WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

White Paper

Shaping the Sustainability of Production Systems: Fourth Industrial Revolution technologies for competitiveness and sustainable growth

In collaboration with Accenture Strategy

January 2019

World Economic Forum
91-93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland
Tel.: +41 (0)22 869 1212
Fax: +41 (0)22 786 2744
Email: contact@weforum.org
www.weforum.org

Contents

Foreword

Helena Leurent, Head, System Initiative on Shaping the Future of Advanced Manufacturing and Production, Member of the Executive Committee, World Economic Forum

Omar Abbosh, Group Chief Executive, Communications, Media and Technology, Accenture, United Kingdom

The future of manufacturing is at an inflection point. Consumers are demanding personalized products and services, instantly fulfilled. Industry incumbents are racing to adjust to this new generation of customers by building new networks of partners and digitalizing operations – all while agile new entrants carve out and capture market share. Meanwhile, global temperatures are rising, demand for resources continues to outpace the Earth's ability to replenish them, and with the industry and manufacturing sectors accounting for 41% of global gross domestic product (GDP),[1] the production sectors are positioned directly at the nexus of economic impact and resource usage. Tomorrow's manufacturers won't be able to operate with the same resource intensity as past generations, and so now, more than ever, we must find ways to remain competitive and sustainable.

By harnessing the combinatorial power of digital, physical and biological technologies, however, the Fourth Industrial Revolution (4IR) presents a way for manufacturing to increase its competitiveness and contribution to regional economies, while at the same time helping to deliver on the United Nations Sustainable Development Goals.

This White Paper quantifies how. It examines the potential impact of 4IR technologies on production systems in two of the world's manufacturing hubs and looks at technologies that can help manufacturers access new levels of efficiency as well as enabling more sustainable business models. In the Indian state of Andhra Pradesh, we identified six 4IR technologies that could unlock an additional $5 billion a year of sustainable value for its fast-growing electronics and automotive manufacturers by 2022. In the US state of Michigan, there are four such technologies with the potential to add $7 billion annually to its automotive sector.

Our analysis is presented as a showcase not only of the regions we have chosen but also of the positive impact potential of 4IR technologies for manufacturing hubs around the world. We hope it will serve as a template for business and government leaders everywhere to increase competitiveness and sustainability. In doing so, we hope to illustrate that not only is there no tension between the two, but that sustainability may actually be an amplifier of competitiveness.

The World Economic Forum's Regional Platforms for Sustainable Manufacturing will offer on-the-ground support to leaders as they seek the new collaborations that will turn the ideas in this report into action. Together, we believe the paper and these platforms can help manufacturers and governments across the globe rise to the challenge and accelerate progress towards a new era of sustainable production.

Executive Summary

Manufacturing is crucial for global economic growth. However, the manufacturing industry is facing unprecedented challenges that must be addressed by companies and governments if it is to succeed: the need to create hyper-personalized experiences and products, to deliver at a lower cost and higher efficiency or to implement new business models and sources of growth that build trust among consumers.

In order to keep up, companies need to embrace the Fourth Industrial Revolution and become disruptors themselves. Fourth Industrial Revolution technologies allow companies to position manufacturing as a source of competitive advantage while contributing to the fulfilment of the Sustainable Development Goals (SDGs).

To show how such technologies can enable new business models that unlock sustainable business value for manufacturers around the world, the project identified three distinct global production hubs for analysis: Andhra Pradesh (India), Michigan (USA) and Guangdong (China). Having completed our studies of Andhra Pradesh and Michigan, the outcomes show that 4IR technologies can drive competitiveness and significant economic growth in both regions, while simultaneously increasing sustainability.

Value opportunity in Andhra Pradesh

Across the electronics and automotive manufacturing sectors in this east Indian state, there are six 4IR technologies that present a cumulative, sustainable value opportunity of $5 billion annually by 2022.

For the electronics industry, advanced electronic design automation (AEDA), 3D printing and digital traceability of materials are the technologies with the highest potential to boost competitiveness while accelerating the realization of the SDGs. By 2022, the state's electronics industry could gain more than $1 billion by implementing AEDA, over $630 million in value through 3D-printed electronics and $127 million through blockchain-enabled traceability of minerals.

In the automotive industry, an augmented workforce could generate additional value of $1.5 billion in 2022, via improved product throughput and enhanced labour practices, whereas cobotics and bio-based plastics could have a commercial impact of $1.4 billion and $424 million respectively. But these technologies may also have a positive impact on society and the environment by upskilling the workforce, reducing CO_2 emissions and increasing safety in the workplace.

The government of Andhra Pradesh is now exploring the creation of a Regional Platform for Sustainable Production to capture those opportunities and ensure the long-term impact and scaled implementation of these technologies.

Value opportunity in Michigan

Michigan is the birthplace of the modern automotive industry, which remains the US state's leading manufacturing sector. The project in Michigan focused on the automotive industry: The implementation of four select technologies in this sector could generate an additional value opportunity of over $7 billion annually by 2022 in the state.

An augmented workforce could have a commercial impact of $2.6 billion in additional revenue due to increased output using AR/VR and AR/VR training. Cobotics could generate additional value of over $2.1 billion due to additional output as well as reduce safety incidences. Digital twins and metal 3D printing could represent an economic opportunity of $1.4 billion and $800 million in 2022 respectively and contribute towards the reduction of CO_2 emissions as well as increasing safety in the workplace.

The World Economic Forum is currently collaborating with Automation Alley, a nonprofit manufacturing and technology business association, to create a manufacturing roadmap that may serve to support the policy and business agendas of leaders across the state.

Value opportunity in Guangdong

China's largest province has become a hub for local and international manufacturers from a number of industries. The Accelerating Sustainable Production project is now quantifying the potential impact of 4IR technologies on the region's electronics and automotive production systems.

The way forward

The Fourth Industrial Revolution presents a unique opportunity to inspire innovation in advanced manufacturing while increasing companies' competitiveness and contributing to the fulfilment of the UN's 2030 Agenda for Sustainable Development.

From the interviews, workshops and research over the past year, the project has identified some common success factors to ensure competitiveness and sustainable growth. Leaders must take a long-term strategic outlook that extends beyond the immediate investment opportunity and collaboration. A network of partners will be vital to allow manufacturers to innovate and adopt new approaches to manufacturing. Finally, following a human-centred approach, where Fourth Industrial Revolution technologies enhance the human role and encourage collaboration between human and machine, will allow companies to position themselves for sustained, long-term success.

The deep dives in Andhra Pradesh, Michigan and

Guangdong can help consolidate action in the regions in focus, but the ideas and findings within them have wider applications. By proving the business value of Fourth Industrial Revolution technologies, they can guide manufacturers around the world as they seek to channel 4IR-driven innovation into their own production systems – at speed and scale.

New mechanisms that encourage public-private cooperation are needed, delivering long-term engagement at scale. The implementation of Regional Platforms for Sustainable Production could facilitate the adoption of 4IR technologies in selected areas by bringing key stakeholders together to exchange knowledge and launch new public-private partnerships. The platforms would be integrated in a Global Centre for Sustainable Production that would provide further strategic guidance, encouraging innovative action that makes manufacturers more competitive and manufacturing more sustainable.

The project's next step is to drive on-the-ground action and facilitate the implementation of 4IR technologies for competitiveness and sustainable growth.

Chapter 1: Fourth Industrial Revolution Technologies for Competitiveness and Sustainable Growth

Manufacturing makes a critical contribution to the global economy. The latest World Bank figures put its share of global GDP at 15.6% (value added).[2] However, its environmental footprint is also significant: Manufacturers account for 54% of global energy use and are responsible for 20% of all greenhouse gas emissions.[3]

Late last year, the UN Intergovernmental Panel on Climate Change published a landmark report that called for urgent and unprecedented action to restrict global warming to 1.5ºC and thus limit its potentially catastrophic impact.[4] But this is not the only imperative facing manufacturers.

Their business status quo has been disrupted, too. At the same time as consumers are demanding hyper-personalized products, economic pressures are forcing manufacturing incumbents to reduce costs – and new competition has also emerged. Start-up businesses, shorn of unwieldy legacy systems, are taking a digital-first, software-led approach that allows them to innovate faster and keep pace with the dizzying rate of technological change that defines the Fourth Industrial Revolution.

If incumbents are going to keep up, they must embrace the Fourth Industrial Revolution and become disruptors themselves. Pioneering manufacturers are innovating the way that products are designed, manufactured and serviced and building new organizational capabilities that reposition manufacturing as a source of competitive advantage. Integrating sustainability into this pivot towards the Fourth Industrial Revolution unlocks new growth, increases profitability and builds stakeholder trust.

New growth with new business models: By developing new 4IR-enabled capabilities around the sustainable design, manufacture and servicing of products, manufacturers can grow revenues by accessing new markets and customers with new business models. Circular economy business models, such as “product life extension” and “product as a service” can help manufacturers tap into a $4.5 trillion global economic opportunity but require new technologies and processes.[5] For example, Caterpillar’s remanufacturing programme returns components at end-of-life to same-as-new condition, reducing carbon, waste and raw material inputs. Otherwise unusable parts are brought back to the latest performance specifications, a crucial differentiator in the sector, for which Caterpillar has developed a unique set of world-class salvage techniques. With profit margins on the sale of remanufactured goods as high as 40%,[6] it makes commercial sense as well.

