WORLD ECONOMIC FORUM

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White Paper

The Next Economic Growth Engine
Scaling Fourth Industrial Revolution Technologies in Production

In collaboration with McKinsey & Company

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Contents

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Foreword

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After a decade of stagnated productivity, the Fourth Industrial Revolution is expected to create up to $3.7 trillion in value by 2025. Technologies such as the internet of things, advanced robotics, artificial intelligence and additive manufacturing are already helping to generate net productivity increases. However, to achieve the desired broad-based economic and societal impact and to maximize productivity benefits, technology must be adopted at scale and diffused throughout the ecosystem. This requires strengthened collaboration between governments, businesses, academia and civil society, thus unlocking the full value delivered to the economy and society.

The World Economic Forum System Initiative on Shaping the Future of Production provides a platform for leaders across the public and private sectors to work together to build a more inclusive and sustainable future of production. In pursuing this, they look to technology and innovation to boost economic growth, and to promote a human-centred approach for the benefit of all. Established in 2016, the System Initiative's community has become more diverse and counts over 60 businesses from 18 industry sectors, 25 ministers of commerce and/or industry, and representatives from top engineering universities, labour unions and civil society organizations.

Within the System Initiative's framework, the Technology and Innovation for the Future of Production project, developed in collaboration with McKinsey & Company, is exploring how industrial companies can take technology adoption in production from proof of concept to industrial scale. The project is also examining how governments and civil society can best support the development of a favourable ecosystem for adopting and diffusing technology across industry sectors.

This White Paper summarizes new findings, conclusions and recommendations for governments and businesses, drawn from desk research and extensive consultations from May to November 2017. The goal is to inform the design of future strategies for the adoption and diffusion of Fourth Industrial Revolution technologies at scale through strengthened public-private collaboration.

Executive summary

With the advent of the Fourth Industrial Revolution, countries and companies have an opportunity to counter and potentially reverse the slowdown in productivity by diffusing and adopting technology at scale. In fast-evolving and converging technologies for production, accelerated growth and maturity are occurring like never before. The latest developments of the internet of things (IoT) allow for connecting and tracking asset performance in real time, as well as for integrating production and consumption processes. Artificial intelligence, which since 2015 has achieved image and speech recognition at the level of the human brain, can process large amounts of data that factories collect to increase efficiencies and inform accurate decision-making. Advanced robots and computers can perform a range of routine physical activities and increasingly accomplish activities requiring cognitive capabilities, such as tacit judgements or sensing emotions. According to the McKinsey Global Institute, more than 60% of all manufacturing activities can be automated with current automation technology.[1,2]

These changes are driving the world towards a future of production characterized by autonomous, self-organizing factories and integrated or hyperconnected production systems. Manufacturing companies, suppliers and customers will ultimately be connected on a common IoT platform. Technology will empower the factory worker and plant manager, with a third of tasks almost fully automated, thus shifting the focus from execution of repetitive and inefficient tasks to innovation. Technologies of the Fourth Industrial Revolution will generate inclusive growth and bring benefits beyond the factory's four walls. They will potentially deliver up to $3.7 trillion in value[3] for the global economy, offering new products and services to society and supporting the environment by optimizing resource consumption.

However, technology's full potential for production, when adopted at scale, is still far from being exploited. While several pioneering companies and early adopters praise technology's positive impact, adoption remains slow and limited across all industry sectors. More than 70% of industrial companies are still either at the start of the journey or unable to go beyond the pilot stage.[4] Most are stuck in "pilot purgatory", where technology is deployed experimentally at reduced scale for an extended period due to the inability or lack of conviction to roll it out at production-system scale. Pilot purgatory occurs across industries and countries, including the most advanced of them, with challenges compounded for small and medium-sized enterprises (SMEs).

To maximize the potential gains in productivity brought by technology, companies must move from pilots to adopting technology at scale, across multiple production facilities and through relevant value chains. They also must take their suppliers (often SMEs) and customers with them to be able to innovate and transform their businesses models. Governments need to develop the right set of policies and protocols to facilitate the dissemination and adoption of technology at the national level. Moreover, international cooperation and public-private partnerships must help to elevate productivity so that it benefits the global economy. Through its work in 2017, the Technology and Innovation for the Future of Production project has generated new insights and actionable recommendations for companies and governments to accelerate the adoption and diffusion of technology at scale.

The findings, conclusions and recommendations in this White Paper are based on structured interviews with select leaders and experts from the public and private sectors, academia and civil society. In addition, the World Economic Forum leveraged insights from McKinsey & Company's technological network of partners; its annual Digital Manufacturing Global Expert Survey, with responses from over 400 experts; and the latest IoT Pulse Survey, with responses from over 300 business leaders. The insights and recommendations in this White Paper will be presented and discussed at the World Economic Forum Annual Meeting 2018 in Davos-Klosters, Switzerland, and used to define key public-private collaborative interventions needed to accelerate technology diffusion across industries and geographies.

1. Technology is shaping the future of production

Despite the recent slowdown in global growth, production continues to be a critical driver of the economy in developed and developing countries. It is the main source of investment in research, development and innovation (R&D&I), with manufacturing companies responsible for more than 85% of the R&D carried out by the private sector in Germany, Japan and South Korea.[5]

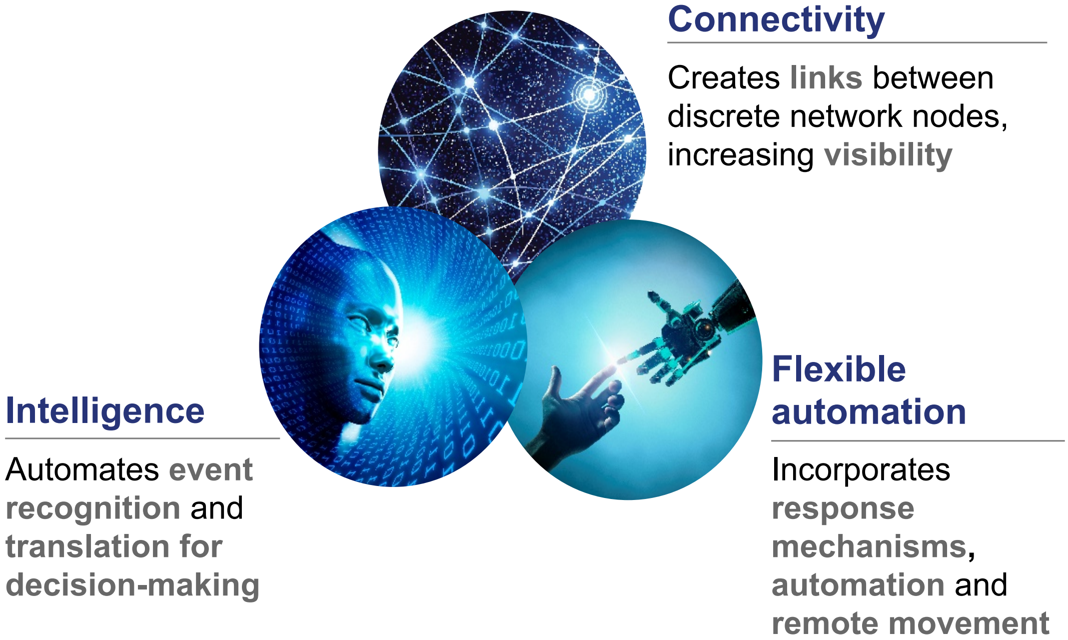
Technology and innovation have been and will remain central to how production evolves and is transformed. Over the past 20 years, worker productivity across industries in the United States increased by 47%,[6] driven primarily by technology adoption and innovation. Society is at the juncture of the increasing convergence of production and consumption, which is mainly driven by new business models enabled by transformations in technology. In the context of the Fourth Industrial Revolution, production is at the cusp of a paradigm shift driven by three technological megatrends that have reached unprecedented pace and breadth (Figure 1), even as their full-scale adoption and benefits in production is yet to be realized.

1. **Connectivity:** Rapidly expanding through the internet of things (IoT), connectivity has reached global scale, with 8.4 billion devices connected.[7] As of today, only 15% of assets are connected in production, but that is changing rapidly. The technology industry is working on more than 700 IoT platforms[8] for industrial use, and major technology companies are investing heavily in hyperscalable IoT platforms.

2. **Intelligence:** Artificial intelligence, advances in computing power and the availability of big data are allowing machine learning algorithms to excel. In fact, speech and image recognition have already reached the accuracy of the human brain. The full potential of artificial intelligence in production is however, yet to be realized; only a small fraction of data is currently used for decision-making. For example, on an oil rig, the research found that while 100% of data was captured, only 0.5% was used to make decisions.

