing through the organization of public meetings, seminars and similar activities. Each city in Zhejiang Province had to develop a strategy to involve the main industries and firms with a local presence. In 2017, over 1,100 seminars were organized, reaching more than 90,000 enterprises and 100,000 participants. Each industrial firm, regardless of its size or type, was invited to attend the seminars aimed at enhancing firms’ willingness and practical capacity to use cloud technologies.

In a second stage, the Zhejiang government selected a number of applications for participation in cloud application projects in various fields, such as advanced manufacturing, trade and commerce, information services, energy and power as well as bio-pharmaceuticals. All enterprises registered in Zhejiang Province could apply. At the same time, the local government established a cloud service platform to link actors with relevant cloud technology or industry expertise—such as well-known cloud service providers (e.g. Alibaba ET Industrial Brain[25]), cloud technology developers, software and hardware developers, as well as industry associations—that could assess the applications and formulate more detailed cloud transformation projects. The Province also pushed for the development of 12 specific industrial cloud application platforms in the fields of textile, commerce, finance and intelligent customer service.

As regards financial support, the Zhejiang government introduced diverse financial schemes to facilitate the adoption of cloud technology and foster related technological innovations. The firms that applied for cloud adoption projects were expected to cover the bulk of the costs, while cloud platform service providers provided discounts or lower costs. Moreover, the implementation of a voucher scheme reduced the costs for firms which could redeem the vouchers with cloud platform service providers. On the basis of technical evaluation, the government also selected certain companies that, due to their strategic economic importance, would benefit from subsidies and serve as pilot or demonstration projects. The local government also pooled funds to support training in cloud technology and the organization of case studies to help companies learn from good practices.

In addition to providing training and financial support, the Zhejiang government promoted the implementation of a differentiated cloud strategy for different firm sizes and stages of development. For small enterprises, the first step is to ensure access to basic cloud computing applications. The complexity of the applications increases with firm size and technological level: in large- and medium-sized enterprises, the application of cloud computing requires a deeper transformation of the production process with the integration of other advanced digital production (ADP) technologies. In this respect, the government collaborated closely with cloud service providers, system integrators and third-party organizations to establish an information communication platform for industrial firms.

The Zhejiang Province's initiative played a significant role in raising awareness, mobilizing and enabling more manufacturing firms to better understand the potentials of the industrial applications of cloud technology. In future, instead of transferring knowledge to firms, the government should record the experiences of selected enterprises in adopting cloud technology and share the lessons learnt from these experiences.

25 See the case study "ZC Rubber: Improving rubber production with cloud computing and big data analytics."

Facilitating SMEs participation in smart manufacturing with C4i4 Lab in Pune, India

Make in India is the Government of India's key national strategy to foster investment, promote technological innovation and enhance skill development to transform the country's manufacturing sector into a world-class industry, prepared to face the challenges as well as to reap the benefits associated with the fourth industrial revolution (4IR). Through the Make in India initiative, the government seeks to combine industry and Internet of Things (IoT) technologies to foster the Indian manufacturing sector's competitiveness.

With the mandate to support the implementation of Make in India, the government established four new centres to promote the adoption of advanced digital production (ADP) technologies associated with 4IR in manufacturing in 2017. The focus of the activities is enhancing the manufacturing sector's competitiveness based on a better understanding and broader adoption of ADP technologies. Though they are independent, the centres fall under the auspices of the Ministry of Industry, Department of Heavy Industry. A triple-helix approach—academia, industry and government—guides their operations. The involvement of the private sector through actors such as technological leaders, large companies and industry associations is an important component of this initiative. Two of these centres are located in Bangalore, and the others in New Delhi and Pune.

Despite their common mission, the four centres work on different projects and take slightly different approaches in promoting the adoption of new technologies. Their activity tends to be tailored to the local industrial specialization as well as the local conditions and competences. While the centre in New Delhi primarily engages automotive industry actors surrounded by a dynamic ecosystem of manufacturing companies, the centres in Bangalore are more oriented towards supporting R&D activities in collaboration with software solutions providers. The centre in Pune (C4i4 lab) offers an interesting example of a policy initiative that focusses on the involvement of small- and medium-sized enterprises (SMEs) integrated in global value chains (GVCs).