New growth with closer customer relationships: Sustainable manufacturing can be the driver that transforms traditional organizations into agile providers of smart products and services that connect manufacturers to their customers and supply chains, building closer relationships and more personalized product experiences. One example is HP’s Instant Ink service, which detects when a printer’s cartridge needs to be replaced, automatically ships a replacement and facilitates the return of the empty cartridge and reprocesses it in its advanced facilities. The solution cuts the carbon footprint of the ink’s purchase and return process by 84% and reduces material consumption by 57%, while offering customers a convenient and cost-effective solution. The key here is being able to access product use-phase data, which can then be fed back into the design of production systems and the product portfolio.

Increasing profitability: Leading CEOs are quantifying how sustainability generates tangible value down to bottom-line profit and loss (P&L), taking action to reduce waste and energy consumption while increasing labour and operational efficiency. For example, Maserati has digitalized manufacturing operations at its Giovanni Agnelli plant near Turin, Italy. Partnering with Siemens, it created a digital twin of the Maserati Ghibli that allows real-time data-sharing between the real and virtual model. This helped Maserati decrease costs and reduce development time by 30%.[7]

Apple’s disassembly robot Daisy separates iPhones into discrete parts that can be reprocessed by its partners. At full capacity, Daisy can disassemble 200 iPhones an hour, removing and sorting components so that Apple can recover materials that traditional recyclers cannot – and at a higher quality.[8]

General Motors has partnered with software company Autodesk to introduce the next generation of light weighting. The pair have produced a proof-of-concept seat bracket that consolidates eight components into a single 3D-printed part that is 40% lighter and 20% stronger than the original part.[9]

Trust: If a company fails to uphold its covenant with customers, profitable growth will be elusive as it will never receive “a licence to grow”. Today, business value is created by building trust and transparency with customers, employees, shareholders and society. We know that 63% of consumers refuse to buy from companies they don’t trust and that pervasive digital technologies are also driving accountability – 92% of individuals trust their peers’ reviews, while only 20% of individuals believe a company’s own claims.[10] The interconnection between sustainability and trust and profitability allows for companies to balance socially acceptable and efficient operations to create reputational and brand value.

For manufacturers, making sustainable manufacturing integral to their strategy can reduce costs and enhance profitability, drive business growth and be used to build trust with stakeholders. For governments, sustainable manufacturing can make a positive environmental and social impact that contributes towards the fulfilment of the UN's Sustainable Development Goals,[11] including SDG12 on Responsible Production and Consumption, and climate change targets. Governments are starting to recognize the potential of Fourth Industrial Revolution technologies, forging new political strategies around them. Combining these efforts in a multistakeholder approach gives industry and government the best chance of achieving their goals. For example, policy-makers can nurture business innovation with favourable regulatory and taxation systems that encourage strong investment flows.

The UK government has established an Industrial Strategy Challenge Fund to increase funding for research and development that strengthens UK science and business. Manufacturing and food materials or transforming food production are among the areas to receive funding.[12]

As part of its government-wide High-Tech Strategy 2025, Germany aims to deploy new technologies to make industrial innovation more dynamic. In particular, it has highlighted the potential of artificial intelligence, circular economies and new digital business models.[13]

The Chinese government has launched the "Made in China 2025" (MIC 2025) policy to drive automation and intelligent manufacturing in the country and transform China into an advance manufacturing leader. MIC 2025 includes plans to digitize industries focusing on programmes to develop internet of things (IoT), robots, intelligent manufacturing systems or cloud computing.[14]

Accelerating Sustainable Production

Accelerating Sustainable Production is a project of the World Economic Forum's System Initiative on Shaping the Future of Advanced Manufacturing and Production. It seeks to inspire the creation of production systems that drive increased efficiency and competitiveness, while simultaneously benefiting society and the environment through the implementation of 4IR technologies.

Last year, the project identified 40 4IR technologies that could transform businesses across four focus industries (electronics; automotive; food and beverage; textiles, apparel and footwear) and developed the Accelerating Sustainable Production framework. This value-at-stake framework quantifies the economic, social and environmental impact of implementing such technologies in production systems.

This year, the focus is on three pioneer regions within some of the largest manufacturing countries in the world: the state of Andhra Pradesh in India; the US state of Michigan; and China's Guangdong province. These regions were chosen because of their economic relevance – within their respective countries and globally – and strong manufacturing histories. The regions of focus are centres of innovative and high-tech product manufacturing industries (e.g. electronics, automotive) with the potential for further transformation. Assessing the implementation of sustainable technologies in these regions allows the study to take a narrow enough lens to see the resultant impacts, while also exploring similar economic sectors so as to potentially link the three studies in the future.

Using the Accelerating Sustainable Production framework, this paper analyses the value opportunities that lie in transforming production systems in Andhra Pradesh and Michigan (see Chapters 2 and 3).

In both regions, the study showed that adopting the right combination of 4IR technologies can deliver significant economic benefits to manufacturers, while also positively affecting society and the environment.

Chapter 2: The Value Opportunity of Fourth Industrial Revolution Technologies in Andhra Pradesh, India

At the start of 2018, India made headlines when the World Bank predicted it would surpass China as the fastest-growing major economy, with GDP growth of about 7.5% over the next two years.[15] In particular, the eastern state of Andhra Pradesh shows immense potential for growth, recording a rate of 11.6% in 2017 versus the national average of 7.1%.[16] Andhra Pradesh's government counts its automotive and electronics industries among twelve "focus sectors" for accelerating industrial growth.

The state has emerged as a hub for the automotive and auto components sector, aiming to attract $3.2 billion in investments by 2020. Manufacturers are expected to create 200,000 new jobs by 2020,[17] thanks to existing and upcoming projects across various automotive segments. Andhra Pradesh's electronics manufacturing sector accounts for 23% of India's electronics production. This share is poised to grow to 50% by 2021.[18] The state aims to manufacture at least 100–150 million of the 500 million mobile phones produced in India by 2020.[19]

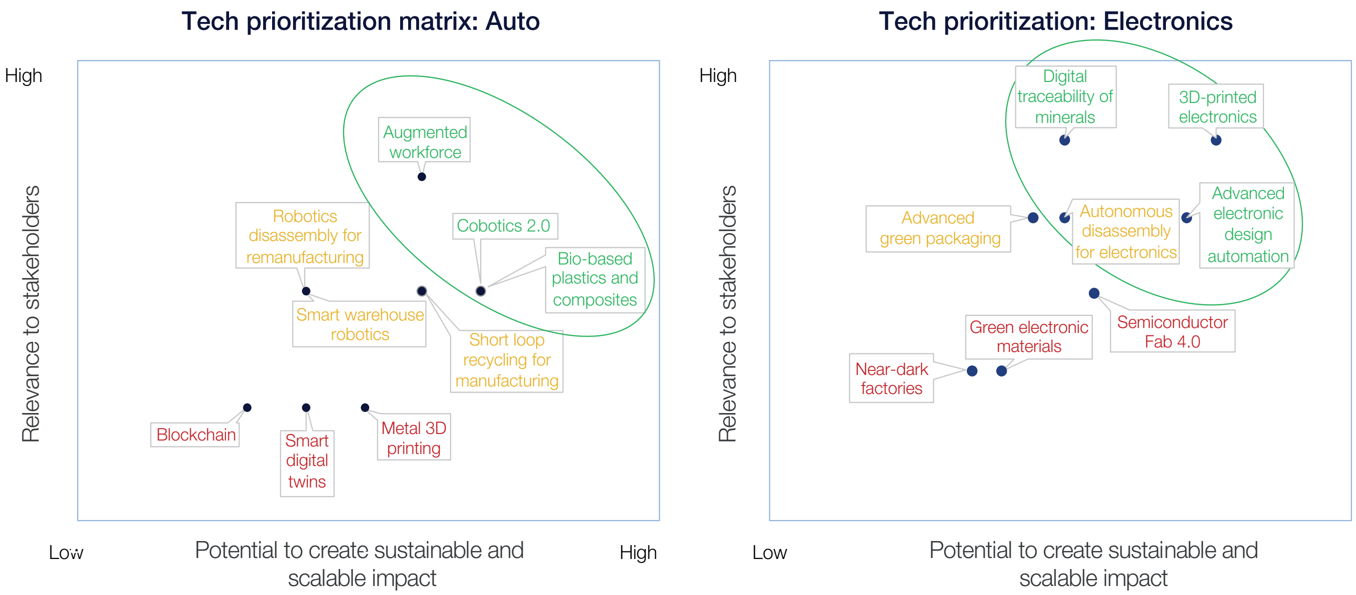
The government of Andhra Pradesh (GoAP) is making a concerted effort to position the state as a high-tech hub. To address the skills gap in emerging technologies, it is setting up the International Institute of Digital Technology (IIDT) in the city of Tirupati.[20] Despite some state-of-the-art technological infrastructure that enables its strong vision for growth, the state's industrial output is below average as a share of GDP, with manufacturing contributing 10.2% versus a national average of about 15%.[21]

This project aims to visualize a strategic, collaborative approach to sustainable production by government and industry that draws on emerging technologies to help the state maintain its growth momentum while realizing the full potential of its production systems.

The potential of Fourth Industrial Revolution technologies in Andhra Pradesh

To identify the 4IR technologies with the biggest triple-bottom-line potential and local relevance for Andhra Pradesh's automotive and electronics industries, a regional working group analysed a long list of the technologies that were identified in last year's White Paper[22] (see the Appendix in this document for detailed framework analysis). For further details on the project in Andhra Pradesh, see the "Accelerating Sustainable Production in Andhra Pradesh" White Paper, published in September 2018.[23]

Figure 1. Technology prioritization matrix



Source – Accenture Strategy

Analysis of the automotive sector identified three top technologies:

- **Cobotics 2.0 (collaborative robots):** A “cobot” is a robot that has been designed and built to collaborate with human beings. In a cobotic system, a cobot and a human collaborate to execute a task. Around the world, using cobots in manufacturing has led to remarkable efficiency gains. The GoAP is enhancing the relevance of cobotics 2.0 in Andhra Pradesh through a recent push to bring in world-class automation by establishing a university for artificial intelligence and robotics training in conjunction with Finland.[24]

- **Augmented workforce:** Augmented reality (AR) layers computer-generated graphics and images on top of an existing reality to deliver information. In Andhra Pradesh’s automotive sector, AR/VR (virtual reality) technology could help to skill the 200,000 employees predicted to join the sector by 2020. The GoAP has laid the foundation for bringing this technology to Andhra Pradesh with the Animation Visual Effects Gaming and Comics (AVGC) policy 2018–2020.