3. **Flexible automation:** Automation technology can currently automate 60% of all manufacturing tasks.[9] However, the current level of penetration of industrial robots is still comparatively low, even in leading adopters such as South Korea, where only 530 robots per 10,000 production workers are deployed.[10a]

Figure 1: Key technology megatrends transforming production



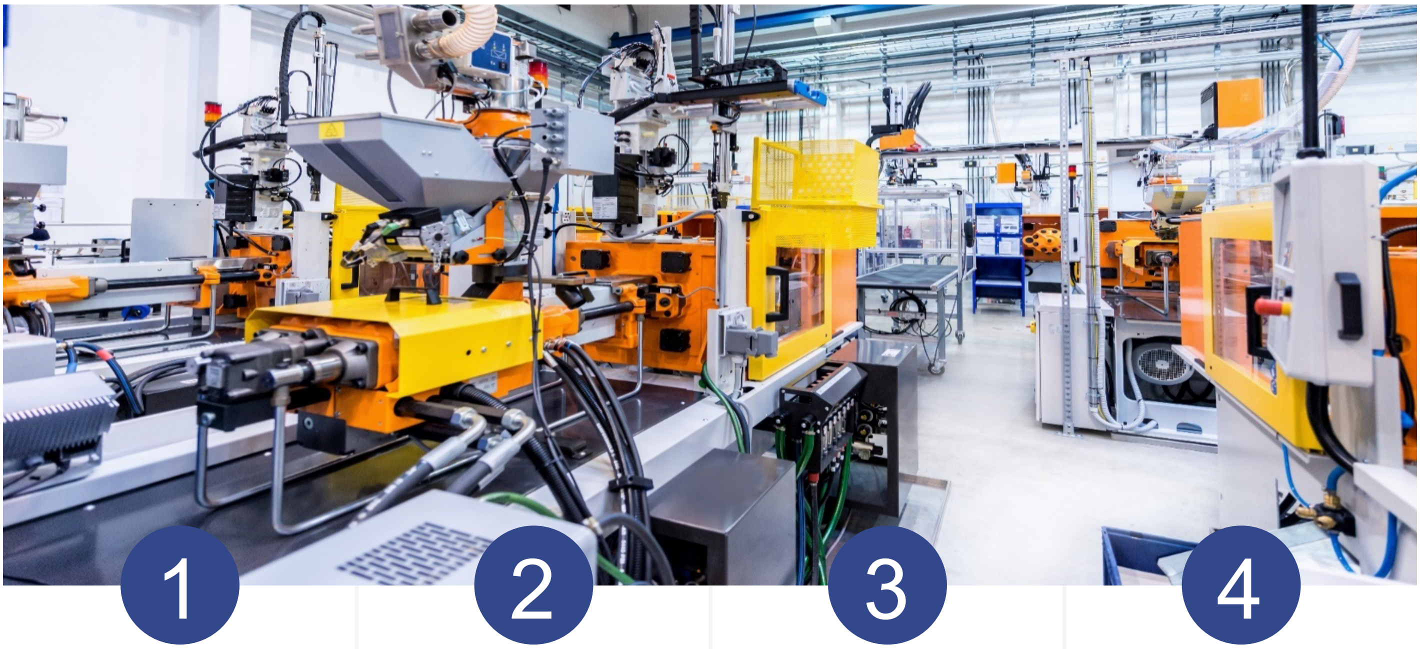
Source: McKinsey & Company

The combined advances in connectivity, intelligence and flexible automation will dramatically transform value generation in production, as illustrated in Figure 2. (Production is defined as the end-to-end activities leading to the realization of products and related services, in the cycle of design-source-manufacture-assemble-distribute-consume-service-end of use.) Four main, radical shifts are expected in the short to medium term:

1. Manufacturing will become self-organizing and more autonomous due to a new class of factory workers or a highly connected and smart shop floor
2. Value chains will be seamlessly connected end to end, allowing manufacturers to drive product innovation twice as fast as today
3. Supply chains will connect to a broader supplier ecosystem that will function as a single platform, enabling business-to-business integration
4. Data will drive the creation of new services and innovations in business models

Customers, employees and society will benefit from these shifts. Customers will have access to products better tailored to their needs; producers will easily capture their preferences and behaviours and input these to customize design and fabrication. Logistics companies, for example, have changed their business model and entered manufacturing by incorporating on-demand 3D printed products in their range of services. For example, SAP has partnered with UPS and Fast Radius on an integrated end-to-end system for on-demand 3D printing.[10b] Manufacturing and product delivery times will be shortened, thanks not only to developments in mobility but also to more interconnected and transparent supply chains, which will be enhanced by process automation. Factories will be reshaped, and workers' capabilities will be strengthened by shifting the focus from execution of repetitive tasks to innovation, in a much safer environment. The environment will benefit from increased efficiency in resource management as technology demonstrates its capacity to reduce energy consumption and material waste. The Accelerating Sustainable Production project of the World Economic Forum System Initiative on Shaping the Future of Production describes a new set of public-private, technology-driven interventions to contribute towards achieving the United Nations Sustainable Development Goals.

Figure 2: Key shifts in production driven by Fourth Industrial Revolution technologies



Source: McKinsey & Company

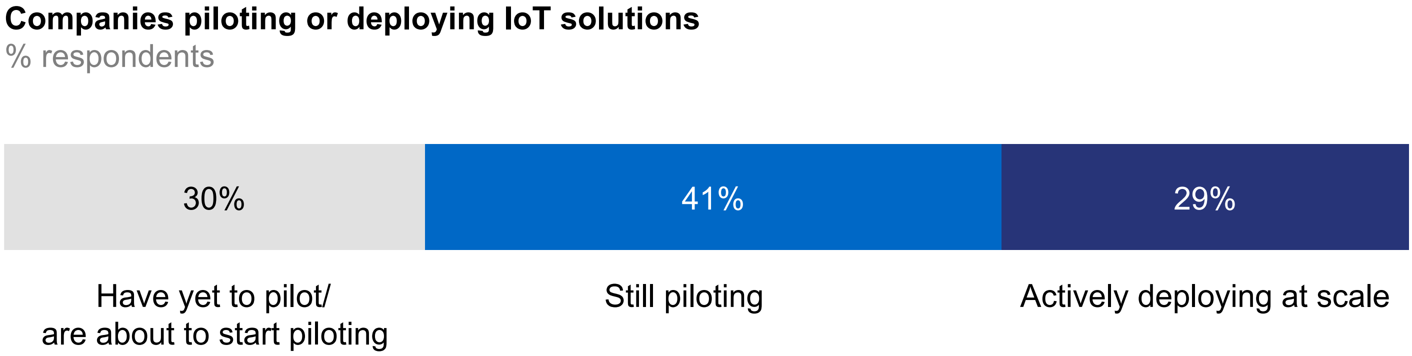
"We need to fully leverage digital and technological advancements to be able to predict and capture consumer demand, and connect it seamlessly through production operations and materials sourcing. This will require reskilling and empowering our workforce to harness the new forces of technology. When doing this responsibly, we create value across the supply chain using resources sustainably and helping our surrounding communities to prosper."

Mohamed Samir, President, India, Middle East and Africa, Procter & Gamble, United Arab Emirates

2. Escaping from pilot purgatory in the Fourth Industrial Revolution

Based on the research, technologies of the Fourth Industrial Revolution are showing positive returns and new opportunities for growth. Nevertheless, the adoption of technology in production still remains slow across industries and regions: only 29% of industrial companies have started to roll out new technological solutions across their production processes; 41% are still piloting solutions at a single site or business unit, and the remaining 30% have yet to or are about to start the journey (Figure 3).[11] More than 400 global digital manufacturing experts have confirmed the slow pace of adoption, which is true across industries and regions.[12]

Figure 3: Technology adoption at scale is lagging



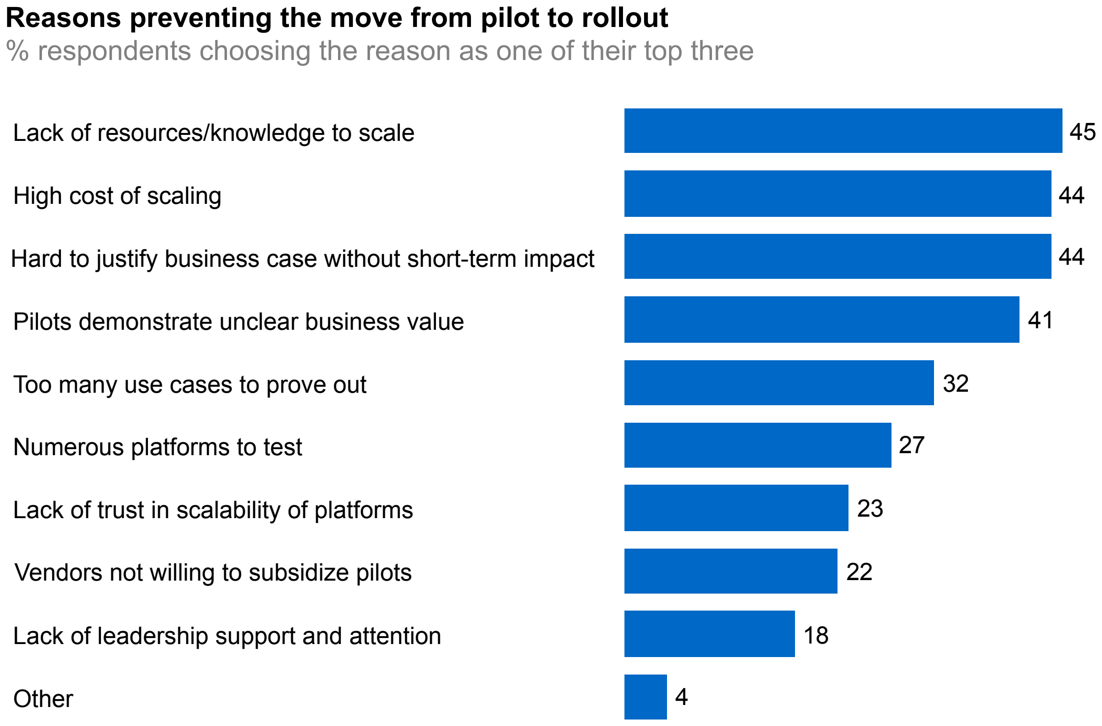
Source: McKinsey & Company

Most companies are struggling to successfully transition from pilots to large-scale, impactful deployments. The principal reasons are the difficulty of aligning the organization around the potential value and return on investment, the uncertainty of digital's value to their performance (especially in the short term), the cost of resources needed to implement new solutions and the investments required to take them to scale. Figure 4 provides more details on the challenges hindering companies from adopting technology at scale.

"We are in the middle of a consumer-driven growth revolution. Business leaders who deliver a customized experience at scale will win the day. Rising innovations like AI, machine learning, blockchain and industrial IoT help make this bold vision into compelling reality."