C4i4 lab operates within a large manufacturing base, as many manufacturing firms have their base in Pune, most of them being tier-1 and tier-2 suppliers in integrated GVCs. Given the importance of SMEs in terms of share of total employment, the centre concentrates its efforts on supporting local SMEs. With a preliminary diagnostic study to determine their main challenges around smart manufacturing, the centre realized that the lack of information about the potential applications and benefits of ADP technologies was one of the main issues preventing their adoption in local SMEs. Thus, the centre's activity focusses on raising awareness about the practical application of ADP technologies in manufacturing.

C4i4 lab organized workshops and practical hands-on demonstrations with examples of ADP technology applications in manufacturing processes, providing the space and equipment to familiarize SMEs and let them experiment with these new technologies. To build confidence and incentivize firms to take the first step towards 4IR, it also offers assistance in the development of pilot projects, for example, by partnering with local developers to realize digital cost-effective solutions tailored to the needs and production conditions of SMEs. In fact, a common issue SMEs face is that the cost for specific and tailored solutions is quite high. By helping SMEs coordinate and aggregate their challenges, a unique call can be issued to local developers, allowing them to share the costs among all SMEs that benefit from the results. The centre thereby also makes it easier to consolidate demands from SMEs, at the same time representing an opportunity for local providers of digital solutions.

Thus, the centre's activity does not focus on raising awareness about the threads of automation, for example, in terms of employment. On the contrary, the focus is on emphasizing the potential benefits of applying new technologies associated with improvements in competitiveness owing to predictive output, improvements in reliability and responsiveness to customers and in delivery by avoiding logistics bottlenecks. All of these benefits do not have to come at the cost of reducing the labour force; they lead to an improvement in the speed and effectiveness to respond to customer and demand.

The adoption of new technologies is not a technological challenge. The main challenges are associated with new ways of managing business, organization as well as mindset. Moreover, the successful implementation of new technologies also requires nurturing close relationships with industry associations, fostering interaction with higher education institutions both for training and skill development, and involving college graduates in various activities.

In terms of financial support, C4i4 lab in Pune received a public grant of USD 2 million and raised an additional USD 700,000 in private funding. The idea is that the centre should not rely on public funding only, but will continue working and collaborating with industry associations and raise funds through cost-sharing mechanisms with the firms that benefit from assistance.

Supporting Malaysian manufacturing firms in embracing the fourth industrial revolution[26]

Malaysia is a multi-ethnic, middle-income[27] country, with an abundance of natural resources. Primary commodities were the main drivers of growth in the early days of independence, as the country was the world's largest producer of natural rubber and tin ore. The country's reliance on primary commodities, however, posed considerable challenges, particularly in terms of vulnerability to volatile global commodity prices. In the early 1980s, the government pushed for a diversification strategy to move into higher value-added activities, implementing a series of policy measures promoting manufacturing and services. These efforts led to a marked increase in the significance of manufacturing: in 2017, the sector accounted for 75 per cent of total export value and 23 per cent of GDP[28]. Today, Malaysia aspires to further strengthen its position as a relevant player in regional and global production value chains and to becoming a primary destination for high-tech industrial production. The surge of the fourth industrial revolution (4IR) is already changing the global manufacturing landscape. More and stronger policy actions are needed to ensure that the country remains a preferred manufacturing location for global manufacturing.

The Malaysian government is aware of the importance of adapting the manufacturing industry to 4IR and to integrate the most advanced digital production (ADP) technologies in production systems, as well as of the challenges transformation pose. The mid-term review of the 11th Five-Year Malaysia Development Plan (2016-2020) identifies technology adoption as one of the main obstacles[29] to productivity growth, highlighting how investments in technology and digitalization at enterprise level are still low. According to the Malaysian Ministry of International Trade and Industry (MITI), the average technological level of Malaysia's manufacturing production currently ranges between mass production and automation. Consequently, the government has been promoting policy measures to bolster its vision into action, with the aim of deepening the adoption of advanced technologies and automation and of increasing the number of skilled and knowledge workers in the manufacturing labour force. Despite the growing number of policy initiatives at national, state and regional levels, promoted by both the government and industry, a streamlined and cohesive national agenda under which these initiatives could be integrated and accelerated was missing. This gap was filled in 2018, with the launch of a comprehensive national policy framework on ADP technologies in manufacturing.