- **Bio-based plastics:** Heavy metal and plastic components can be replaced with high-performance elastomers, thermoplastics and composites created partially or wholly using plant feedstock and emerging chemical and nanotechnologies. Used in various vehicle systems, including power-train applications, they can make cars lighter and more fuel-efficient. Andhra Pradesh is well positioned with agricultural input supply and a suitable talent base to support this solution’s expansion and cater to its auto sector’s needs.

For the electronics sector, the following technologies were identified:

- **3D-printed electronics:** 3D-printing technology for building auto components and spare parts with metal substrates. By 3D-printing circuit boards, for example, designers can build faster prototypes, reducing time to market and using resources more efficiently. The GoAP has laid the foundation for 3D-printing application in the state at the Andhra Pradesh MedTech Zone (AMTZ) near Visakhapatnam,[25] and along with HP has created an institute of excellence for disseminating knowledge on 3D printing in Amaravati.[26] Industry players are starting to reap the benefits from this technology beyond the lab.

- **Digital traceability of minerals:** Private-permissioned blockchain tech can chronologically and permanently log information across a computer network accessed by multiple collaborating parties. Blockchain-enabled software for precious and industrial metal markets can prevent “conflict minerals” from entering the value chains of electronic products. Andhra Pradesh is on the way to becoming a prominent figure in blockchain. The GoAP signed a memorandum of understanding (MoU) with ConsenSys, which will provide technical advice and assist with educating on blockchain through a developer programme.[27]

- **Advanced electronic design automation (AEDA):** AEDA is a simulation technology in the field of electronics design. It calculates and predicts material and component performance to create the optimum configuration for products. Used in chip design, it is now being applied to the entire development process of an electronic device, in combination with machine learning, to increase the efficiency and accuracy of both design and production. Andhra Pradesh has 24% of India’s IT and electronics engineers and is aggressively working towards becoming a knowledge hub for skilled engineers through partnerships with international institutes.[28]

The value opportunity of Fourth Industrial Revolution technologies in Andhra Pradesh

These six technologies have the potential to create more than $5 billion in annual value for Andhra Pradesh's automotive and electronics industries by 2022. At the same time, they can help realize some of the United Nations Sustainable Development Goals, including:

– SDG 4: Quality Education – through skills development

– SDG 5: Gender Equality – through including women in the workforce

– SDG 8: Decent Work and Economic Growth – through job creation

– SDG 12: Responsible Consumption and Production – through reduced material consumption

– SDG 13: Climate Action – through reduced greenhouse-gas emissions

There are risks associated with the adoption of 4IR technologies, however. Some of them have a high energy footprint; others may lead to unemployment. Businesses must account for such potential negative externalities before implementing the technologies.

Electronics

The sector stands to gain more than $1.7 billion in annual value by 2022 if it uses the top three 4IR technologies to reconfigure its production systems.

AEDA accounts for more than half ($1 billion in annual value) of that potential value. India's chip-design automation industry is steadily growing, pegged to increase globally at a compound annual growth rate of 5.5% between 2017 and 2022.[29] it reduces the risk of product failure by using machine learning and artificial intelligence to design products. Meanwhile, it reduces a business's environmental footprint by lowering water and material consumption through virtual design in product development. In Andhra Pradesh, it could supply close to 36,000 people from the local talent pool.

3D printing ($630 million in annual value) promises cost savings in Andhra Pradesh through just-in-time spare-part inventory management and additional revenue through product premiums from customization. Process efficiencies also mean less virgin plastic is used.

Digital traceability of materials ($127 million in annual value) improves sustainable sourcing practices. The biggest scope for realizing value lies with electronics original equipment manufacturers (OEMs). Digital traceability can establish and record a material's place of origin and life cycle of inputs, laying the foundation for recycling electronics. It can improve transparency throughout the supply chain, making it easier to identify faulty and counterfeit components.

Automotive

By 2022, three 4IR technologies could be worth more than $3.3 billion in annual value for Andhra Pradesh's automotive industry.

An **augmented workforce** ($1.5 billion in annual value) could improve workers' productivity and reduce training investments. Virtual training modules can help address the local manufacturing sector's skills gap, as well as widening access to vocational skills and thus helping to include more women in the workforce.

Figure 2. Value impact of the top 4IR technologies for Andhra Pradesh's electronics and automotive industries

Technology	Commercial impact	SDG impact	Associated risks
ELECTRONICS: Advanced EDA	**$1** billion in costs averted through reduced product failures and prototyping	Create **36,000 new AEDA jobs** to be filled by AP talent pool. **Save 125,000 litres of water**	AEDA technology is accessible to big players, thereby creating inequalities
ELECTRONICS: 3D-printed electronics	**$630** million in cost savings and enhanced product premiums	Reduce material consumption **– plastics: 170 tonnes**	3D printing can cause potential health concerns from toxic fumes
ELECTRONICS: Digital traceability	**$127** million in cost savings through reduced warranty claims and improved employee loyalty	Reduce risk of **counterfeit phones** affecting **about 39 million** phones produced in 2022	Digital traceability is an energy-intensive capability/technology
AUTOMOTIVE: Augmented workforce	**$1.5** billion in value through higher output from increased work efficiency and reduced training costs	Train **1 million self-help group women** to include them in mainstream manufacturing using AR/VR	AR/VR content can overshadow realism and blur real-virtual experiences

AUTOMOTIVE: Cobotics 2.0	**$1.4** billion in value through improved product throughput and enhanced labour practices	Save **150,000 working days (about 20%)** through reduced health and safety incidences in AP	Cobotics may threaten 28% of low-skilled jobs in the market
AUTOMOTIVE: Bio-based plastics	**$424** million in value through reduced manufacturing emissions and improved product premiums	Reduce **500,000 tonnes of CO_2** emitted in 2022 due to lighter cars in AP	Bio-based plastics are costlier than petro-plastics and lack economies of scale

Source – Accenture Strategy

In Andhra Pradesh, **Cobotics 2.0** ($1.4 billion in annual value) can be exploited to bridge the skills deficit in manufacturing and boost output generation through a more productive workforce and assembly lines. In terms of skilling, AR/VR-enabled vocational courses can improve access and impact and reduce the cost of training new employees. Collaborative robots may also significantly reduce the number of workplace accidents.

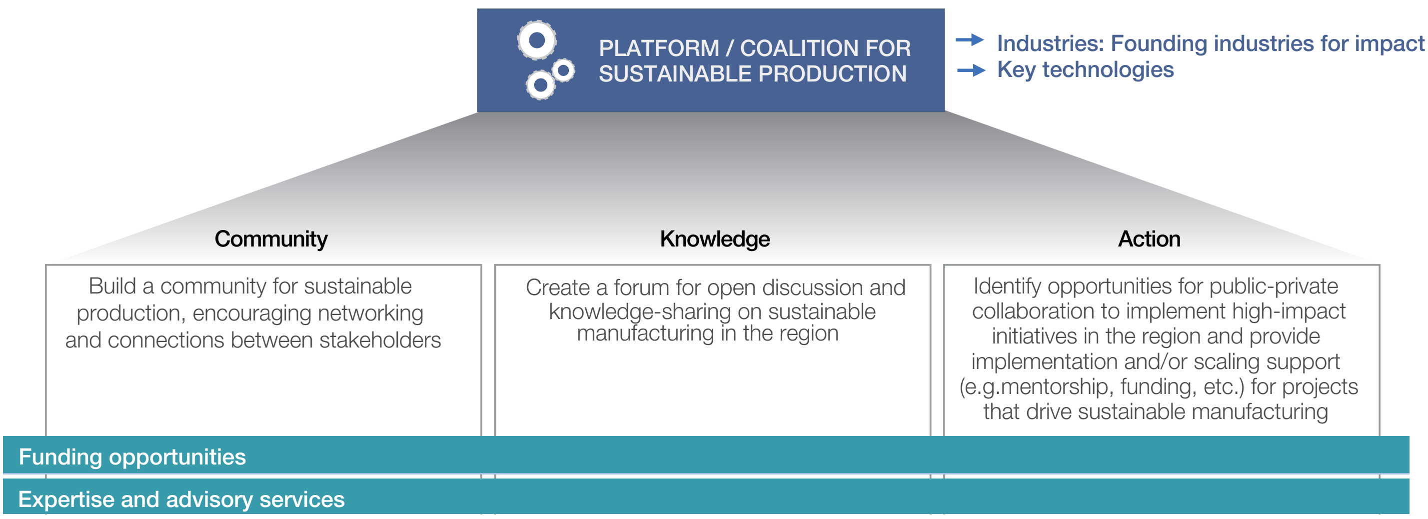
Bio-based plastics and composites ($424 million in annual value) lower the externality cost of carbon emissions in manufacturing, with bio-based plastics reducing the weight of passenger vehicles. Bio-based plastics and composites offer potential premiums on eco-friendly vehicles. The technological solution has been shown to consume 30% less energy than the manufacture of conventional plastic.