Bill McDermott, Chief Executive Officer, SAP, Germany

Figure 4: Challenges to scaling up the adoption of technologies



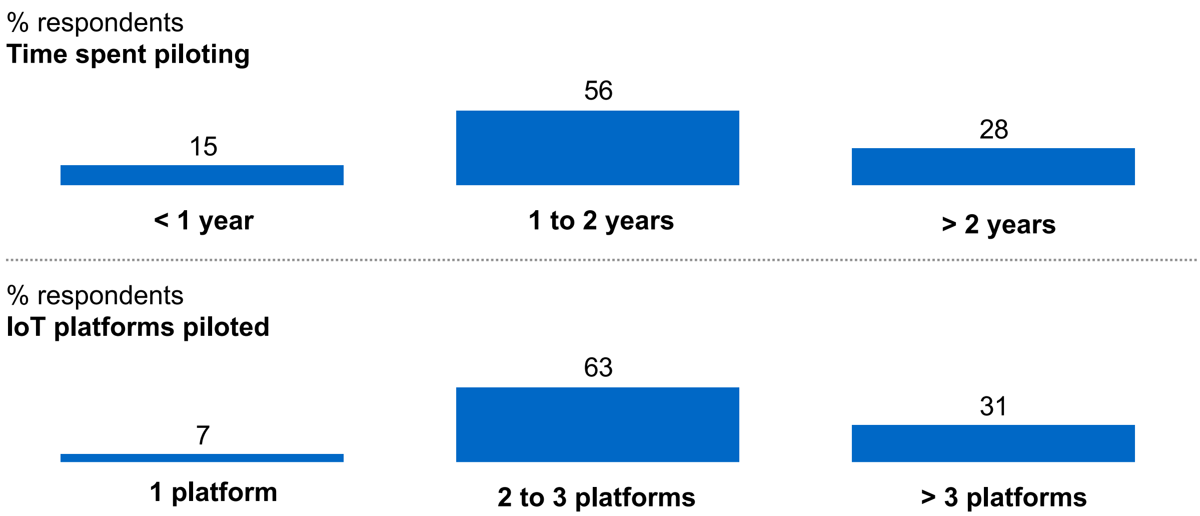
Source: McKinsey & Company

The difficulties of transitioning to impact at scale are shown in Figure 5. Pilot phases exceeded 1 year for 84% of respondents in McKinsey & Company's IOT Pulse Survey, and lasted more than 2 years in 28% of the cases.[13] The pilots' extended duration is problematic. Pilots must be short to test a significant number of technology applications, as the experience from pioneering companies shows that at least 20 to 30 applications are needed to transform the production system effectively. Given technology's short development cycles, an extended pilot phase might not keep up with the current pace of technological evolution.

The number of IoT platforms piloted before selecting the best one for a company attests to the complexity of the pilot phase and the implication of delays. In 63% of cases, companies piloted two to three IoT platforms, and in 31% more than three. Only 7% of the surveyed companies successfully piloted a single platform.[14]

The extended pilot phase and the inability of production organizations (manufacturers) to move technologies from pilots to company-wide rollout is termed **"pilot purgatory"**.

Figure 5: Difficulties in transitioning to large impact at scale



Source: McKinsey & Company

3. Accelerating adoption of Fourth Industrial Revolution technologies: recommendations for business leaders

Accelerating technology adoption is essential to unlocking productivity growth and bottom-line returns, and to keeping up with the pace of technological developments of the Fourth Industrial Revolution.

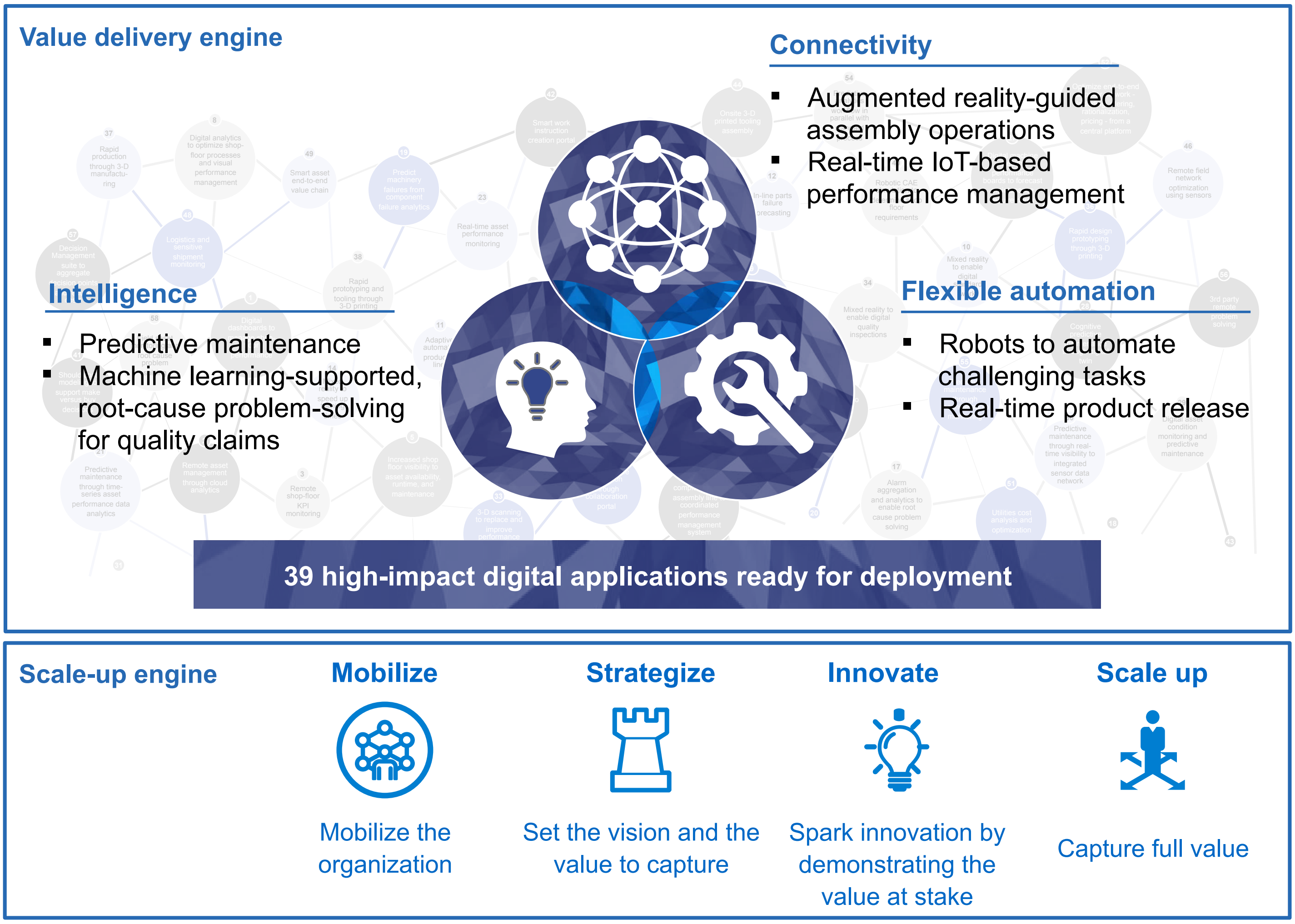
Together with McKinsey & Company, the World Economic Forum has developed an industry toolkit (Figure 6) that provides practical recommendations to companies eager to embark on and accelerate their journey of adopting technologies and thus escaping pilot purgatory. The toolkit consists of two sections or “engines”:

– **Value delivery engine:** A compendium of 39 production use cases of the Fourth Industrial Revolution (as defined in the next section), identified by scanning over 500 technology solution providers and analysing their most relevant implementations

– **Scale-up engine:** A detailed framework describing 12 best practices along four main phases of scaling technologies. This engine builds on the results of extensive research, field work and structured interviews with leading manufacturing companies and early technology adopters in production

See Annexes 1 and 2 for more details about the toolkit, or contact the Technology and Innovation for the Future of Production team at the World Economic Forum.

Figure 6: Industry toolkit for accelerating adoption of technology



Source: McKinsey & Company. Fourth Industrial Revolution scale-up engine, in collaboration with the World Economic Forum

3.1. The value delivery engine – high-impact use cases

A growing number of technology providers have a wide range of offers, such as artificial intelligence, the IoT, robotics, virtual reality, augmented reality (AR), 3D printing, digital twins (i.e. digital representations of physical objects) and intelligent process automation. Manufacturers that adopt and scale these technologies are challenged to prioritize the required solutions from those available.

The research shows that a practical approach should be taken when adopting Fourth Industrial Revolution technologies, based on each technology's ability to address specific production and business problems. Otherwise known as the production/business problem-driven approach, or more succinctly as the use-case approach, it places business value at the centre, with new technologies as enablers for solving problems. The approach is especially recommended for companies in the initial stages of adopting Fourth Industrial Revolution technologies.

High-impact use cases typically combine several Fourth Industrial Revolution technologies to create the required systemic change. Use cases can be deployed at small scope with immediate returns. As such, they can be used as stepping stones for building future production systems. While some business leaders still hope for a silver bullet – the one, ultimate use case – a combination of 20-30 use cases and 60-80% of Fourth Industrial Revolution technologies is typically required to successfully transform the production system within a single company.

The Technology and Innovation for the Future of Production project has selected a compendium of 39 use cases relevant to a broad set of companies, industries and regions, building on proprietary McKinsey & Company research that analysed over 500 technology solution providers. The use cases are deployed across all production functions: the factory floor (assembly and machining, maintenance, quality and performance management) as well as the supply chain and product value chain (including design, prototyping and sourcing). A key takeaway from the use cases is that many highly mature technology applications already deployed are ready for scaling.

Each of the use cases is presented in detail, including its business goal, the production problem being resolved, how the technologies were implemented and the impact achieved. In the example of a food and beverage manufacturer (Figure 7), the goal was to improve its efficiency by reducing losses in productivity from manual processes. A digital solution was deployed to convert the manual standard operating procedures onto a digital platform, accessible by remote devices and able to connect the production departments involved. This led to an increase in equipment availability and a massive reduction in manual paper work.

