WORLD ECONOMIC FORUM

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White Paper

Fourth Industrial Revolution
Beacons of Technology and Innovation in Manufacturing

In collaboration with McKinsey & Company

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

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Foreword

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

Enno de Boer, Partner and Global Leader Manufacturing, McKinsey & Company, USA

Emitting powerful light that pierces fog and darkness, lighthouses are vital to maritime navigation. They serve as beacons and guides, ensuring safe passage for shipping. At the World Economic Forum's Annual Meeting 2018 in Davos-Klosters, Switzerland, leaders from public and private organizations decided to seek out manufacturers in a broad range of industries who are leading the way in Fourth Industrial Revolution innovation. Connected by the World Economic Forum's platform, these model factories – recognized as Fourth Industrial Revolution "lighthouses" – are beginning a unique learning journey that will benefit the production environment.

Manufacturing has experienced a decade of productivity stagnation and demand fragmentation; innovation is long overdue. Organizations that have taken Fourth Industrial Revolution innovation to scale beyond the pilot phase have experienced unprecedented increases in efficiency with minimal displacement of workers. However, most companies appear to be stuck in "pilot purgatory". Widespread adoption of Fourth Industrial Revolution technology at scale, through the combined efforts of companies and governments, can lead to a sizeable increase in global wealth production, benefiting people throughout society.

The Fourth Industrial Revolution in manufacturing remains a top priority for many leaders of private and public organizations. It is having an enormous disruptive impact on value chains, industries and business models. With one-third of the total economic value of the internet of things (IoT) coming from production,[1] factories are the centre of gravity of the ongoing revolution. While manufacturing represents 16% of global GDP,[2] manufacturing industries account for 64% of global R&D spend.[3] However, there is potential for worker displacement if changes are not handled properly. Strengthened collaboration among stakeholders is needed to understand unexpected consequences and manage the transition.

"Lighthouses" are demonstrators of digital manufacturing and globalization 4.0, and exhibit all of the essential characteristics of the Fourth Industrial Revolution. Moreover, they confirm the hypothesis that they have the potential to generate new economic value, driven by improvements in the full spectrum of production value drivers: resource productivity and efficiency, agility and responsiveness, speed to market and customization to meet customer needs. Transforming existing production systems, innovating value chains and building new business models with disruptive potential for established businesses can create value.

Lighthouses highlight the global nature of production – for example, the lighthouse network includes German-owned factories in China and a site in Ireland owned by a US company. This shows that innovation is equally relevant in all geographical areas and contexts, from sourcing basic materials to process industries to advanced manufacturers addressing specialized needs. Furthermore, it proves that companies of all sizes, from established global blue-chips to small local businesses with fewer than 100 employees, can achieve radical Fourth Industrial Revolution innovation.

Lighthouses value collaboration and open their doors to thousands of visitors annually, recognizing that the benefits of this collaborative culture far surpass potential competitive threats. They can serve as an inspiration for defining a strategy, improving the skills of the workforce, collaborating with Fourth Industrial Revolution communities and managing changes from the shop floor throughout the value chain. While they vary in size, industry and geographic location, lighthouses embody nine common distinguishing characteristics. This white paper explores findings derived from these characteristics and calls on industry and government leaders to act. Governments, universities, technology providers and companies are encouraged to use this unique network to navigate and accelerate the inclusive diffusion of technology.

The Fourth Industrial Revolution in manufacturing presents the next engine of economic growth, ushering in opportunities to learn and embed values in a way that past revolutions could not. The adoption of technology, guided by an inclusive vision for a better world, can yield a stronger, cleaner, global society.

Executive summary

Many companies are piloting Fourth Industrial Revolution initiatives in manufacturing, but few have managed to integrate Fourth Industrial Revolution technologies at scale to realize significant economic and financial benefits. The World Economic Forum, in collaboration with McKinsey & Company, scanned more than 1,000 leading manufacturers. Subsequent outreach enabled visits to the most advanced sites and identification of the few factories that are true guiding lights in the context of Fourth Industrial Revolution production: lighthouses.