In May 2017, the Cabinet tasked MITI, the Ministry of Science, Technology and Innovation (MOSTI) and the Ministry of Higher Education (MOHE) to lead the creation of a national policy

26 This case study has been conducted with the assistance of Nidhi Sharma.

27 World Bank income classification 2018.

28 Malaysian Investment Development Authority (MIDA), Department of Statistics (2018).

29 Other obstacles and challenges include talent, industry structure and accountability, business environment and mind set.

framework. A high-level task force (HLTF)[30] headed by MITI was established to follow the development of the strategy and consider stakeholders' feedback, such as industry. Five main themes were identified as being fundamental for the transition of Malaysia's manufacturing sector in the face of 4IR: i) upskilling and reskilling of the existing and future labour force; ii) inclusion of small- and medium-sized enterprises (SMEs); iii) considerable developments in innovation capabilities and collaborative platforms; iv) focussed funding support to kick-start adoption of new technologies; v) adequate digital infrastructure. These themes represent the backbone of the national strategy that was launched in 2018.

In October 2018, MITI launched the national strategy 'Industry4WRD: National Policy on Industry 4.0'. The strategy focusses on fostering the adoption of ADP technologies in the manufacturing and manufacturing-related services industries. The policy document identifies some strategic enablers—derived from the five themes identified during the formulation of the strategy—that can leverage the digital transformation of firms. Identified by the abbreviation F.I.R.S.T, these are:

- Providing **Funding** and outcome-based incentives
- Creating enabling ecosystems and efficient digital **Infrastructure**
- Ensuring of **Regulatory** framework and industry adoption
- Up-**Skilling** existing and ensuring future talent is generated, and
- Providing access to smart **Technologies**.

Specific action plans have been developed to achieve sectoral goals and to involve relevant actors, some of who received funding from the government and others from industry initiatives. Following the publication of the 11th Malaysia Plan Development Plan (2016-2020), the Industry4WRD distinguishes catalytic and high-growth potential industries (electrical and electronics, machinery and equipment, chemicals, aerospace and medical devices) "as game changers for the manufacturing sector" from other more mature high-growth sectors (automotive, textiles, transport and pharmaceuticals). An action plan fosters the adoption of 11 advanced technologies[31] associated with 4IR to increase productivity and competitiveness in the catalytic and high-growth potential industries.

30 The task force included the Ministry of Finance (MOF), Ministry of Multimedia and Communications (KKMM), Ministry of Human Resources (MOHR), Ministry of Education (MOE), and Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC).

31 Malaysian Department of Statistics. https://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=159&bul_id=cEI0bklp-ZHJaTlhRNDB3d2ozbnFIUT09&menu_id=TE5CRUZCblh4ZTZMODZIbmk2aWRRQT09

SMEs, including microenterprises, have been integral to Malaysia's economic transformation process. Particular attention is paid to SMEs, given their significance for the country's economy: in 2017, 36.6 per cent of Malaysia's GDP originated from these actors, whose share of exports corresponded to 17.3 per cent and contributed to 66 per cent of total employment[32]. SMEs typically display lower levels of activity and collaboration in research, limited access to highly qualified human capital, and a lack of investment in strategic planning. SMEs need to transform their production modes into advanced manufacturing modes of production or risk being left behind. To support SMEs in exploiting the potential of new technologies within the scope of the national strategy Industry4WRD in 2019, the government launched Industry4WRD Readiness Assessment, a programme to help determine SMEs' readiness to adopt ADP technologies, identify gaps and areas for improvement for smart manufacturing, and to raise the technological capabilities of 500 SMEs between 2019 and 2021. The programme will allocate MYR 210 million. The proposed assessment tool focuses on three shifting factors—people, process and technology—and uses a predetermined set of indicators to understand present capabilities and gaps and to enable firms to prepare feasible strategies and plans for technological upgrading. One of the assessment's novel features is a module tailored to manufacturing-related services. Readiness is measured based on points scored by the assessed firm. A first call in March 2019 received around 300 applications, and the government is planning to expand the programme and conduct more intensive awareness activities, especially in smaller cities.