In a use case from the aerospace industry (Figure 8), a manufacturer sought to improve its agility in production scheduling by reducing the manual work and associated problems. It deployed a solution combining connectivity and intelligence, allowing for automated production sequencing to track and process the digitized quality information from all components along the assembly process. This led to an increase in the factory's throughput and a reduction of scrapped materials from inadequate scheduling.

What is a use case?

A use case consists of applications of Fourth Industrial Revolution technologies (typically more than one in combination) oriented to reinvent production processes and drive business value by solving specific production problems. These can be across machining, assembly, maintenance, quality, supply chain, design, prototyping and engineering.

What business value drivers do they contribute to?

- Speed to market
- Agility and responsiveness
- Resource productivity and efficiency
- Customization to customer needs
- Value-added services and business model innovation

Which production problems do the use cases solve?

Use cases have resolved problems across different areas of production and beyond the factory's four walls. Examples include:

- Variability in inspection times for large and highly customized products
- Component traceability and quality data not integrated in production scheduling and sequencing
- Long and expensive prototyping cycles

Figure 7: Use case – digitizing standard operating procedures

Business goal

Maximize resource productivity and efficiency

Problem in production

Inconsistent paper-based procedures leading to lost productivity in manual processes (changeover, start-up, line cleaning)

Technology applied

- All shop-floor procedures were digitized in a common platform accessible through mobile phones and tablets
- Operators captured results directly on their tablets, adding pictures and videos of the operations if needed
- Operators were connected to supervisors and technicians through a digital real-time workflow

Results

- Increase in available equipment
- 85% decrease in paper work and transcription

Source: McKinsey & Company

Figure 8: Use case – automating and optimizing material selection in inventory management

Business goal

Agility and responsiveness

Problem in production

Manual-based production scheduling and sequencing generating problems in quality (rework, scrap) that were difficult to trace

Technology applied

- All components were tracked along the assembly process
- Quality (expiry date, exposure time) was digitized and captured in real time
- Analytics software optimized the production scheduling, incorporating quality and customer data

Results

- Increased throughput and capacity

Source: McKinsey & Company

Throughout the research, companies pioneering technology adoption explained that technologies are driving more than just productivity: they are impacting quality, worker safety and sustainability, and creating other forms of business value in addition to enabling the company to better focus on innovation. In this sense, the use cases are classified by value driver (speed to market, agility and responsiveness, resource productivity and efficiency, and customization to customer needs, as shown in Figure 9). Underscoring their relevance and applicability, 70% of the use cases from the compendium can be deployed to enhance more than one value driver.

Figure 9: Delivering impact on four production value drivers

Shop floor | Supply Chain | Product Value

Agility and responsiveness

- 2 Light-guided assembly sequence
- 3 Mixed reality to enable digital standard work
- 4 Mixed reality to accelerate training times
- 5 Real-time locating system for key manufacturing components
- 8 Predictive maintenance aggregating data from historian systems
- 9 Predictive maintenance through audio monitoring
- 10 Predictive maintenance through temperature monitoring
- 11 Predictive maintenance through machine vibrations monitoring
- 12 Predictive maintenance using historical data from downhole instrumentation
- 14 Remote assistance using augmented reality
- 20 Real-time asset performance monitoring and visualization
- 22 3D scanning to replace and improve performance for high-cost coordinated measuring machine scans
- 24 Digital work instructions and quality functions
- 25 Digitized standard procedures for line operations with integrated workflow and multimedia sharing
- 26 Mixed reality glasses to guide operators in the end-of-line inspection
- 27 Expanded high-performance computing to reduce product design simulation life cycles
- 28 Product costing software integrated into 3D design
- 29 Rapid design prototyping through 3-D additive manufacturing
- 31 Cost modeling to support make-versus-buy decisions
- 34 Automated logistic operations decision-making
- 35 Automation and optimization of manual material selection and inventory management
- 36 End-to-end, real-time supply chain visibility platform
- 39 Single platform for real-time supply chain decisions

Resource productivity and efficiency

1 Cycle time optimization through big-data analytics on lines' programmable logic controllers	2 Light-guided assembly sequence	3 Mixed reality to enable digital standard work	4 Mixed reality to accelerate training times
5 Real-time locating system for key manufacturing components	6 Cost optimization of heavy operations through sensor analysis	7 Machine alarm aggregation, prioritization and analytics-enabled problem-solving	8 Predictive maintenance aggregating data from historian systems
9 Predictive maintenance through audio monitoring	10 Predictive maintenance through temperature monitoring	11 Predictive maintenance through machine vibrations monitoring	12 Predictive maintenance using historical data from downhole instrumentation
13 Real-time pipeline cost optimization based on edge sensors	15 Analytics platform for remote production optimization	16 Digital dashboards to monitor overall equipment effectiveness	17 Digital twin for remote production optimization
18 Enterprise manufacturing intelligence system to upgrade operations management	19 Integration platform to connect machine-level data with enterprise software	21 Sensor-based manufacturing reporting of key performance indicators	23 Automated in-line optical inspection to replace end-product manual inspection
25 Digitized standard procedures for line operations with integrated workflow and multimedia sharing collaboration portal	32 Aggregate demand across end-to-end supplier network	33 Automated field service parts identification and ordering	37 In-process traceability and quality
39 Single platform for real-time supply chain decisions			

Speed to market

27 Expanded high-performance computing to reduce product design-simulation life cycles	28 Product-costing software integrated into 3D design	30 Rapid, outsourced prototyping of metal parts	36 End-to-end, real-time supply chain visibility platform

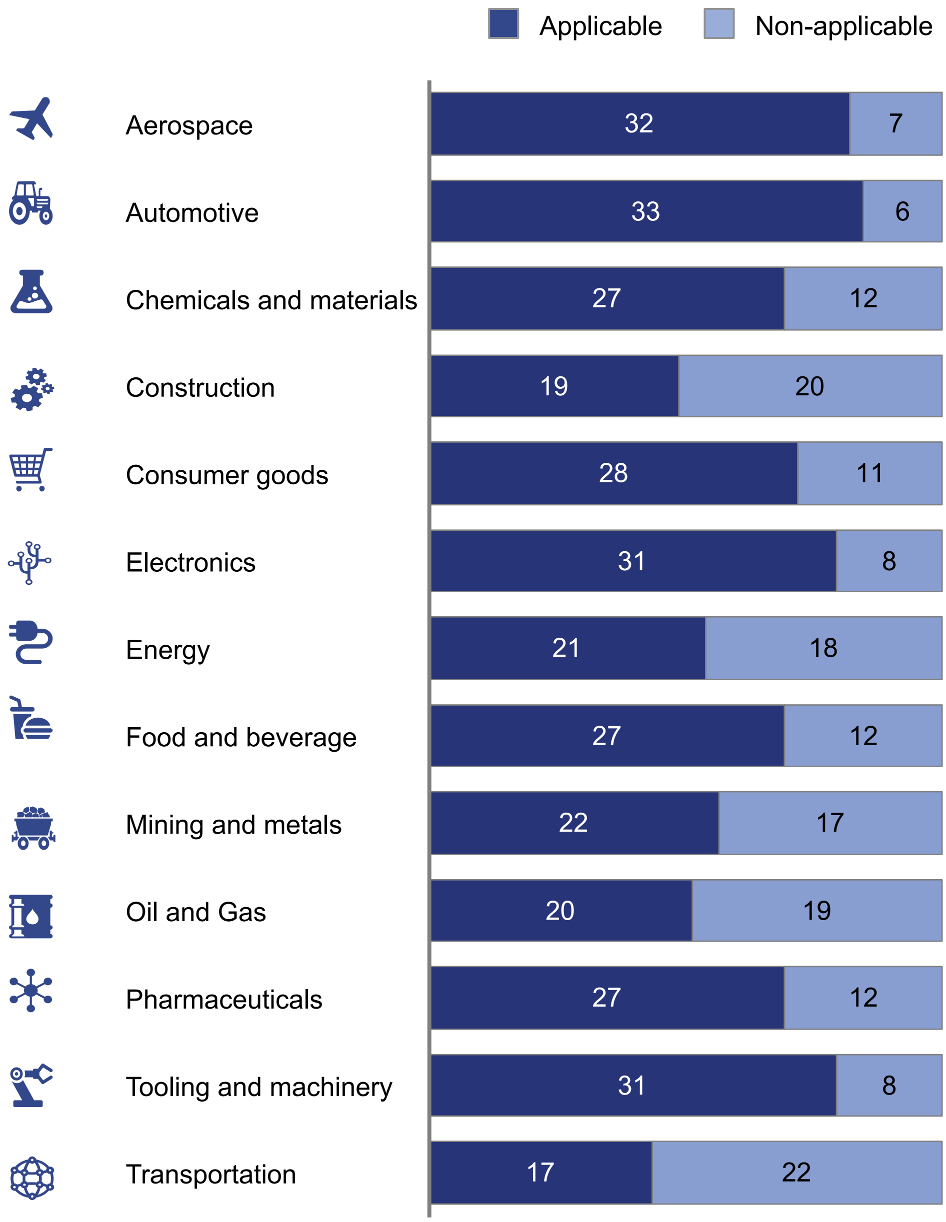
Customization to customer needs

17 Digital twin for remote production optimization	18 Enterprise manufacturing intelligence system to upgrade operations management	23 Automated in-line optical inspection to replace end-product manual inspection	29 Rapid design prototyping through 3D additive manufacturing
35 Automation and optimization of manual material selection and inventory management	38 Part traceability from unique digital tag based on surface scanning		

Source: McKinsey & Company

The use-case library contains examples from different production industries, with their distribution shown in Figure 10. Over 80% of use cases are applicable in other industries besides the one from their example, thus indicating an opportunity for cross-industry collaboration in use-case exchange and development.