This select group of manufacturing sites represent the leading edge of adopting technology at scale. These sites serve as beacons for the world, exemplifying the type of production approach that can drive the next engine of global economic growth. They demonstrate how forward-thinking engagement of technology can create a better, cleaner world through new levels of efficiency in manufacturing. Likewise, they illustrate how Fourth Industrial Revolution technology at scale can transform the nature of work itself by engaging and improving the skills of human workers with minimal displacement.

Three technological megatrends are the principal drivers of this transformation in production: connectivity, intelligence and flexible automation. Front-runner production sites that have embraced these megatrends at scale have seen a step change in performance. These "lighthouse factories" have taken Fourth Industrial Revolution technology from pilots to integration at scale, thus escaping the inertia of "pilot purgatory", in which many organizations remain.

Lighthouses serve as real-world evidence to dispel widespread myths and misunderstandings posing obstacles to the adoption of innovative technology at scale. These beacons shed light on the characteristics, differentiators and success factors that realize optimal scaling.

– Lighthouses are injectors of human capital. Rather than replacing operators with machines, lighthouses are transforming work to make it less repetitive, more interesting, diversified and productive.

– Lighthouses are industry leaders resetting benchmarks. They have moved beyond the continuous improvement efforts that have characterized factories for decades, instead making a change that resets benchmarks.

– They are open innovators and collaborators. They engage a trisector innovation system comprising business, government and the social sector, including academia.

– These sites represent both large and small companies. Fourth Industrial Revolution innovation is accessible not only to large organizations but also to small- and medium-sized enterprises (SMEs).

– Lighthouses can be found in emerging and developed economies. Fourth Industrial Revolution technologies are also paying off in manufacturing environments that benefit from low labour costs.

– Lighthouses achieve high impact with minimal replacement of equipment. Most were created by transforming existing brownfield operations. Optimizing existing infrastructure and augmenting it with new machinery can deliver many benefits.

Lighthouses achieve impact at scale in different ways. The Forum has identified two principal routes to scale by which manufacturing pioneers can chart their course. These routes are not mutually exclusive; rather, they can complement each other:

– Innovate the production system: expand competitive advantage through operational excellence.

– Innovate the end-to-end value chain: create new businesses by changing the economics of operations.

Lighthouses have employed five value drivers to create impact at scale using Fourth Industrial Revolution technologies. They demonstrate four distinct capabilities that serve as scale-up enablers. The annex of this white paper provides perspectives from lighthouses that exemplify these value drivers or enablers.

The value drivers are:

– Big data decision-making
– Democratized technology on the shop floor
– Agile working models
– Minimal incremental cost to add use-cases
– New business models

The four scale-up enablers are:

– Fourth Industrial Revolution strategy and business case
– IoT architecture built for scale-up
– Capability-building through acquiring new skills
– Workforce engagement

In addition to the perspectives offered in the annex, this white paper offers an in-depth look at two lighthouses operated by two companies that differ substantially in size. The first, Procter & Gamble's Rakona plant, represents a large multinational. The other, Rold Cerro Maggiore, is operated by a small SME headquartered in Italy. The story of change at each of these sites offers valuable insights into the broad transformation occurring in the manufacturing environment.

The World Economic Forum issues a call to action to break out of productivity stagnation and address the significant challenges – such as climate change, resource scarcity and an ageing workforce – the world is facing. The Forum suggests six principle-based actions to ensure the Fourth Industrial Revolution in manufacturing delivers the maximum positive benefit for society:

- Augment, instead of replace, the operator.
- Invest in capability-building and lifelong learning.
- Diffuse technologies throughout geographical areas and include SMEs.
- Protect organizations and society through cybersecurity.
- Collaborate on open Fourth Industrial Revolution platforms and handle data carefully.
- Address the challenge of climate change using Fourth Industrial Revolution technologies.

The responsibility for action lies with both the public and private sectors, and the Forum encourages them to engage the network of lighthouses to be part of a unique learning journey. By engaging the findings and example of the lighthouse network, organizations and governments can realize the great potential that lies with the Fourth Industrial Revolution in production. Coupling this knowledge and technology with a commitment to environmental stewardship and social responsibility can play a role in driving the next economic growth engine towards a brighter future for all of society.