The implementation of Malaysia's industrial transformation will require a concerted effort across many ministries and agencies, industry, research facilities and academic institutes. MITI will supervise and chair the Malaysia Industry4WRD Council, as well as work with various working groups to coordinate all stakeholder activities and drive progress.

For a general impact assessment, the strategy also identifies four measurable targets: i) to increase the level of manufacturing labour productivity by 30 per cent; ii) to elevate the manufacturing sector's total contribution to the economy from MYR 254 billion to MYR 392 billion; iii) to strengthen the improvement of the country's innovation capacity and capability, reflected in climbing from 35th to the top 30 in the World Intellectual Property Organization's Global Innovation Index by 2025; iv) to increase the number of high-skilled workers in the manufacturing sector from 18 per cent to 35 per cent.

The national strategy Industry4WRD represents an important step towards boosting manufacturing and moving the country towards its goal of becoming a developed, inclusive, equitable and sustainable economy. The proposed action plans demonstrate the government's commitment to creating a supportive policy environment to provide businesses with stability and to allow them to execute these long-term strategies of technological upgrading. This will help position the country as an attractive hub for high-technology, as well as for innovative and high value-added industries in years to come.

32 Additive manufacturing, artificial intelligence, big data analytics, advanced materials, cyber-security, virtual simulation, could computing, augmented reality, Internet of Things (IoT), autonomous robots, system integration.

While it is still too early to assess the impact of the national strategy Industry4WRD, Malaysia's commitment, policy-backed, holistic, coordinated multi-partner approach exemplifies how a country can foster the adoption of new technologies and at the same time pursue an industrial development model that has far-reaching impacts across industries, societies and the broader economy.

Supporting technological innovation within the realm of the fourth industrial revolution in Pakistan[33]

The Pakistan National Technology Fund—known as Ignite[34]—was established in 2006 with the aim of funding innovative technology and entrepreneurial projects. Convinced that creativity and innovation will make the difference in the fourth industrial revolution (4IR), Ignite's mission is to "fix the innovation value chain in Pakistan." In the past two years, the fund has supported around 40 innovative projects with a total investment of about USD 7 million.

Closely tied to the Ministry of Information Technology (IT) and Telecommunication, Ignite is financially supported by the Government of Pakistan, which collects and transfers contributions from the licensees of the Pakistan Telecommunication Authority. These contributions, which correspond to half a percentage point of the telecommunication providers' gross revenues, are allocated to the fund, representing its main financial source.

Operating under the auspices of the Ministry of IT implies that Ignite is not part of the country's industrial policy. The majority of projects funded result in technological innovations, whose exploitation and commercialization often involve manufacturing and production processes.

In terms of financial support, Ignite has promoted innovation in various ways, such as through seed funds, final year project (FYP) funds, incubation and trainings. Seed funds are used for innovative start-ups that deploy new technologies associated with 4IR to address local problems and to simultaneously exploit emerging business opportunities in the health, education, energy, telecom, finance and other sectors. Following a review process, the applicant receives assistance in fulfilling any missing requirements and in refining the application. If the assessment of the application is positive, it is forwarded to two external industry experts, who further evaluate it and forward the application to a high-level team for final approval. The basic selection criteria for applications to the seed fund programme include an elaboration of how the new 4IR technologies will be used, prospective job creation and export orientation. FYP funding, on the other hand, aims to give students the opportunity to realize prototypes and models of their ICT-centred final year projects (FYPs), to showcase their creativity and innovation abilities and apply hands-on engineering skills. Ignite furthermore

33 This case study has been developed with the assistance of Azhar Zia Ur Rehman.

34 www.ignite.org.pk

supports a national network of incubators that aim to nurture start-ups and link them with mentors, investors and corporations. This network currently includes five centres scattered around Pakistan, namely in Islamabad, Lahore, Karachi, Peshawar and Quetta.