Next steps in Andhra Pradesh

The GoAP is now working on a framework that will allow it to capture these opportunities. Rather than solely aiming to implement a case example of one of the identified technologies, the GoAP is looking to ensure the long-term impact and scaled implementation of these technologies by exploring the creation of a Regional Platform for Sustainable Production (see figure 3).

The GoAP hopes that its Regional Platform for Sustainable Production may serve as an example to other regions around the world. If successful, these Regional Platforms could be interconnected to share best practices and expand their collective economic opportunities.

Figure 3. Key pillars of the Regional Platforms/Coalitions for Sustainable Production



Source – Accenture Strategy

Chapter 3: The Value Opportunity of Fourth Industrial Revolution Technologies in Michigan, USA

Michigan is the birthplace of the modern automotive industry. It is where Henry Ford innovated modern mass production techniques, including the moving assembly line, in the early 20th century. Today, automotive is Michigan's biggest manufacturing sector, making up over 40% of its total manufacturing output.[30] Home to 20% of US auto manufacturing jobs,[31] the Midwestern state produces more cars and trucks than any other state in the country (more than 2 million vehicles a year).[32]

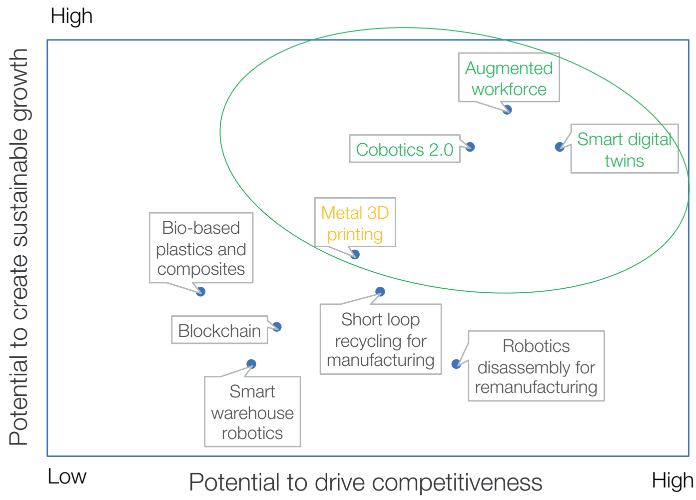
After years of economic turmoil, the state government is positioning Michigan to lead the way in advanced manufacturing globally. The state is attracting mobility start-ups with initiatives such as PlanetM Landing Zone, a subsidized mobility hub funded by the Michigan Economic Development Corporation and Detroit Regional Chamber. It is also first in mobility-related patents, with 2,583 awarded over the past five years,[33] and it leads the USA in the number of projects and amount of legislation passed for connected and autonomous vehicle (CAV) testing. Michigan is home to the world's first self-driving highway test facility, the American Center for Mobility, a joint initiative between the state, academia and business to advance the safe deployment of CAVs.

For Michigan to maintain its position in the automotive industry and be a pioneer in the future of mobility, there needs to be a clear understanding of which 4IR technologies have the highest potential to drive competitiveness and sustainable growth.

The potential of Fourth Industrial Revolution technologies in Michigan

With support from Automation Alley, a non-profit manufacturing and technology business association that serves as the state's industry 4.0 knowledge centre, key stakeholders in Michigan were interviewed, including leaders from business, academia and state government. After interview analysis and secondary research, four technologies were prioritized, according to their potential to drive competitiveness and create sustainable growth in Michigan's automotive sector (see Appendix 2 for a detailed prioritization framework).

Figure 4. Technology prioritization matrix



Source – Accenture Strategy

The following technologies were identified:

– **Augmented workforce** equips employees with additional information through virtual interventions such as AR and VR. In Michigan's automotive sector, AR can bridge the growing skills gap that has led to a shortage of skilled workers – a major concern for manufacturers in the state.[34] The fast pace of technological change means there is a continuous need to train and retrain workers. AR is a cost-effective way of building technological resilience, offering on-demand guidance as the work is being done. It boosts worker productivity from first use, even without prior training; some manufacturers report performance improvements of more than 30%.[35] AR also enables real-time communication with remote experts – raising performance while reducing costs.

– **Cobotics 2.0 (collaborative robots)** are designed and built to work alongside humans. They can learn multiple tasks to assist workers on the factory floor. Cobots can help bring manufacturing back to the US by diminishing the labour cost advantage of emerging economies. Michigan has the highest automotive manufacturing workforce of all the US states, but it has been diminishing in the face of outsourcing and automation. Robot-human teams are 85% more productive than either robots or humans alone.[36] Cobots increase job satisfaction – and safety – as they can handle the "dirty, dull, difficult and dangerous" work, freeing up human workers to innovate.[37] This helps attract and retain workers, as the perception of manufacturing jobs improves.

– **Smart digital twin** technology can create digital replicas of physical assets, processes and systems. The convergence of digital twin technology with the industrial internet of things (IIoT) and machine learning enables near-real-time updates and digital asset representations created by sensors deployed in machines. Michigan has the largest number of robots of any US state and its automotive industry is highly automated.[38] Preventing losses from production downtime is critical. With smart digital twins, predictive asset maintenance minimizes unscheduled downtime. Moreover, as the use of data and software in production grows, digital twin technology plays an increasingly important part in the design and development process.

– **Metal 3D printing** fabricates components, building them in sequentially added layers of material. Michigan's "Big Three" – Ford, General Motors (GM) and Fiat Chrysler Automobiles (FCA) – all have 3D-printing initiatives in place, but the technology is not yet mature enough for the automotive industry to use it to produce at scale. However, Michigan's industrial landscape of OEMs, suppliers and the University Research Corridor encourages innovation and collaboration, giving the state a competitive advantage in the race to scale metal 3D printing. The University of Michigan's Smart and Sustainable Automation Research (S2A) Lab has already developed a software algorithm to speed up 3D printing, which could theoretically make production more feasible at scale. 3D printing can reduce material costs by up to 90% and supports aggressive vehicle lightweighting[39] – a top priority for automakers seeking to produce fuel-efficient vehicles.

The value opportunity of Fourth Industrial Revolution technologies in Michigan

Cumulatively, these four technologies present an opportunity for Michigan's automotive sector to create more than $7 billion in annual value in 2022. They can make existing production systems more efficient, enable cost savings across the value chain and boost revenue through increased throughput. As well as making current operations more competitive, the technologies can open additional revenue channels for manufacturers: from new products and services, and from premiums for customized, high-quality products. At the same time, they can help realize some of the United Nations Sustainable Development Goals, including:

– SDG 3: Good Health and Well-being – through increased safety at workplace

– SDG 8: Decent Work and Economic Growth – through higher levels of efficiency

– SDG 12: Responsible Consumption and Production – through reduced material consumption

– SDG 13: Climate Action – through reduced greenhouse-gas emissions

Figure 5. Value impact of the top 4IR technologies for Michigan's automotive industry

Technology	Commercial impact	SDG impact	Associated risks
Augmented workforce	$2.6 billion in value through higher output from increased work efficiency and reduced training cost	Number of people that can be skilled due to reduced training time in AR/VR set up is doubled	AR/VR content can overshadow realism and blur real-virtual experiences
Cobotics 2.0	$2.1 billion in value through improved throughput and enhanced labour practices	Save 7,900 working days (~5%) through reduced safety incidences; 7,300 jobs created by reshoring to USA, leading to GDP growth of $355 million	Absence of liability in case of any injuries caused by cobots on the shop floor
Smart digital twins	$1.4 billion in value through cost savings from preventive asset maintenance and reduced product development costs; revenue increase due to premium charged on DT-enabled servicing	Reduction in CO_2 emissions by 620,000 tonnes due to better-maintained cars; 20% reduction in road accidents due to timely defect detection	Lowering labour demand by reduced need for human intervention and making existing hardware skills insufficient
Metal 3D printing	$800 million in value through cost savings due to lean spare parts inventory and enhanced product premiums due to customizable parts production	Reduction in CO_2 emissions due to lightweighting of vehicles by 370,000 tonnes	Metal 3D printing releases toxic fumes in the process, which could have adverse effects on workers' health

Source – Accenture Strategy

At the same time, these four technologies can address critical social and environmental challenges. They can create high-skilled jobs in the USA, help upskill workers, and improve safety and quality of life. Their deployment would also reduce CO_2 emissions, fuel consumption and material use.

– **Augmented Workforce** ($2.6 billion in annual value) applies to various stages of the vehicle production process, including assembly, maintenance and design. AR can streamline the design process, with concepts being evaluated and altered in real time as they are developed. It can also increase worker productivity and bridge the growing skills gap by reducing training time by 75%. Because more workers can be trained more quickly, AR technology has the potential to create more than 7,000 jobs in Michigan.

– **Cobots** ($2.1 billion in annual value) enhance the speed, precision and repeatability of manufacturing operations. They are easy to programme and set up, flexible and mobile, and can work safely with workers – they do not need to be caged off like traditional industrial robots. Improved human-robot productivity could increase the number of vehicles produced by 2%. Cobots also bring a cost efficiency to the manufacturing process: By diminishing the labour cost advantage of emerging economies, current vehicle imports could be substituted by domestic manufacturing. The onshoring of manufacturing could create 7,300 jobs in 2022. Michigan's manufacturers could also save an estimated 7,900 working days thanks to improved safety and ergonomics that reduce the number of workplace safety incidents.