Figure 10: Use cases by industry and cross-industry applicability



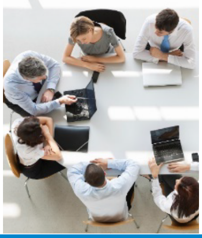
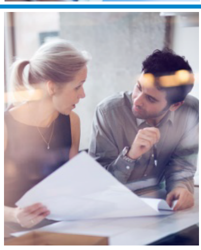
Source: McKinsey & Company

3.2. The scale-up engine – actionable best practices

The complex journey of scaling up is one of the biggest challenges production organizations face when trying to move out of pilot purgatory. Few of them know this journey, as only a minority of companies are successfully rolling out Fourth Industrial Revolution technologies across their network of plants, suppliers and customers. Interviews with companies and experts, as well as desk research, have helped to demystify the journey by identifying key success factors. The resulting scale-up engine (Figure 11), a four-phase framework to mobilize, strategize, innovate and scale up, contains actionable best practices and recommendations across 12 key activities required to drive technology and innovation at scale in production.

The 12 key activities are sequenced to build growing conviction and technological readiness (moving from initial awareness and conviction after the first phase to the construction of the top-down and bottom-up scalability enablers during the strategize and innovate phases). The scale-up engine describes a common approach, applicable across industries and countries. Nevertheless, the sequence of the key activities needs to be tailored to each organization's culture and starting point in terms of digital maturity. For example, some companies strategize (top-down) and innovate (bottom-up) in parallel, while others only begin to reinvent the process after top-down sponsoring is granted from the executive level.

Figure 11: Scale-up engine – framework for adopting technology

SCALE-UP ELEMENTS			SCALE-UP BEST PRACTICES
Mobilize		Rally the organization	▪ Run low-scale proof of concepts ▪ Set up a cross-functional innovation team
Strategize		Set the vision and the value to capture	▪ Set a bold aspiration aligned with business strategy ▪ Prioritize digital applications ▪ Develop a rolling two- to three-year roadmap
Innovate		Spark innovation by demonstrating the value at stake	▪ Reinvent through digital applications ▪ Modernize technology infrastructure ▪ Build capabilities and partner network
Scale up		Capture full value	▪ Implement digital performance management ▪ Roll out digital applications across the production footprint ▪ Create a centre of excellence ▪ Enrol suppliers and customers

Source: McKinsey & Company, in collaboration with the World Economic Forum

Mobilize: rally the organization

Most production organizations must mobilize before starting a production-wide programme of adopting new technology and innovation. This phase can take up to 9 to 12 months, depending on the company. Two activities typically come first: executing small-scale proofs of concept, and creating the team to lead the programme. Deploying Fourth Industrial Revolution technologies requires reinventing existing processes to unlock their maximum potential. Such change offers the opportunity to go beyond the factory's four walls to connect production functions (from engineering to the supply chain). Therefore, companies embarking on the journey start with the early engagement of cross-functional teams able to drive the transformation through innovation and to break organizational silos.

The key success factor of this phase is to execute short and specific proofs of concept that serve not only as learning platforms, but also as success stories to foster conviction, which is communicated broadly. Successful experiences from the research prompted the recommendation to have proofs of concept target production problems that are solvable within weeks and achieve three core goals:

- Create tangible impact at a small scale (at the line or product level)
- Design the next stages of implementation
- Communicate results and success stories to generate organizational momentum

Strategize: set the vision and the value to capture

A clear and dynamic roadmap that lays out the path forward is required because of the complexity of technology and use cases, the required process and cultural change, and the investment needed to scale a strategy. Sponsoring by top executives and a forward-thinking vision are the key success factors in this critical phase and for the subsequent, required implementations.

Strategy starts with the executive level defining the case for production to embark on adopting Fourth Industrial Revolution technologies. This involves not only a **business case** (linking the corporate strategy to the business drivers and specific business objectives), but also an **aspirational vision**. In this phase, executives can show the value of a future-oriented approach and help the organization see its role in the Fourth Industrial Revolution environment. The aspirational vision must be followed by the selection of technology use cases that can generate the desired value. For example, BMW is focusing on deploying six key applications of Fourth Industrial Revolution technologies in its production system: context-sensitive assistance systems, innovative robot systems, simulation and factory digitalization, planning and control systems, smart logistics, and advanced analytics.[15] A company-wide framework that drives the implementation is also recommended to ensure homogeneous execution across the production unit and sites, which might have different starting points in terms of performance and maturity.

The strategy phase should conclude with the **creation of a company-wide roadmap**, built in collaboration with the business units. Roadmaps are normally structured in waves, based on the complexity of the use cases to be implemented and the starting point of each business unit.

"Changing mindsets from stage-gate innovation to agile thinking is an important driver of technology transformation in production."

Kurt Bock, Chairman of the Board of Executive Directors , BASF SE, Germany

Innovate: spark innovation by demonstrating the value at stake

In parallel with executive sponsorship and funding, the business units must prove the value of Fourth Industrial Revolution technologies by deploying a first wave of use cases while scalability enablers are being built. Piloting is crucial in this phase, which is mainly driven by the business units; this not only helps to achieve success, but also creates an innovative company culture open to technology.

Use cases deployed in the first wave are no longer proofs of concept, but implemented pilots with sizable impact. They demonstrate real business value and **reinvent processes**. Two main scalability enablers should be undertaken before rolling out technologies at production-system scale:

– **Modernize technological infrastructure:** Operations and information technology (IT) need to work hand in hand to reinforce the technological backbone. This involves integrating the right data from the information technology and operational technology systems (IT/OT convergence) and creating the delivery engine that will develop the use cases to the business needs. Cybersecurity must be actively addressed, such as through analysing the threads to the existing and future systems. Understanding legacy systems and their adaptability to the upcoming platforms is also essential at this stage.

– **Build capabilities and partnering networks:** Fourth Industrial Revolution technologies require a new set of capabilities. Companies need to upskill and acquire new talent, putting their capability-building models at the centre of the transformation. A new approach to collaborating with technology solution providers, academia and researchers is also critical. Adidas and Siemens, for example, began collaborating in 2017 on joint research and development programmes to drive the digitization of the former's plant of the future, known as Speedfactory.[16] In addition, ABB and Microsoft announced a strategic partnership in 2016 to develop industrial digital solutions.[17]

Scale up: capture full value

After establishing the scale-up enablers and creating a company-wide roadmap, use cases should be extended to full production systems at scale. This requires mobilizing the entire organization through:

– **Digital performance management** – Recognized by experts and technology adoption leaders as a must-have, this **use case underpins assurance of value both directly and through additional use cases**. It integrates operational data from the entire production footprint onto a company-wide platform; the data can be used for site-to-site comparisons, simulations and enhanced decision-making.

– **A centre of excellence** – Responsible for managing the change process, it governs projects, codifies the new production system and guides the transformation approach in a standardized manner.

– **Diffusion of use cases to the value chain ecosystem of partners (Tier-*n* suppliers and customers)** – Diffusion of use cases helps to complete the value capture. Extending connectivity of operational data, for example, can create a single production ecosystem. While such integration offers new possibilities for competition and opportunities for innovation, it must be done carefully to avoid confusing suppliers and creating many diverse data platforms.

4. Diffusing strategies: recommendations for country leaders

The Fourth Industrial Revolution will lead to a new type of competition between and within countries, along with growing uncertainties across manufacturing nations. However, the latest technological developments represent a concurrent opportunity for countries to accelerate progress and transition towards the future of production.

Most of the industrial companies consulted in 2017 agreed on government's critical role in creating an enabling environment and production ecosystem conducive to the development, diffusion and adoption of technology. While industrial policy and strategy have existed for several decades, the focus in recent years has been on technology and innovation, as governments try to keep pace with the Fourth Industrial Revolution's opportunities and challenges. At the national level, policy-makers continue to work at managing macroeconomic levers; namely, they look to create market conditions favourable to manufacturing companies, to reinforce critical infrastructure (especially for telecommunications and IT connectivity) and to develop appropriate trade policies that support the market for manufactured goods.

"The next generation of industrial strategy will have to be holistic, drive innovation across the value chain and keep pace with the new and emerging technologies for all kinds of industries."

Suresh Prabhakar Prabhu, Minister of Commerce and Industry of India

Moreover, more specific efforts to diffuse and adopt technology, often aggregated under an umbrella national programme, are on the rise. In the last six years, eight of the top 10 manufacturing countries have launched national efforts – best known as Industry 4.0 strategies – to capture productivity gains and strengthen their position globally for the future. The reasons behind this increased focus on production, with technology as a key foundational pillar, include the following:

– Countries can potentially leapfrog their industrial development and journey to modernize by accelerating adoption of new technologies
– For industries to adopt technologies at scale, an enabling environment including infrastructure, IT connectivity and appropriate intellectual property laws must be developed
– An economy's success depends on promoting R&D&I so that technology can be adopted and diffused at a lower cost for large, medium and small enterprises

For the Technology and Innovation for the Future of Production project, over 20 countries' efforts were analysed, focusing especially on technology. In parallel, the Country Readiness for the Future of Production initiative profiled over 100 countries against key drivers of production and current levels of readiness to successfully transition towards the future of production. Examples of mechanisms for diffusing technology, as used by the countries analysed, are shown in Figure 12.

The case of the United States

Recently, manufacturing has declined more rapidly in the United States than in other advanced economies. While it makes up only 9% of employment and 12% of the country's gross domestic product (GDP), manufacturing drives 30% of US productivity growth, 60% of exports and 70% of private-sector R&D. Although the largest US manufacturers have managed to thrive despite growing headwinds, SMEs have been hit hard. This has implications for the broader economy, as manufacturing's decline represents two-thirds of the fall in labour's share of US GDP and has limited the prospects of middle-income workers. Larger manufacturers are also concerned because they face more risk without a healthy ecosystem of domestic suppliers to provide agility and opportunities for collaboration. In addition, the US manufacturing sector has been slow to adopt digital technologies, thus dragging down its productivity.