Innovation is also promoted through skill development of a broader audience. In this respect, Ignite launched the DigiSkills.pk programme aimed at providing youth, freelancers, students and professionals with the necessary knowledge, skills, tools and techniques to seize the opportunities offered through online job market places, internationally as well as locally. The skills promoted under this programme are related to the use of new technologies, whose relevance is rising in the face of 4IR. In addition to training and financial support, the fund includes corporates, professionals, entrepreneurs, academics, media and policymakers in Ignite programmes, with the aim of raising awareness about the advantages of 4IR as well as about its challenges and threats, and informing them about the importance of innovation in the new reality.

The programmes funded by Ignite cover a wide range of domains—from medical to agriculture, engineering, education, manufacturing—that will potentially be affected by the surge of 4IR technologies. The Medical Devices Development Centre (MDDC) exemplifies how a project supported by Ignite can lead the transition towards 4IR in a country like Pakistan, and even compete with global leaders from wealthier countries in terms of innovation, functionality and product quality.

The primary goal of MDDC is to harness the capacities of academia and industry to locally design, develop and produce quality medical devices at competitive prices. Due to its focus on technological innovation for health solutions, the project has been co-funded by the Ministry of Science and Technology. MDDC’s activity combines biotechnology, engineering, computer science and manufacturing technology. A team of around 35 qualified professionals conceive, design, prototype, test and even produce quality medical devices. For example, MDDC’s team has designed an innovative stent system integrated with a smart displacement sensor. The product combines the advantages of a coronary stent system with non-invasive monitoring capabilities. In fact, using radio frequency (RF) technology, the stent system can monitor health conditions and communicate real-time data to clinicians. For patients who are not hospitalized, the RF device can notify the patient to visit the hospital based on changes sensed in the patient’s health condition, and allows for modification of the treatment plan without the need of expensive or invasive diagnostic procedures. Thus, this novel stent can really function as a real-time monitoring system, helping enormously in preventing problems caused by delays in diagnosis or treatment. In addition to offering an innovative and high-quality solution, the stents also cost significantly less than other commercially available stents, thus bringing treatment within the reach of most of Pakistan’s population. Other products being developed by MDDC are a heart valve and a quantitative wound treatment system that monitors the wound and applies treatments based on its level of healing. The latter has already been commercialized in collaboration with a commercial company in Karachi.

The biggest challenge after design and development is being able to successfully commercialize products. MDDC is an example of how technology can be transferred all the way from university laboratories to commercial production. In this respect, MDDC has also been involved in the design and development of the production systems needed for manufacturing its products. These production systems cost a small fraction of similar systems sold in the international market, and MDDC can thus license out the entire manufacturing technology, in addition to engaging in direct production. MDDC's production capacity is currently being expanded to be able to cater to both Pakistan and export markets. The new production facility will host an automated smart manufacturing system integrated with an interconnected control system using advanced production (ADP) technologies, such as the Internet of Things (IoT).

Building and strengthening capabilities

Building and strengthening capabilities	Development of human resources

Governments can support firms in building and strengthening the necessary capabilities to be able to adopt and effectively use ADP technologies. Policy initiatives should include the development of dedicated learning centres and new approaches to technical and vocational education and training that are aligned with the emerging requirements of firms in terms of skills and abilities. Particular attention should be paid to the re-skilling of existing workers and allowing them to participate in the ongoing transformation of manufacturing jobs.

Case study

Facilitating firms in Penang Automation Cluster (Malaysia) in becoming regional and global players[35]

The Malaysia Productivity Blueprint launched in May 2017 identified the electrical and electronic products sector as one of the priority sub-sectors with high growth potential. In fact, this sector accounted for over 38.78 per cent of Malaysia's total exports in 2017, whose major export destinations are China, the United States, Singapore, Hong Kong SAR, China and Japan, and attracted the highest amount of foreign investments (84.5 per cent), mostly from Singapore, the Netherlands, Japan, and Germany[36]. The sector is expected to continue growing in upcoming years and to generate a gross national income impact of MYR 53.4 billion and to create 157,000 new jobs. The 2018 Malaysian American Electronics Industry (MAEI) Survey Report states that the electrical and electronic products sector has enabled Malaysia to successfully position itself in the global supply chain of electronic manufacturing services, outsourced semiconductor assembly and testing as well as in research, design and development[37].