– **Smart digital twins** ($1.4 billion in annual value) drive operational efficiency and can optimize the production process by enabling manufacturers to run real-time simulations, virtually testing and validating various design and production scenarios without interrupting workflow. As well as reducing product development costs, they deliver savings through predictive asset maintenance that decreases asset downtime and the associated cost of asset failures in plants. Manufacturers can also increase revenues by charging a premium on cars sold with a digital twin-enabled maintenance service, comprising digital upgrades and constant monitoring of safety statistics. Better maintenance improves the fuel economy of cars and could reduce CO_2 emissions by 620,000 tonnes.

– **Metal 3D printing** ($800 million in annual value) saves energy by eliminating production steps, using substantially less material and producing lighter materials. Lightweighting improves fuel economy and could reduce CO_2 emissions by 370,000 tonnes. Metal 3D-printing technology can enhance product premiums and reduce inventory costs by printing production parts on demand. It also enables decentralized manufacturing: Items can be fabricated closer to consumers, reducing transportation costs and emissions. Metal 3D printing makes postponed, mass customization possible, providing new revenue opportunities for automakers, who can charge a premium for personalized vehicles.

Next steps in Michigan

As the state of Michigan prepares for a new budget cycle, the above findings represent an enormous opportunity to inform targeted policies to drive 4IR technologies in manufacturing, with the potential to accelerate the state's economic success of the past decade. To this end, the World Economic Forum is collaborating with Automation Alley to create a roadmap – informed by a working group of Michigan manufacturers, labour leaders and academics – that may serve to support the policy and business agendas of leaders across the state.

Chapter 4: Conclusion and Next Steps

The Fourth Industrial Revolution presents an unprecedented opportunity to lead the next wave of innovation in advanced manufacturing while restructuring the global economy at speed to respond to carbon reduction targets and the UN's 2030 Agenda for Sustainable Development.

If we get it right, the Fourth Industrial Revolution can help us achieve those goals. If not, things will only become increasingly challenging for the economy, societies, and the environment.

The studies in Andhra Pradesh and Michigan have shown how the right combination of 4IR technologies can deliver economic benefits to both manufacturers and the regions in which they operate while contributing to the fulfilment of the UN Sustainable Development Goals. The task now at hand is to disseminate this approach to other manufacturing centres globally and put into practice the approaches discussed.

From the interviews, workshops and research with the sustainable production community over the past year, the project has identified some common success factors that can act as guiding principles to implementing 4IR technologies in manufacturing to ensure competitiveness and sustainable growth:

1. **Systems leadership:** To unlock the full potential of the Fourth Industrial Revolution, leaders must take a strategic outlook that extends beyond the immediate investment opportunity and thinks critically about how the development, manufacture and deployment of technology affects our social and environmental systems. Value-based systems leadership recognizes that the "true ends of technological development are always the planet and its people" and can ripple through an organization, recalibrating the approach to manufacturing, providing purpose for employees and having a positive effect on an organization's reputation. Policies, standards, incentives and certification schemes at regional and national levels are important in supporting change, but elected leaders have a vital role in cultivating a shared vision for transformational change.

2. **Collaborative innovation:** In a fast-evolving competitive landscape, where new entrants are challenging incumbents and new technologies are redefining what's possible, businesses must think beyond their own organizational structures to maximize the commercial and sustainability opportunities. Collaboration with a network of partners will allow manufacturers to develop the "new norms" – the new business models, the new relationships with their supply chain partners, the new technologies and the new relationships with their customers – that will enable the transformation journey to more sustainable manufacturing, which regional governments can support with a favourable innovation and investment framework.

3. **Human-centred approach:** Although the Fourth Industrial Revolution plays a crucial role in the future of factories, humans will remain at the centre. The technologies of the Fourth Industrial Revolution can enhance the human role and promote collaboration between people and machines, with technologies that position manufacturers for sustained, long-term success. Similarly, given the rapid pace of technological change, training and retraining the workforce is vital. Without skilled workers to programme and run smart factories, the value of the Fourth Industrial Revolution will not be realized.

Transformative change to accelerate sustainable production at the necessary speed and scale will require a shared vision for change and public-private collaboration to implement it. Manufacturers must transform the way that goods are designed, manufactured and serviced – the very heart of their operations. This must be supported with the right enabling environment and coordinated cross-border policy and regulation.

Next steps

The regional studies in Andhra Pradesh and Michigan revealed value opportunities around 4IR technologies respectively worth more than $5 billion and $7 billion a year by 2022. But the Accelerating Sustainable Production project has a wider, global ambition: to set manufacturing hubs across the world on the same path.

New mechanisms that encourage public-private cooperation are needed to bring Fourth Industrial Revolution technologies into the manufacturing mainstream. It is essential that such public-private partnerships drive collaboration and knowledge exchange, convene key stakeholders from the public sector, large corporations, small- and medium-sized enterprises, start-ups and academia and pursue targeted activities to identify and support the implementation of high-potential sustainable production projects.

In addition, any new mechanism intended to drive the implementation of Fourth Industrial Revolution technologies that optimizes competitiveness and enhances sustainability must go beyond supporting a single instance of technology implementation or piloting and find a way to deliver long-term engagement at scale. This could take the form of a scaled/expanded version of Andhra Pradesh's Regional Platform for Sustainable Production, a broader global body that could provide strategic guidance and resources to promote the adoption of 4IR technologies for competitiveness and sustainable growth, or a combination thereof to connect the local with the global.

The project's next step is to turn the ideas in this paper into on-the-ground action that uses 4IR technologies to create sustainable new production systems that improve the economic, environmental and social footprints of manufacturers around the world. To do so requires a coalition of partners willing to seize the economic and sustainable benefits enabled by the Fourth Industrial Revolution, as well as agreement and refinement of the mechanism that will most effectively drive the realization of these benefits.

Appendices

Appendix 1: The value opportunity of Fourth Industrial Revolution technologies in Guangdong, China

Guangdong is the largest economy by GDP among all of the provinces on the Chinese mainland. In addition, Guangdong's GDP accounts for 2% of the world's total GDP.[40]

Foreign investment helped Guangdong's manufacturing sector to developed rapidly,41 and numerous local companies have become global references in their respective industries (e.g. Huawei, Xiaomi and Guangzhou Automobile Industry Group).

The next step in this project will be to identify the top 4IR technologies for the electronics and automotive industries in the province and quantify the value impact of these innovations, with the final objective of encouraging the adoption of 4IR technologies across Guangdong's production systems.

Appendix 2. Fourth Industrial Revolution technologies for competitiveness and sustainable growth in Andhra Pradesh and Michigan: Scope, methodology

Scope of the study

The 4IR technologies for competitiveness and sustainable growth in Andhra Pradesh and Michigan research builds on the World Economic Forum's "Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation" study. This study focused on four industries that were chosen based on the interest of the project community. These industries were low- and high-tech product manufacturing industries with high environmental productivity, end-consumer visibility and good potential for further transformation:

– Electronics

– Automotive

– Textiles, apparel and footwear

– Food and beverage

In addition, the "Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation" study identified 40 4IR technological developments that could drive competitiveness and sustainable value across the value chains of the four focus industries.

Figure 6. Fourth Industrial Revolution technological developments for driving competitiveness and sustainable value

Automotive (9)	Electronics (8)	Food and beverage (11)	Textiles, apparel and footwear (12)
Short loop recycling	Green electronic materials	Precision agriculture	Precision agriculture
Bio-based plastics and composites	Autonomous disassembly	Advanced bio-farming	Biofabricated leather
Robotic disassembly for remanufacturing	Semiconductor Fab 4.0	Genome editing	Alternative natural fibres
Cobotics 2.0	Advanced green packaging	Agriculture 5.0	Gene-edited fibre crops
Metal 3D printing	Digital traceability of minerals	Cellular and tissue engineering	Advanced organic wastewater treatment
Blockchain	Advanced electronic design automation	Automated agriculture	Advanced bio-farming
Augmented workforce	3D printed electronics	Advanced organic wastewater treatment	Next gen bio-based polyester
Smart digital twins	Near-dark factories	Supply chain traceability and control	Upcycled textiles
Smart warehousing		Vertical farming	Blockchain for fashion
		3D food printing	Footwear factory 5.0
		Supply-side advanced packaging	Automated sewing
			Nanotech-enhanced fabrics

Source – World Economic Forum and Accenture strategy, "Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation"

For Andhra Pradesh, the automotive and electronics industries were selected as the industries of focus because of their relative economic importance to the state's economy and their strategic relevance for the region. For Michigan, the automotive industry was selected because of its contribution to the state's GDP, number of jobs and the historical relevance of this industry to the state.

The 40 4IR industry developments identified in the "Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation" study were considered as the starting point in selecting the top developments presenting the most significant upside potential for competitiveness and sustainable growth in the electronics and automotive industries in Andhra Pradesh and the automotive industry in Michigan.

Local working groups

Local working groups in Andhra Pradesh and Michigan were formed, consisting of select local and international companies from the selected industries. The working groups provided consultation and expertise to the project team throughout the study.