The role of technology and innovation

According to the McKinsey Global Institute, the United States could capitalize on its strengths to boost manufacturing output by 14-20% by 2025. This is based on the impact of progressively higher adoption of technology, export growth and share of domestic content in finished goods. The World Economic Forum Country Readiness for the Future of Production project sees the United States as strongly positioned for the future, scoring in the top five across all drivers of production, especially in innovation and technology.

Figure 12: Efforts to diffuse technology and innovation at the country level

	Examples	Other countries analysed
Awareness	Over 225,000 visitors joined the Hannover Messe's 2017 edition Over 2,300 events organized during "Industry Weeks"	
Financial incentives	A two-year plan valued at €3.3 billion for boosting the transformation of SME manufacturing capabilities towards Industry 4.0 technologies Manufacturer-led outbound investment in technology, with €20 billion to acquire German-based companies	
Legal framework	Ju-RAMI 4.0, a framework for understanding the main legal aspects of most common use cases Regulated drone operations via introduction of the Drone Operator Safety Act in the US Senate	
Accreditation	Alliance Industrie du Futur: Agency coordinating relevant industry stakeholders (private and public sectors, academia and civil society)	
Connectivity and data security	Cybersecurity for the Future, a research project of the Frauenhofer-Gesellschaft, with a dedicated taskforce for the industrial security of networks and systems	
R&D&I	Technology development test beds: Internet of things Artificial intelligence Augmented and virtual reality	
Talent & education	Primary and secondary school curriculum updated, including programming skills and piloting the inclusion of 3D printing New curriculum at universities: Massachusetts Institute of Technology's (MIT) Industry 4.0 massive open online course; the Stanford Program in Law, Science and Technology	

Source: McKinsey & Company

Countries starting earlier on this journey differed in maturity compared to countries that were lagging, based on detailed analysis of specific efforts and levers available to promote technology diffusion, adoption and innovation. Pioneering countries have been able to shift their focus from creating awareness on new technologies for their industries to building an institutional framework that supports the scalability of Fourth Industrial Revolution technologies.

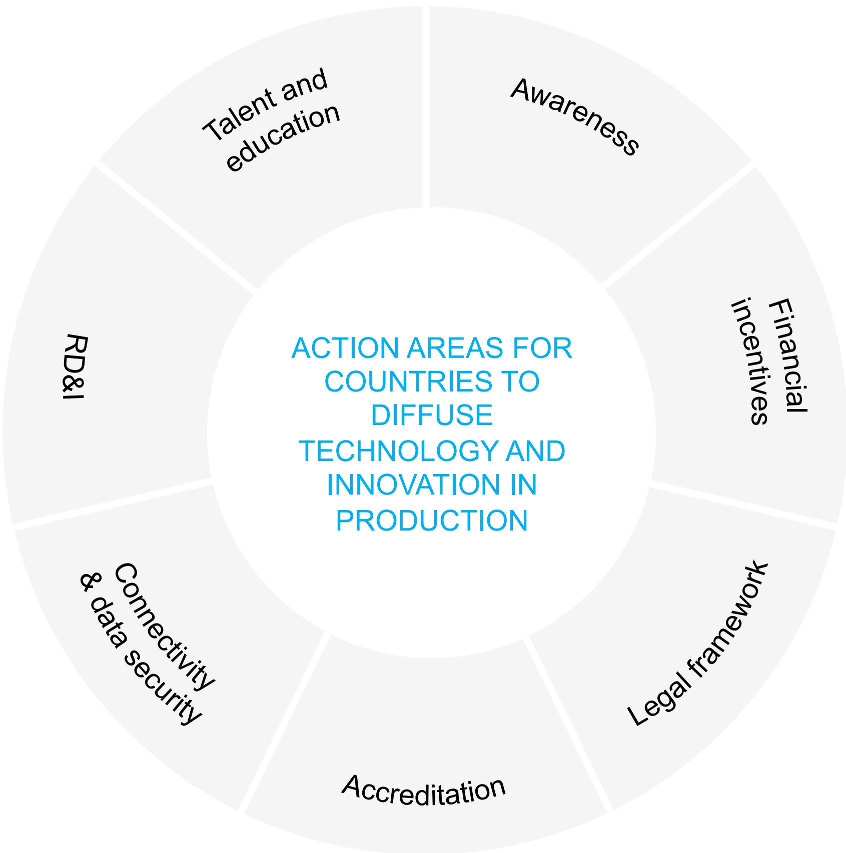
Of the countries analysed, Germany was the first to launch an Industry 4.0 programme (in 2011), followed by the United States, Italy and France between 2012 and 2013. Asian countries (South Korea, Japan and China) have kicked off their national efforts more recently. China's 2016-2020 plan seeks to upgrade key areas of its 10 priority traditional manufacturing sectors to digital manufacturing. This initiative is part of the country's long-term strategic vision to develop intelligent manufacturing to generate new growth and strengthen Chinese manufacturing. Russia became the latest large economy to create a national programme by launching its Advanced Industrial Technologies in 2017. The Indian government launched the Make in India initiative, and is slated to come up with a revamped industrial policy with a key focus on technology adoption. Many other countries, including Australia, Canada and Spain, have also started national-level programmes.

As many of these efforts are in the early stages, a full assessment of their impact is not yet possible. However, some results already show that R&I projects are advancing manufacturing and increasing access to finance for SMEs.

Depending on country-specific nuances and a nation's industrial sector mix, national plans can consider a wide list of policy levers and actions. From these levers, seven types of government-led national efforts have been identified that facilitate adopting and diffusing technologies in production (Figure 13):

- Building **awareness** by communicating the importance of national initiatives and programmes to industrial policy, and by sharing success stories and lessons from technology and innovation adoption journeys for pioneering companies
- Establishing **financial incentives**, such as tax credits or public loans, that support the acquisition and development of Fourth Industrial Revolution technologies for large, medium and small enterprises
- Creating a robust **legal framework** to regulate areas impacted by new technologies (e.g. intellectual property, data protection, cross-border flows)
- Spurring **accreditation** of companies that successfully adopt Fourth Industrial Revolution technologies, nationally and internationally, thus supporting the technology and industry ecosystem
- Expanding **connectivity and data security** protection with specific efforts in production, for example creating dedicated taskforces, institutions and frameworks on cybersecurity
- Promoting **R&D&I** for Fourth Industrial Revolution technologies applied to production
- Setting up new **talent and education** programmes adapted to the future of the production workforce

Figure 13: National diffusion mechanisms for technology and innovation



Source: McKinsey & Company

As countries continue to revamp and build out strategies for their local industries, national and global efforts must be strengthened in other areas (as highlighted in the following section) to create the right environment for the future of production. Reinforcing cybersecurity, creating common standards for new technologies such as the industrial internet of things, and developing protocols for interoperability stand out as three of the key areas of immediate focus for the global community of countries and companies working on production.

5. Building opportunities for public-private collaboration at the World Economic Forum

A concerted global effort dedicated to adopting and diffusing technology is required that goes beyond existing national efforts. The breadth and complexity of recent developments in production, as well as the related opportunities and challenges for both companies and governments, underline the need for this expansive approach. An Acatech study[18] shows that constituents from leading manufacturing countries, including Germany, the United States, China, Korea, the United Kingdom and Japan, cited the need for cooperation in key areas, including standards, international coordination of national initiatives, training and business model development. Constituents from civil society, academia, and the public and private sectors interviewed during this research also asserted this need.

Global cooperation exists – for example, Japan's collaboration with Germany on issues regarding Industry 4.0 and the IoT,[19] and bilateral agreements between India and Sweden[20] on a range of sectors, including automotive and pharmaceuticals. But the scale, network and number of countries involved are still limited. Moreover, these programmes have strategies and visions that are not always aligned, and efforts are sometimes disaggregated. Based on this analysis, three areas require strengthened collaboration through public-private partnerships and at the global level:

- **Joint infrastructure for best-practice sharing, testing and capability building**
  To catalyse technology adoption and diffusion, joint infrastructure is critical at both an industry and a cross-industry level, given the opportunities for replicability (e.g. use-case sharing)

  - **Systems testing of mature use cases and technologies** – Mature technologies need test beds, going one step beyond proofs of concept to test their impact on the production system and to integrate anticipated challenges. Joint test beds would substantially reduce pilot times and accelerate adoption of use cases. Test beds seeking to facilitate international collaboration include FELIX, the EU-Japan project[21] that is working to define a common framework for future internet test beds dispersed across continents. Such efforts require collaboration across a wider set of countries.
  - **Awareness and diffusion** – To showcase Fourth Industrial Revolution technologies in action, sites are required to demonstrate the impact of top technology use cases to a wider audience. They will also show how they are transforming production through productivity and improvements in quality. Global expansion of the network must go beyond current country-level efforts or company-specific sites.
  - **Capability building** – Cited by constituents as a key issue, capability building is a vital component of digital production. It is required to both align and prepare business functions for the technology-driven transformation of production.

- **Industrial standards and interoperability**
  International standards and interoperability could potentially increase the efficiency of connected devices and deliver maximum impact. While the Industrial Internet Consortium (IIC) is leading efforts to create frameworks to enable interoperability, over 100 standards exist; further collaboration is needed to increase standardization.

- **Safety, cybersecurity and data protection**
  Research reveals that manufacturing was the industry most susceptible to cyberthreats in the first half of 2017.[22] The industry's internet-connected computers accounted for about one-third of all cyberattacks. Data, a key component of digital production and integrated value chains, also involves flows and enhanced protection, making it a key item to address through collaborative efforts. Regional and international initiatives on international data flows include the International Data Protection Commissioner's initiatives, or regional initiatives at the EU level.[23] Collaboration is needed on production, especially in the context of integrated production value chains. In addition, specific focus is required for international collaboration on cybersecurity in industries.