The success of Malaysia's local electrical and electronic products sector started in the 1970s with the establishment of the Free Trade Zone (FTZ) in Penang. Penang, located in the northern region of the country, has developed and transformed from a stagnant and quiet state in the 1970s into one of the most dynamic and competitive states in Malaysia. Attracted by the incentives offered by the FTZ, the first eight manufacturing companies were established by multinational companies (MNCs) in 1972. Since then, the manufacturing sector has become Penang's economic backbone, making up 44.7 per cent of its commercial activity and contributing 12.8 per cent of Malaysia's manufacturing output in 2015[38].

Although high level of technology diffusion in Penang is attributable to various factors, the local government has played a crucial role. The Penang regional government and the state development agency Penang Development Corporation (PDC) actively promoted initiatives to attract foreign firms specialized in electronic products, which resulted in a potential for synergies. Some of the MNCs that were attracted—such as Intel, Motorola and Dell—were strongly committed to fostering the development of local innovation and to generating cluster dynamics. Their presence fostered the enhancement of skills and the consolidation of an entrepreneurial base in the region, which is a prerequisite for an endogenous process

35 This case study has been conducted with the assistance of Nidhi Sharma.

36 Malaysia Productivity Blueprint 2018.

37 www.thestar.com.my

38 The Edge Market special report 2017. https://www.theedgemarkets.com/article/special-report-penang-manufacturing-ready-industry-40

of technological diversification and sectoral specialization. This generated a positive dynamic, attracting scientists and engineers in large numbers. The number of highly-qualified professionals in the region today is several times higher than Malaysia's average.

The ecosystem of Penang's electrical and electronic products sector mostly relies on a network of over 3,000 local suppliers, albeit not only, operating in automation, electronics, packaging, plastics, precision engineering and metal work as well as software development. Local companies not only assemble, test or supply component parts, but also develop the machinery and equipment used to assemble and test the electronic parts, thus building original equipment manufacturing (OEM). These increasingly sophisticated machines play a critical role in the process of advanced automation, one of the advanced digital production (ADP) technologies associated with the fourth industrial revolution (4IR). The local government believes that with the right level of support and coordination, these local companies can lead the electrical and electronic products sector towards 4IR. Companies like ViTrox, Pentamaster and Walta, for example, underwent steep learning curves due to customers' (MNCs) stringent requirements in terms of high precision, high accuracy and international standards. These local companies became important players in the global value chain in electrical and electronics, obtaining the status of Large Local Companies (LLCs). Today, these LLCs actively contribute to the development of a local ecosystem by identifying and providing support to local SMEs, as they typically find automation to be expensive, challenging or out of their firm's capacity or skill set. Their experience led to the establishment of the Penang Automation Cluster (PAC) in 2016.

PAC was formed as a joint venture of three LLCs—ViTrox Corporation Berhad, Pentamaster Technology (M) Corporation Berhad and Walta Engineering Group—with the aim of driving the growth of local SMEs, especially in precision metal fabrication within the automation cluster. PAC is an industry-led initiative, but was supported with investments by the state agency Penang Development Corporation (PDC). It also had the local government's full support, which offered a five acre plot at the Small Medium Industries (SMI) Village Batu Kawan Industrial Park at a special discounted price. The local government also offers tax incentives and grants for training, R&D, equipment, tools and shared services facilities for this cluster. The realization of PAC will be completed by the end of 2019.

The LLCs promoting PAC are leading companies in Penang's electrical and engineering industry, specialized in design, development and the manufacture of high precision metal fabrication components, modules and systems for automation, semiconductors, electronics, automotive, aerospace and other high growth industries in the region. These LLCs are introducing ADP technologies such as data analytics, the Internet of Things (IoT) and machine-to-machine communication in manufacturing processes in PAC. One example of their technological level is the development of ViTrox's V-ONE, a software-based solution and a highly customizable platform that enables data-driven decisions in production processes by allowing for control, visualization and monitoring. Implementing these technologies in manufacturing processes allows users to detect issues in real-time and to receive alerts on faults via a mobile application, email or SMS.