Methodology

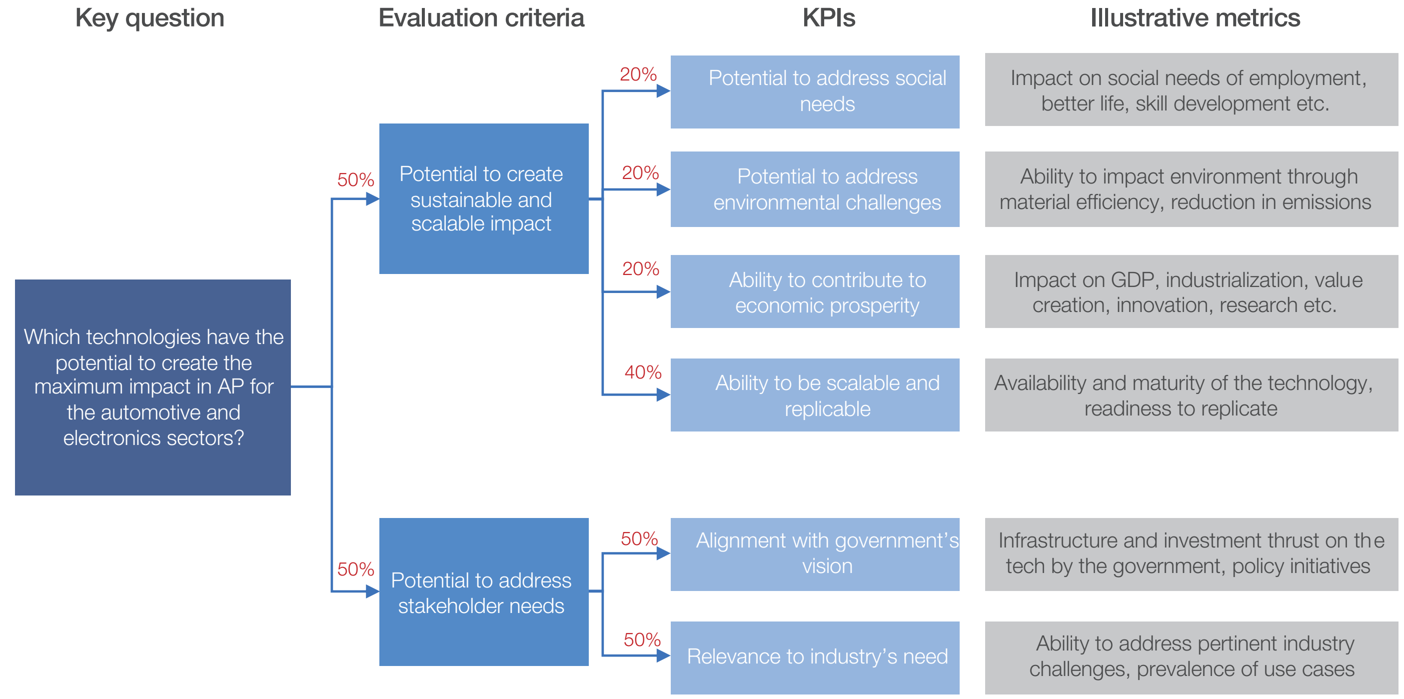
To develop this study, a mixed-method research, combining qualitative (i.e. interviews) and quantitative (i.e. data collection, value quantification exercise) analysis, was used.

Secondary research and prioritization framework

A technology prioritization framework was created for a first assessment of the 4IR technological developments, to identify those with the most significant upside potential for competitiveness and sustainable growth in the electronics and automotive industries in Andhra Pradesh and the automotive sector in Michigan.

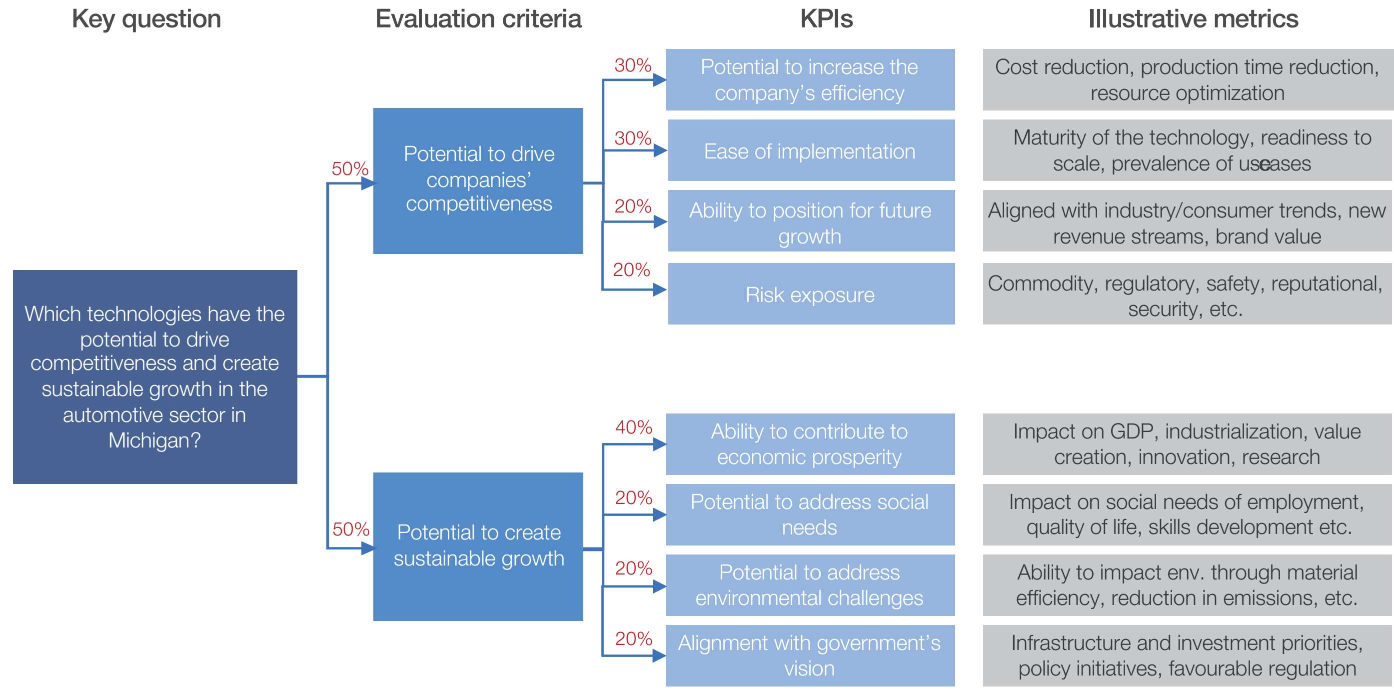
The framework had a twofold purpose: (1) to measure the potential to create impact of 4IR developments; and (2) to identify the top developments with the most significant upside potential in the states' selected industries.

Figure 7. Technology prioritization framework for Andhra Pradesh



Source: Accenture Strategy

Figure 8. Technology prioritization framework for Michigan



Source: Accenture Strategy

Primary and secondary research was conducted to assess the technologies, including interviews of subject-matter experts, identification of case studies and analysis of available public and private data.

This assessment concluded with the preselection of the top technology developments for Andhra Pradesh's electronics and automotive industries and Michigan's automotive sector.

Subject-matter expert interviews

Subject-matter experts from the selected sectors in Andhra Pradesh and Michigan were interviewed to validate the top developments preselected according to the technology prioritization framework criteria. They also helped explain the relevance of the selected technology developments. One-to-one discussions were conducted with industry experts from relevant manufacturing domains.

Workshops

For the Andhra Pradesh study, a workshop was held in Vijayawada, Andhra Pradesh, in June 2018. The workshop, which brought together the local working group members and the project team, had the following objectives:

– To explain the project goals and outcomes to the working group and discuss and agree upon the roles and responsibilities

– To determine the challenges across the value chain for both sectors and the potential 4IR technological interventions to address those challenges

In the USA, the Michigan Roundtable (November 2018) served as an opportunity to bring together important companies in Michigan to validate the initial list of top technologies for the automotive industry and start preliminary conversations about potential collaborations to facilitate the implementation of these technologies in the state.

Value quantification exercise

This exercise drew on the Accelerating Sustainable Production framework developed in the World Economic Forum's "Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation" study.

Figure 9. Framework for analysing value at stake for individual production technology developments

Level 1 Value Levers	Level 2 Value Levers	Level 3 Value Levers
Value Addition	Operating profits (from incremental revenues)	Improved yield / volume, higher premium
	Costs saving	Reduced costs (including direct/indirect costs)
Value Migration	Revenue shift	Revenues (from new/substitued products, service, technology solutions etc.)
Customer Benefits	Time saving	Improved access (due to better connectivity, reduced congestion, improved access etc.)
	Costs saving	Reduced prices
	Quality benefit	Increased health benefits (sustainable products/services)
Labour	Job oppotunities	Increased net jobs (due to direct/indirect job creation), improved employability (due to upskilling initiatives)
	Income growth	Improved salaries (due to high-skill jobs, improved revenues etc.)
	Working conditions	Reduced job-related injuries and fatalities
Society	Health and safety	Reduced mortality rate attributable to basic living conditions (air ambiance, water sanitation etc.), reduced mortality from accident-related injuries
	Quality of life	Improved access to basic amenities, reduced inequalities (gender, income, etc.)
Environment	Emission to air	Reduced GHG emission and particulate matter
	Water use	Improved water usage (water use efficiency, recycling etc.), improved water discharge
	Land use	Improved land use
	Material use (including waste management)	Improved material usage (use of renewable inputs, circular models, recycling etc.), reduced waste generation (including hazardous waste)

Note: Levels 1, 2 and 3 indicate different levels of value levers
Source: World Economic Forum and Accenture Strategy. "Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation", White Paper, January 2018

The framework was applied to each of the top technological developments identified. The value levers with the potential to create the highest impact were selected for each and quantified to ascertain their commercial impact as well as their social and environmental impact. The assumptions and resulting numbers that formed the basis of the quantitative analysis were gathered through primary inputs from industry experts and secondary research and were validated in the final call.

Although the Andhra Pradesh and Michigan studies followed the methodology described above, the scope of the study and the size of the selected industries in the two regions varied, thus contributing to the differences in the outcomes of the two studies. In Andhra Pradesh, the industries of focus were the automotive and the electronics industries; six technologies were selected to quantify their value impact (three technologies in each sector). In Michigan, one industry was selected for the analysis, i.e. automotive, and four technologies were identified.