The issues highlighted above can also be discussed through an industry-specific lens, as the complexity and regulatory requirements vary across industries. Some highly regulated sectors, such as pharmaceuticals, must adhere to varying international regulatory requirements, which compound the challenges of transforming production at scale across their regional sites. This highlights why global cooperation, even when the agenda is specific to an industry, is crucial.

Areas of collaboration and proposals to expand leveraging of the World Economic Forum platform

The System Initiative on Shaping the Future of Production brings together a dedicated community spanning 26 countries and more than 60 companies from 18 industry sectors, and over 40 academic and civil society organizations. In addition, the World Economic Forum Technology Pioneer community includes top technology solution providers in production. This extensive network provides the potential for collaboration on a much larger scale; it brings the nuances and needs of not only pioneers, but also countries and companies that might lag in the journey of adopting technology. The Forum's platform can be leveraged to catalyse action on the key issues described above.

Annex 1: Value delivery engine – Use-case library

The value delivery engine contains details on the selected use cases, describing the business problem addressed, the impact achieved and applicability across industries. For more details, contact the Technology and Innovation for the Future of Production team at the World Economic Forum.

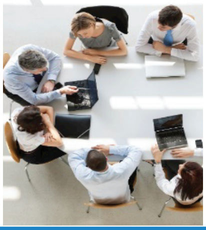
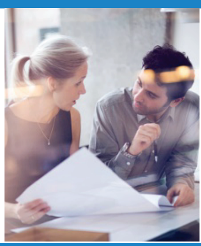
Use case		Business problem addressed	Description
		FACTORY FLOOR: ASSEMBLY AND MACHINING USE CASES	
01	Cycle time optimization through big-data analytics on lines' programmable logic controllers (PLCs)	Need to increase line productivity or increase capacity in a highly automated line	▪ Deployed a software solution that aggregates all the PLC data from an assembly line's equipment to the very granular motion level to identify bottlenecks and loss of capacity (in seconds). This data can easily visualize performance and be used to drive preventive maintenance actions or to create a predictive maintenance engine. ▪ The solution did not require installing additional hardware.
02	Light-guided assembly sequence	Variability in assembly processes that also require long training times	▪ Developed light-based augmented reality (AR) display system that guides operators on error-prone, manual part-picking process. It helps to accelerate the off-line training of operators and also can be applied to on-line assembly.
03	Mixed reality to enable digital standard work	Delays in production caused by quality problems during the assembly process	▪ Implemented AR operator instructions using smart glasses to facilitate the assembly process of highly customized airplanes. The operator can use voice-command to search the standard operating procedure for an assembly step. Video features allow to connect with engineers located remotely.
04	Mixed reality to accelerate training times	Need to reduce training time and improve effectiveness of on-boarding new shop-floor workers	▪ Developed new digital training instructions that overlay with real-world, on-the-job training environment through use of an AR helmet.
05	Real-time locating system (RTLS) for key manufacturing components	Production times extended due to time wasted searching for parts	▪ Deployed a solution allowing workers to easily find all in-process parts in a highly customized production environment through sensor-based RTLS at custom automotive manufacturer.
		FACTORY FLOOR: ASSEMBLY AND MACHINING USE CASES	
06	Cost optimization of heavy operations through sensor analysis	Reduce pumping operating costs	▪ Leveraged sensor to identify the key cost parameters and optimize them to reduce the costs associated with salt water disposal.
07	Machine alarm aggregation, prioritization and analytics-enabled problem-solving	Recurrent quality problems without an identified root cause	▪ Clustered multi-source data alarms, sequenced alarm variety, assigned priority and made rapid analysis to determine the root cause and solution at pharmaceutical manufacturer.
08	Predictive maintenance aggregating data from historian systems	High maintenance costs to analyse equipment performance (e.g. failure root-cause analysis, benchmarking costs across original equipment manufacturers)	▪ Developed a time-series data analytics solution that rapidly streamlines asset modelling, receiving data from multiple data points across the historian systems. ▪ This data can be used in a model to forecast equipment failure.
09	Predictive maintenance through audio monitoring	Machine downtime/ excessive maintenance cost	▪ Monitored audio signals of over 100 machines and forecasted machine maintenance requirements to minimize downtime.
10	Predictive maintenance through temperature monitoring	High downtime costs of equipment, strengthening the need to anticipate failures early on	▪ Developed an engine to generate real-time insights and alerts on critical equipment, based on the relevant sensor data (e.g. gearbox temperature and vibration). ▪ Applied a predictive model to the engine to drive anticipated maintenance actions before expected failures.
11	Predictive maintenance through machine vibrations monitoring	High maintenance costs to monitor vibration across large facilities for preventive actions	▪ Installed remote vibration sensors in the energy plant's critical equipment (e.g. water injection pumps) to facilitate consistent data collection. The sensor data was connected to a machine-learning engine to calculate alerts for unusual activity in the equipment that could result in a breakdown. Alerts and real-time results were visualized in a multi-platform app to increase visibility on the equipment's health.
12	Predictive maintenance using historical data from downhole instrumentation	High downtime costs of equipment, strengthening the need to anticipate failures early on	▪ Installed a multivariate engine, based on collected and analysed data, to clearly represent the signals and elements predictive of adverse events. This engine was used to repair or replace equipment before its failure and to modify the operating conditions of the moving systems (e.g. lifts) to extend the life of the critical equipment.
13	Real-time pipeline cost optimization based on edge sensors	High maintenance costs of pipelines to maintain the required uptime levels	▪ Deployment of an edge solution that uses installed sensors to monitor and analyse data in real-time and allow for proactive decisions (e.g. shutting down a valve) based on predictive models. The edge solution allowed to deploy a data analytics solution in remote assets where transporting data was expensive and unreliable.
14	Remote assistance using augmented reality	Complex operations (e.g. machine set-up) requiring presence of expert(s)	▪ Implemented a solution that allows operators and technicians to connect through tablets with remote experts who can provide guidance through audio and written comments, or via drawings over the visualized images in real-time.

Use case	Business problem addressed	Description
	FACTORY FLOOR: ASSEMBLY AND MACHINING USE CASES	
15 Analytics platform for optimizing remote production	High scrap costs from late detection of a component's quality problems, and lack of data in the root-cause analysis	▪ Built an analytics platform to automate the data acquisition (from PLCs, databases and enterprise resource planning [ERP]) and analysis of the different processes involved in the fabrication. During the platform's creation, additional data sources not captured previously in the ERP were identified to improve traceability. ▪ The collected data was then cleansed, aggregated and represented in a customized data model to analyse and identify the root cause. ▪ The analytics platform enabled company-wide automated root-cause analysis and statistical process control.
16 Digital dashboards to monitor overall equipment effectiveness (OEE)	Low shop-floor productivity due to ineffective analysis of key performance indicators (KPIs)	▪ Built digital dashboards with operator and supervisor performance dashboards (OEE, downtime analysis, quality losses, changeover duration) based on captured PLC data.
17 Digital twin for optimizing remote production	Suboptimal productivity across a network of sites without enough visibility into their performance to define effective corrective actions	▪ A digital twin (digital real-time representation of the production processes) was created for all sites in the network to allow for global visualization of operating performance. ▪ Different dashboards were established to visualize the data in real time, comparing different sites and identifying new insights and shop-floor improvements. ▪ This platform helped to create a cognitive predictive maintenance engine to form automated prediction models of future breakdowns.
18 Enterprise manufacturing intelligence (EMI) system to upgrade operations management	Growing complexity in the product variants, requiring more advanced production management	▪ Installed an EMI system with over 400 IoT devices (sensors). The system allowed for real-time monitoring and the display of results, predictive intelligence for maintenance and quality, and partial traceability.
19 Integration platform to connect machine-level data with enterprise software	High manufacturing costs and lack of an integrated view of real-time operational performance to allow effective problem-solving and resolution	▪ Deployed a platform for a real-time production monitoring system, combining data captured across the shop-floor functions, ERP and the manufacturing execution system. ▪ This platform allowed for improved issue resolution by maintenance and engineering. It also enabled creation of a new digital performance management system that displayed real-time operating results with end user-adapted cockpits (e.g. operator, team leader, manager).
20 Real-time asset performance monitoring and visualization	High maintenance costs for monitoring transformers via routine manual samples	▪ Deployed a cloud-based solution, connected to any mobile device, to monitor real-time performance of all integrated assets in the power plant.
21 Sensors-based manufacturing KPI reporting	Low shop-floor productivity due to lack of data capture from equipment	▪ Rapid installation of sensors to connect machines with ERP and quality management systems for deploying KPI visualization software, which generates reports with multi-platform access (worker device, PCs) and enables continuous improvement.
	FACTORY FLOOR: QUALITY USE CASES	
22 3D scanning to replace and improve performance of high-cost coordinated measuring machine (CMM) scans	Manual, slow or inaccurate 3D scanning of parts	▪ Installed and automated 3D scanning machine to replace CMMs for high-precision quality inspections, decreasing the overall throughput time and increasing inspection points.
23 Automated in-line optical inspection to replace end- product manual inspections	Suboptimal optical inspection done manually	▪ Installed automated optical inspection tools in the production line to replace end-of-line manual inspection processes and increase the depth of analysis. The tool's software used automated image analysis to automatically quantify the defects and AI algorithms to classify them. The reports generated can be integrated with quality systems, such as the Laboratory Information Management System.
24 Digital work instructions and quality functions	Low quality across different products with a paper-based quality control (QC) process	▪ Installed an IoT platform on the shop floor, which allowed integration of multiple sensor data from production equipment and tooling. The platform's apps reinforced the quality processes by digitizing work instructions, the QC/quality assurance data forms and real-time dashboards.
25 Digitized standard procedures for line operations, with integrated workflow and multimedia sharing collaboration portal	Inconsistent paper- based procedures leading to lost productivity in manual processes (changeover, start-up, line cleaning)	▪ Developed a digital standard operating procedure that runs on any platform (e.g. mobile, tablet). The solution provided clear and visual instructions, recorded evidence of the results, reduced paperwork and shortened training time. The system included a mobile workflow platform to coordinate start-up and changeover process steps, as well as audiovisual sharing (text, audio, photos, videos).
26 Mixed reality glasses to guide operators in the end-of-line inspection	Variability in inspection times for large and highly customized products	▪ Deployed the scalability platform to manage software for a smart glasses solution. The tablet-based work instructions were replaced by 3D glasses, as the tablets were breaking frequently during inspections.