PAC's experience exemplifies how leading local companies can contribute to the development and strengthening of local technological capabilities and of the local supply chain ecosystem. Once completed, PAC aims to house various SMEs (currently 18) to carry out activities including precision engineering and sheet metal fabrication, tooling, machining, finishing and coating services, all of which are necessary to produce components to make high-end testing equipment designed and manufactured by the three main shareholders. It will provide business opportunities, coaching and training to cluster SMEs to upscale their work performance in order to supply competitive products. This will accelerate the development of capabilities of SMEs and allow PAC to become a world-class SME precision metal fabrication cluster, providing a one-stop metal parts supply chain hub through collaborative efforts between LLCs and SMEs. In terms of job creation, PAC is expected to generate about 500 skilled jobs and to achieve a total local large company revenue of MYR 980 million by 2021.

The focus in PAC is providing training activities to foster the development of skills and capabilities needed for the technological transformation of the electrical and electronics sector. Qualified employees have the opportunity to attend the German Dual Vocational Training (GDVT) course offered by the Penang Skill Development Centre (PSDC), aimed at equipping them with the skills required to use the new technologies. PSDC was established in 1989 and is the first tripartite, industry-led skills training and education centre in Malaysia. The GDVT course in industrial management is designed to upskill the existing technical workforce and recent graduates with international-level skills and competencies. Apprentices are trained through a two-pronged approach, where training is conducted at both the workplace and training institutions in actual working conditions under the guidance of competent coaches and classroom trainers. The Penang State Government is investing MYR 6 million in this training programme; it also provides for a double tax deduction for other similar training schemes.

References

Andreoni, A. and Anzolin, G., 2019. *A Revolution in the Making? Challenges and Opportunities of Digital Production Technologies for Developing Countries*. Background paper prepared for the Industrial Development Report 2020. Vienna: United Nations Industrial Development Organization.

Brynjolfsson, E., Rock, D. and Syverson, C., 2017. *Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics*. NBER Working Paper, 24001.

Calza, E. and Fokeer, S., 2019. *Absorbing Advanced Digital Production Technologies to Foster Industrialization. Evidence from Case Studies in Developing Countries*. Background paper prepared for the Industrial

Development Report 2020. Vienna, Austria: United Nations Industrial Development Organization

Chukwuekwe, D., Schjølberg, P., Rødseth, H. and Stuber, A., 2016. Reliable, Robust and Resilient Systems: Towards Development of a Predictive Maintenance Concept within the Industry 4.0 Environment. Proceedings of EFNMS Euro Maintenance Conference.

Eurostat, 2017. *Methodological Manual for Statistics on the Information Society. ICT Usage and E-Commerce in Enterprises- Survey Year 2018, Version 2.1*. Eurostat.

IFR, 2018. *Demystifying Collaborative Industrial Robots*. Frankfurt.

Kupfer, D., Ferraz, J.C. and Torracca, J., 2019. *A Comparative Analysis on Digitalization in Industry in Selected Developing Countries: Firm Level Data on Industry 4.0*. Background paper prepared for the Industrial Development Report 2020. Vienna: United Nations Industrial Development Organization.

OECD (Organisation for Economic Co-operation andDevelopment), 2017. *The Next Production Revolution: Implications for Governments and Business*. Paris: OECD Publishing.

Mayer, J., 2018. *Digitalization and Industrialization: Friends or Foes?* UNCTAD Research Paper No. 25. Geneva: United Nations.

Schaeffer, E., 2017. *Industry X.0: Realizing Digital Value in Industrial Sectors*. 1 edition. London: Kogan Page.

UNIDO (United Nations Industrial Development Organization), 2017a. *Accelerating Clean Energy through Industry 4.0: Manufacturing the Next Revolution*. Vienna.

---------, 2017b. *Industrial Development Report 2018. Demand for Manufacturing: Driving Inclusive and Sustainable Industrial Development*. Vienna.

---------, 2017c. *Industry 4.0 - The Opportunities behind the Challenge*. Vienna.

---------, 2019. *Industrial Development Report 2020. Industrializing in the digital age*. Vienna.

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