Figure 10. Overview of the 4IR technological developments evaluated for Andhra Pradesh's and Michigan's automotive sector

Development	Brief Overview
Short loop recycling for manufacturing	With short loops, all of the recycling processes remain in the automotive sector, and are set up to recover and recycle materials for (re)manufacturing, drawing on multiple partnerships enabled by digital platforms and geo-proximity. Current examples are short loops set up to recycle raw materials such as steel, copper, textiles and plastics, keeping them as much as possible in the local automotive industry.
Bio-based plastics and composites	Heavier metal and other plastic components are replaced with engineering-grade biopolymers and/or lighter natural-fibre-reinforced plastics created partially or wholly using plant feedstock. For example, structures can use flax fibres and bio-epoxy resin intermingled with carbon fibres in hybrid composites, which are lighter, cheaper and more environmentally sustainable than conventional polymers. These materials and parts are suitable for multiple vehicle systems, including powertrain applications.
Cobotics 2.0	A cobotic system includes a cobot and a human collaborating to achieve higher productivity and also protecting human workers from potentially hazardous jobs (e.g. jobs with higher rates of accidents). A lighter-weight, mobile plug-and-play generation is arriving on the factory floor to collaborate safely with human workers thanks to advances in sensor and vision technology, and computing power.
Metal 3D printing	A shift towards metal printing to allow more flexibility in general and some application-specific materials. Applications in the auto industry are characterized by the broad adoption of additives for production tooling, spare and custom parts, and an increased industrial uptake to print components of end products. Building objects from the bottom up and using the material only when needed reduces waste, enables weight reduction and has a cost advantage, especially when using materials such as titanium and nickel-alloy steels.
Smart digital twins	The convergence of existing digital twin technology with the industrial internet of things and machine learning technologies provides near-real-time updates and digital asset representation created by sensors deployed in the machines. The digital twin paradigm enables manufacturers to operate factories efficiently and gain timely insights into product performance.
Blockchain	Blockchain is a distributed ledger technology that enables the creation of an immutable record of transactions to share with multiple participants in a business network. In the automobile sector, blockchain technology could enable all stakeholders to trace the origin of spare parts and components back through every step in the supply chain, as well as in reverse logistics applications to enable remanufacturing and recycling.
Augmented workforce	This is the use of augmented reality (AR) technology in various stages of the vehicle production process. AR can support complex assembly, machine maintenance, expert support needs and quality-assurance processes in the automotive industry. It is a collaborative tool that facilitates automation on the shop floor, enables productivity gains and resource efficiency, and drives health and safety improvement.
Robotics disassembly for remanufacturing	Robots are widely used in automotive manufacturing but not in remanufacturing, particularly at the critical stage of disassembly. Advances in this sphere could mean that end-of-life product disassembly for remanufacture will become easier, faster and more cost-effective, driving efficient resource use and enabling the circular economy in the industry.
Smart warehouse robotics	Advances in autonomous mobile robotics (AMR) technology now make it possible to deploy robots in warehouses, where they support high volumes of small, multi-line orders, often in collaboration with warehouse workers. This leads to productivity gains, a decrease in accidents and injuries among workers, and opportunities for skills development and retraining. Current research is focusing on incorporating machine learning into AMR solutions.

Source: World Economic Forum and Accenture Strategy. "Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation", White Paper, January 2018

Figure 11. Overview of the 4IR technological developments evaluated for the Andhra Pradesh electronics sector

Development	Brief overview
Digital traceability for minerals	Blockchain-enabled software for precious and industrial metals markets helps prevent "conflict minerals" from entering electronic product value chains. Private permissioned blockchain tech can chronologically and permanently log information that is copied across a computer network accessed by multiple collaborating parties. Transactions involving the source of ore can be linked back to previous sales transactions.
Semiconductor Fab 4.0	This refers to the application of advanced manufacturing techniques to the production of electronic components such as silicon wafer fabrication, semiconductors and microchips, which is highly energy- and resource-intensive. Optimizing operations can help improve sustainability significantly, with a focus on the adoption of industrial internet of things (IIoT), big data, advanced analytics, machine learning and cobotics in both front- and back-end fabs, especially in emerging markets where there is a considerable opportunity for energy and resource efficiency gains.
Advanced electronic design automation	EDA, a simulation technology in the field of electronics design, calculates and predicts materials and components performance to create the optimum configuration for products. Used in chip design, it is now extending to the entire development process of an electronic device in combination with machine learning to increase the efficiency and accuracy of both design and production, resulting in faster time to market with accelerated prototyping, fewer batch defects and product recalls.
Near-dark factories	These automated factories with robotic systems manufacture electronic products with limited or no human intervention. Though true lights-out production is still rare, more processes are running with limited human interaction. This results in considerable productivity gains, increased throughput and higher total capacity, while minimizing errors and waste.
Autonomous disassembly for electronics	This refers to the disassembly of electronic products for component reuse and recycling, reducing the demand for virgin material and enabling closed material loops and circular economy business models. This development is enabled by modular design technology and advanced robotics and automation within mini disassembly factories. It decreases supply chain risk, mitigates reputation risk in the case of electronics and conflict minerals, and ensures the continuous reuse and valorization of raw materials.
3D-printed electronics	This is when 3D printing is used to produce hardware components of electronic products. Using 3D printing printed circuit boards (PCBs), designers can obtain faster prototypes, thereby accelerating time to market and ensuring the efficient use of resources. This application of 3D printing is very new and limited to prototyping at present, but companies are already experimenting with a focus on conductive inks to match the properties of the traditional metals used for electronics.
Green electronic materials	Synthetic biological materials from organic sources such as bacteria and microbes can help meet the increasing demand for smaller and more powerful devices. Currently functioning as wires, transistors and capacitators, these materials can decrease the dependence on non-renewable resources and the use of toxic components in electronics in a cost-efficient way. Proposed applications include biocompatible sensors, computing devices and components of solar panels.
Advanced green packaging	Material science innovation has allowed leading electronic product companies to incorporate sustainable packaging in the products leaving the factory gates, such as mycelium-based protective foam, use of AirCarbon and leftover wheat straw processed by enzymes. Benefits include improved company reputation and reduced carbon footprint.

Source: World Economic Forum and Accenture Strategy. "Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation", White Paper, January 2018

Appendix 3: Key terms and definitions

Production: The full spectrum of value-adding activities in the cradle-to-factory-gate part of a given industry value chain. It excludes those assumed to be out of the scope of this analysis.

Sustainable production: The manufacturing of products and product inputs, and the creation of related services, which respond to consumer and market needs, bring a better quality of life and generate a positive impact on the environment, the economy and society.

Fourth Industrial Revolution sustainable production development: A set of digital, physical and/or biological Fourth Industrial Revolution technologies converging to change manufacturing inputs, processes and outputs. They enable new business models with the potential to increase value creation across the triple bottom line (economic, social and environmental).

Appendix 4: Working group members

Fourth Industrial Revolution Technologies for Competitiveness and Sustainable Growth in Andhra Pradesh, India

Accenture India, Agility Logistics, Andhra Pradesh Electronics and IT Agency, Andhra Pradesh Industrial Infrastructure Corporation, Bharat Forge, Confederation of Indian Industry (CII), Department of Industry and Commerce, Andhra Pradesh, Department of IT, Electronics and Communications, Andhra Pradesh, Economic Development Board, Andhra Pradesh, Foxconn, Gayam Motor Works, GMR Group, Hitachi Consulting, India, HP, Infosys, JSW Steel, Mahindra Electric, Mitsubishi Heavy Industries, Panasonic India, Sun Mobility, Thyssenkrupp, Xiaomi

Fourth Industrial Revolution Technologies for Competitiveness and Sustainable Growth in Michigan, US

ABB US, Accenture US, AFL-CIO Industrial Union Council, Altair, Automation Alley, Ascent Aerospace, Borg Warner, Bosch Rexroth, Brose, CAR, DEGC, DENSO International America, Inc., Desktop Metal, Dow Chemical, Fabrication, Inc., Fanuc, FCA Group – Fiat Chrysler Automobiles, Flex-N-Gate, Ford Motor Company, Fori Automation, General Dynamic Land Systems, GS3, Hilite, Hirotec America, Joyson Safety Systems, Kelly Services, LIFT, Macomb County, Mahindra, Michigan Economic Development Corporation, Microsoft , NLB Corporation , OPS Solutions, LLC , Park Corporation , Pratt & Miller Engineering , RCO Engineering , Siemens, Soft Robotics, Stanley Black & Decker, Sundberg Ferar, Tata Technologies, University of Michigan, Vickers Engineering

Contributors

The World Economic Forum Accelerating Sustainable Production project team would like to thank the members of the broader community of the System Initiative on Shaping the Future of Advanced Manufacturing and Production for their ongoing commitment and support.

We would also like to express our gratitude to the working group members (see Appendix 4) for their generous contribution, comments and insights in the development of the studies in Andhra Pradesh and Michigan.

Finally, sincere thanks go to our knowledge partners at Accenture Strategy and to the Forum colleagues who provided support throughout the preparation of this White Paper and the studies in Andhra Pradesh and Michigan.

World Economic Forum

Project team

Helena Leurent, Head, System Initiative on Shaping the Future of Advanced Manufacturing and Production

Ian Cronin, Lead, System Initiative on Shaping the Future of Advanced Manufacturing and Production

Partnering organization

Project team

Peter Lacy, Senior Managing Director, Global Lead – Growth, Strategy & Sustainability, Accenture Strategy

Quentin Drewell, Strategy Principal, Sustainability, Accenture Strategy

Jennifer Ruiz Moreno, Business Strategy Consultant, Sustainability, Accenture Strategy; Secondee, World Economic Forum

Acknowledgments: Jessica Long, Sundeep Singh, Jennifer Bogart, Palak Kapoor, Zeina Lamah, Shrestha Padhy, Arushi Garg

Endnotes

1 World Bank, “World Development Indicators: Structure of output”, http://wdi.worldbank.org/table/4.2# (accessed 18 December 2018).