Use case	Business problem addressed	Description
		PRODUCT VALUE CHAIN
27 Expanded high-performance computing to reduce product design simulation life cycles	Long and iterative design cycles due to lack of computing capacity	▪ Reduced the iteration cycles in the design phase of a complex part by leveraging additional computing capacity from a cloud-based, high-performance computing provider.
28 Product costing software integrated into 3D design	Long cycles to calculate costs of new/customized products	▪ Implemented product costing software that integrates with the design software (computer-aided design [CAD] phase) to provide early estimates of manufacturing costs. The software calculated the cost by analysing the CAD and defining the cost drivers. It also suggested manufacturing routings.
29 Rapid design prototyping through 3D additive manufacturing	Long and/or expensive prototyping cycles of plastic/ nylon parts	▪ Printed and assembled prototype designs using an in-house, small-scale printer.
30 Rapid outsourced prototyping of metal parts	Long and/or expensive prototyping cycles of metal parts	▪ Outsourced metal prototyping of parts to a modern computer numerically controlled (CNC) machining manufacturer. The external vendor was able to quickly manufacture and ship the parts by installing a plug-in to the designers' CAD software that checks the manufacturability and price of the prototype and transmits the file directly to its CNC machine.
31 Cost modelling to support make-versus-buy decisions	Lack of rapid and effective cost analysis tools for purchasing negotiations	▪ Implemented a product costing software to rapidly generate cost analyses of parts (e.g. clean sheets) to inform make-versus-buy decisions and negotiations with suppliers.
		PRODUCT VALUE CHAIN
32 Aggregate demand across end-to-end supplier network	Delays in supply chain due to poor communication of demand needs across network of sites and suppliers	▪ Deployed a material demand aggregation engine to map all parts used across all the suppliers that deliver to all sites in the manufacturing network. The engine grouped the common parts used at different points in the process, monitored part purchase points and created visibility to all tiers of suppliers.
33 Automated field service parts identification and ordering	Need to reduce unnecessary parts ordered by field service engineers	▪ Developed new automated parts identification process for field services based on analysis of historical inventory management and service orders, and on identification of regions with poor ordering history (high return rates).
34 Automated logistic operations decision-making	Labour-intensive logistics planning	▪ Built a logistics and optimization app that mathematically models human expertise in real time, recommending the best decision output based on priority and defined scoring.
35 Automation and optimization of manual material selection and inventory management	Manual-based production scheduling and sequencing, generating quality problems (rework, scrap) and poor traceability of problems	▪ Implemented a software-based solution to track parts, raw materials and tools as they moved through the assembly process. The software collected information (e.g. expiration date, exposure time) and its changes during production to ensure that audit requirements were met and material use optimized. This solution optimized the parts released for work orders, shifting from a basic first in, first out system to better matching of customer orders to the shelf life of parts, and the coordination of parallel jobs. ▪ The tracking of material and work order completion shifted from paper-based to digital.
36 End-to-end (E2E), real-time supply chain visibility platform	Lack of E2E visibility across supply chain performance to enable decision-making	▪ Installed E2E real-time supply chain management software for centralized inventory management and supplier and site performance monitoring.
37 In-process traceability and quality	Quality problems across the supply chain without integrated visibility of performance	▪ Created production traceability system to ensure product quality and provide end-to-end supply chain visibility and analytics across multi-plant network.
38 Part traceability from unique digital tag based on surface scanning	Counterfeiting/traceability	▪ Reduced counterfeiting and traced regulated parts back from suppliers to final assembly through digital tagging based on surface patterns. Parts were scanned before shipping (in the plant) and at the customer site. The scanner compared the parts and identified any difference (counterfeiting or modification).
39 Single platform for real-time supply chain decisions	Lack of E2E visibility across supply chain performance to enable decision-making	▪ Automated purchasing, sourcing, inventory modelling and tracking on a single connected platform, enabling simulations and fact-based decision-making.

Annex 2: Scale-up engine

The full version of the scale-up engine includes details of the phases and activities on the journey to scale, details per activity, exploration and assessment of key activities with real cases, and a compilation of key lessons learned by leading executives/constituents. For the full version of the toolkit, or for more information, contact the Technology and Innovation for the Future of Production team at the World Economic Forum.

SCALE-UP ELEMENTS			SCALE-UP BEST PRACTICES
Mobilize		Rally the organization	▪ Run low-scale proof of concepts ▪ Set up a cross-functional innovation team
Strategize		Set the vision and the value to capture	▪ Set a bold aspiration aligned with business strategy ▪ Prioritize digital applications ▪ Develop a rolling two- to three-year roadmap
Innovate		Spark innovation by demonstrating the value at stake	▪ Reinvent through digital applications ▪ Modernize technology infrastructure ▪ Build capabilities and partner network
Scale up		Capture full value	▪ Implement digital performance management ▪ Roll out digital applications across the production footprint ▪ Create a centre of excellence ▪ Enrol suppliers and customers

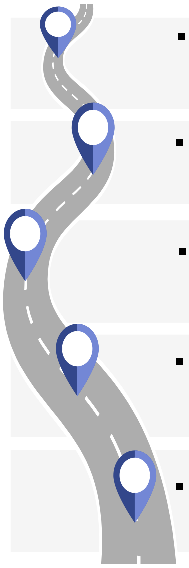
Source: McKinsey & Company, in collaboration with the World Economic Forum

Key activities per enabler based on lessons learnt from pioneering companies

STRATEGY

Prioritize digital applications

Key activities



- **Create transparency on existing opportunities** through a structured assessment of the performance and capability gaps across business units
- **Create a pipeline of Fourth Industrial Revolution technology use cases**, driven by the innovation team in collaboration with the business units
- **Design use cases and calculate the business case**, identifying infrastructure requirements and process enablers

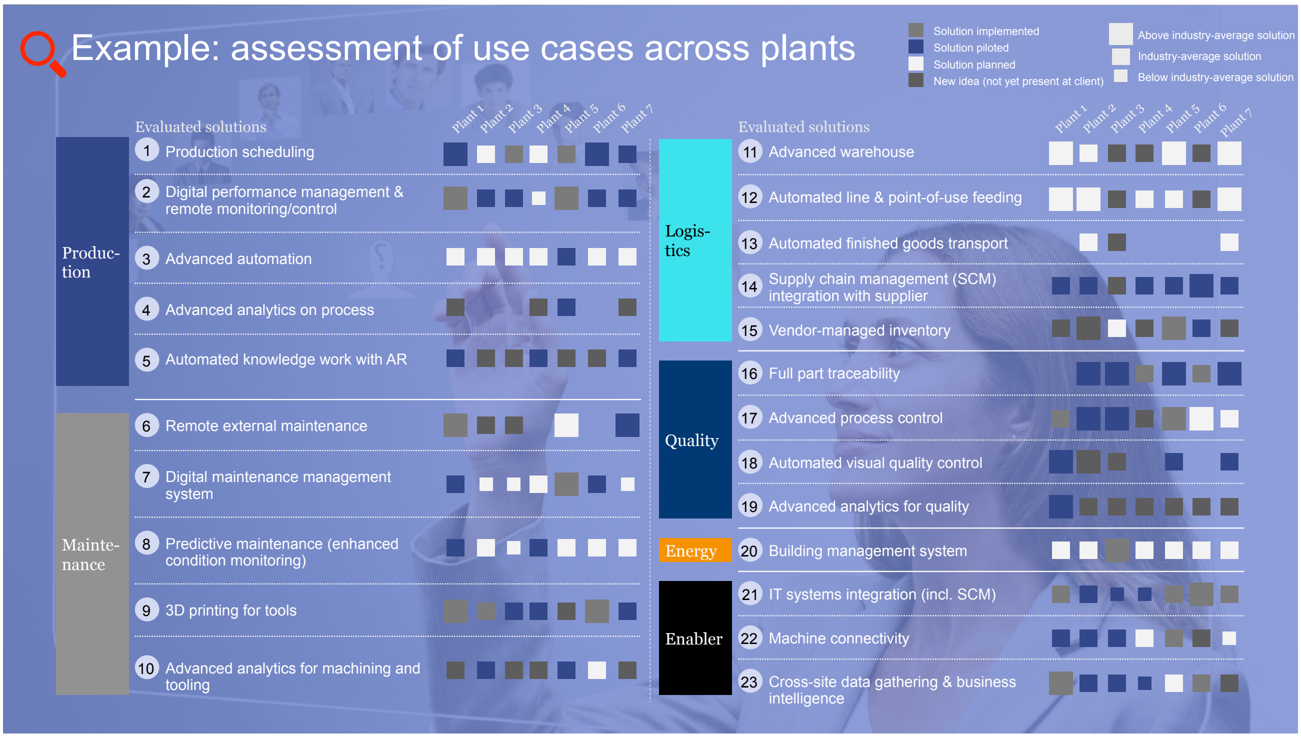
Example

- **Assess the applicability of each use case and the impact maturity** across business units/sites

Example

- **Prioritize the applications to be implemented** based on the aggregated value at scale

Illustrated examples on key activities



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