2 World Bank, “Manufacturing, Value Added”, https://data.worldbank.org/indicator/NV.IND.MANF.ZS?year_high_desc=true (accessed 11 December 2018).

3 World Economic Forum and Accenture Strategy, “Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation”, January 2018, http://www3.weforum.org/docs/WEF_39558_White_Paper_Driving_the_Sustainability_of_Production_Systems_4IR.pdf (accessed 19 December 2018).

4 The Intergovernmental Panel on Climate Change, “Global Warming of 1.5°C”, an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, October 2018, https://www.ipcc.ch/sr15/ (accessed 11 December 2018).

5 Lacy, Peter and Rutqvist, Jakob, “Waste to Wealth”, Palgrave Macmillan, 2015.

6 Assembly, “Remanufacturing is Profitable and Green”, 24 February 2010, https://www.assemblymag.com/articles/84787-remanufacturing-is-profitable-and-green (accessed 17 December 2018).

7 Eureka, “Maserati Has Fused Cutting-Edge Digitalization Methods with Italian Passion to Meet Customer Demand”, 2 October 2017, http://www.eurekamagazine.co.uk/design-engineering-features/interviews/maserati-has-fused-cutting-edge-digitalisation-methods-with-italian-passion-to-meet-customer-demand/161332/ (accessed 14 November 2018).

8 Apple, “Apple Adds Earth Day Donations to Trade-in and Recycling Program”, 19 April 2018, https://www.apple.com/newsroom/2018/04/apple-adds-earth-day-donations-to-trade-in-and-recycling-program/ (accessed 5 December 2018).

9 Autodesk, “How GM and Autodesk Are Using Generative Design for Vehicles of the Future”, 3 May 2018, https://adsknews.autodesk.com/news/gm-autodesk-using-generative-design-vehicles-future (accessed 5 December 2018).

10 Accenture Strategy, “Trust, Transparency and Traceability”, 2016, https://www.accenture.com/t20160729T074954__w__/cr-en/_acnmedia/PDF-27/Accenture-Trust_Transparency_Infographic.pdf (accessed 17 December 2018).

11 United Nations – Sustainable Development Goals, https://www.un.org/sustainabledevelopment/sustainable-development-goals/ (accessed 11 December 2018).

12 UK Research and Innovation, “Industrial Strategy Challenge Fund”, https://www.ukri.org/innovation/industrial-strategy-challenge-fund/ (accessed 11 December 2018).

13 Federal Ministry for Economic Affairs and Energy (BMWI), “A Modern Industrial Policy”, https://www.bmwi.de/Redaktion/EN/Dossier/modern-industry-policy.html (accessed 11 December 2018); UK Science & Innovation Network, “UK Science & Innovation Network Country Snapshot: Germany”, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/680376/171024_Germany_snapshot__002_.pdf (accessed 11 December 2018).

14 Asia Perspective, “‘Made in China 2025’: Intelligent Manufacturing Initiative Offers Foreign Investment Opportunities”, 23 August 2018, http://asiaperspective.net/2018/08/23/made-in-china-2025-intelligent-manufacturing-foreign-investement-opportunities/ (accessed 13 December 2018).

15 The Economic Times, “World Bank Forecasts 7.3 Per Cent Growth for India; Making it Fastest Growing Economy”, 6 June 2018, https://economictimes.indiatimes.com/news/economy/indicators/world-bank-forecasts-7-3-per-cent-growth-for-india-making-it-fastest-growing-economy/articleshow/64478238.cms (accessed 13 August 2018).

16 Andhra Pradesh Economic Development Board, “About Andhra Pradesh”, http://apedb.gov.in/about-ap.html (accessed 13 August 2018).

17 Department of Industries, Government of Andhra Pradesh, "Gearing up to Be a Global Automobile Hub", https://www.apindustries.gov.in/apindus/userinterface/singlewindowservicesapplication/public/AutomobileAndAutoComponentsPolicy.aspx (accessed 19 December 2018).

18 APEDB Database (not publicly available).

19 The Hindu Business Line, "AP Set to Become Leading Cell-Phone Making State: Experts", 26 February 2018, https://www.thehindubusinessline.com/info-tech/ap-set-to-become-leading-cell-phone-making-state-experts/article22858504.ece(accessed 19 December 2018).

20 ElectronicsB2B, "Journey of Andhra Pradesh towards Industry 4.0", 11 January 2017, https://www.electronicsb2b.com/headlines/tale-state-journey-towards-industry-4-0/ (accessed 13 August 2018).

21 Asian Development Bank, "In Andhra Pradesh, India, New Economic Corridors Create Path to Prosperity", 18 April 2018, https://www.adb.org/results/andhra-pradesh-india-new-economic-corridors-create-path-prosperity (accessed 13 August 2018).

22 World Economic Forum and Accenture Strategy, "Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation", January 2018, http://www3.weforum.org/docs/WEF_39558_White_Paper_Driving_the_Sustainability_of_Production_Systems_4IR.pdf (accessed 11 December 2018).

23 World Economic Forum and Accenture Strategy, "Accelerating Sustainable Production in Andhra Pradesh", September 2018, http://www3.weforum.org/docs/WEF_White_Paper_Accelerating_Sustainable_Production_report_2018.pdf (accessed 11 December 2018).

24 The Hindu, "India's First AI University to Come up at Amaravati", 26 February 2018, https://www.thehindu.com/todays-paper/tp-national/tp-andhrapradesh/indias-first-ai-university-to-come-up-at-amaravati/article22853983.ece (accessed 13 August 2018).

25 Andhra Pradesh MedTech Zone LTD, "AMTZ, THINK3D announce $6M Medical Device 3D Printing Facility in India", 19 June 2017, https://amtz.in/newspage/amtz-think3d-announce-6m-medical-device-3d-printing-facility-in-india/ (accessed 13 August 2018).

26 APEDB, "HP Plans an Institute of Excellence for 3D Printing in Amaravati", 23 January 2018, http://apedb.gov.in/news-hp-plans-institute-excellence-3d-printing.html (accessed 13 August 2018).

27 The Hindu, "ConsenSys to Launch Blockchain Training Course in Vizag in June", 5 April 2018, https://www.thehindu.com/news/national/andhra-pradesh/consensys-to-launch-blockchain-training-course-in-vizag-in-june/article23437751.ece (accessed 13 August 2018).

28 APEDB Database (not publicly available).

29 Business Insider, "Electronic Design Automation Market Growing at 5.5% CAGR to 2021", 2 March 2017, https://markets.businessinsider.com/news/stocks/electronic-design-automation-market-growing-at-5-5-cagr-to-2021-1001800507 (accessed 13 August 2018).

30 National Association of Manufacturers, "State Manufacturing Data", http://www.nam.org/Data-and-Reports/State-Manufacturing-Data/ (accessed 27 November 2018).

31 mlive, "Michigan Remains No. 1 in Auto Manufacturing, and More Fast Facts", 15 January 2018, https://www.mlive.com/news/index.ssf/2018/01/manufacturing_jobs_michigan.html (accessed 28 November 2018).

32 Detroit Regional Chamber, "The Auto Industry in Michigan", http://www.detroitchamber.com/econdev/chamber-initiatives/michauto-universal-name/the-auto-industry-in-michigan/ (accessed 27 November 2018).

33 ibid.

34 Abraham, Magid and Annunziata, Marco, "Augmented Reality Is Already Improving Worker Performance", Harvard Business Review, https://hbr.org/2017/03/augmented-reality-is-already-improving-worker-performance (accessed 27 November 2018)

35 ibid.

36 Business Facilities, “Advanced Manufacturing: The Cobots Are Coming”, 15 May 2018, https://businessfacilities.com/2018/05/advanced-manufacturing-cobots-are-coming/ (accessed 27 November 2018).

37 Reuters, “The Auto Plants of the Future May Have a Surprisingly Human Touch”, 27 April 2018, https://ca.reuters.com/article/technologyNews/idCAKBN1HY060-OCATC (accessed 27 November 2018).

38 Tech Republic, “Michigan Tops the List of US States Dominated by Robots”, 21 August 2017, https://www.techrepublic.com/article/michigan-tops-the-list-of-us-states-dominated-by-robots/ (accessed 17 December 2018).

39 3Dprint.com, “Software Algorithm Developed at University of Michigan Speeds Up 3D Printing”, 3 November 2017, https://3dprint.com/193133/algorithm-speeds-3d-printing/ (accessed 27 November 2018).

40 Asia Times, “Guangdong on Track to Become World’s 6th Largest Economy”, 7 May 2018, http://www.atimes.com/article/guangdong-on-track-to-become-worlds-6th-largest-economy/ (accessed 28 November 2018).

41 HKTDC, “Guangdong: Market Profile”, 23 February 2018, http://china-trade-research.hktdc.com/business-news/article/Facts-and-Figures/Guangdong-Market-Profile/ff/en/1/1X000000/1X06BUOU.htm (accessed 6 December 2018).

COMMITTED TO
IMPROVING THE STATE
OF THE WORLD

The World Economic Forum, committed to improving the state of the world, is the International Organization for Public-Private Cooperation.

The Forum engages the foremost political, business and other leaders of society to shape global, regional and industry agendas.

World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744

contact@weforum.org
www.weforum.org