1. Lighthouses: Sites Embracing the Megatrends of the Fourth Industrial Revolution

Seeing the light: A radical leap forward for Fourth Industrial Revolution front runners

Three technological megatrends are the principal drivers of a Fourth Industrial Revolution transformation in production: connectivity, intelligence and flexible automation (Figure 1). Lighthouses have embraced these megatrends and the results are compelling.

Adoption of Fourth Industrial Revolution technologies at scale can have a radical impact upon organizations. A close look at one of these three megatrends makes it clear just how powerful this effect can be. For example, a McKinsey Global Institute analysis projects a remarkable gap between companies that adopt and absorb artificial intelligence (AI) within the first five to seven years and those that follow or lag behind. The analysis suggests that AI adoption "front runners" can anticipate a cumulative 122% cash-flow change, while "followers" will see a significantly lower impact of only 10% cash-flow change (Figure 2).

This shows the importance of early adoption of technology, since companies that wait risk missing a large share of the benefits. Company leaders who move to implementation early, rather than waiting for decreased technology and transition costs, will realize the greatest benefit. Thus, the largest factor here is related to the competitive advantage of front runners, which by far outweighs the higher transition costs and capital expenditure related to the early adoption.[4]

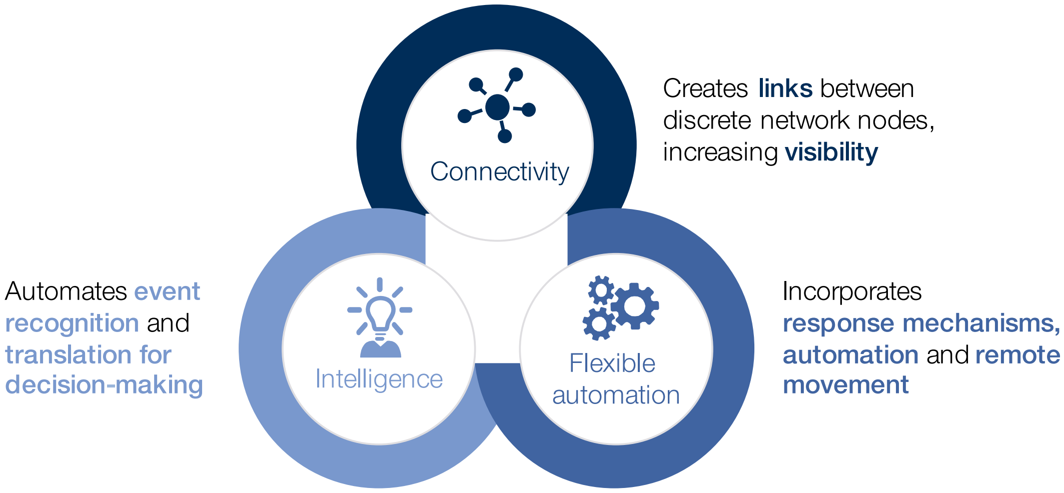
Identifying lighthouses

The lighthouses of the Fourth Industrial Revolution are the factories that have taken Fourth Industrial Revolution technology from pilot schemes to integration at scale, thus realizing significant financial and operational benefits. Qualification as a lighthouse requires meeting high standards in four categories: significant impact achieved; successful integration of several use-cases*; a scalable technology platform; and strong performance on critical enablers such as managing change, building capability and collaborating with a Fourth Industrial Revolution community.

Identification of lighthouses followed a comprehensive scanning of more than 1,000 leading manufacturers in all industries and geographical areas. Contact with more than 150 of the most advanced companies yielded proposals from many companies' most sophisticated sites to be considered lighthouses. Site visits were carried out to document findings, which were then presented to a Fourth Industrial Revolution expert panel of members from private organizations, universities and technology pioneers. This panel selected 16 lighthouses and recognized them as the most advanced production sites, including factories operated by Bayer, BMW, Bosch, Danfoss, Fast Radius with UPS, Foxconn, Haier, Johnson & Johnson, Phoenix Contact, Procter & Gamble, Rold, Sandvik Coromant, Saudi Aramco, Schneider Electric, Siemens and Tata Steel (Figure 3).

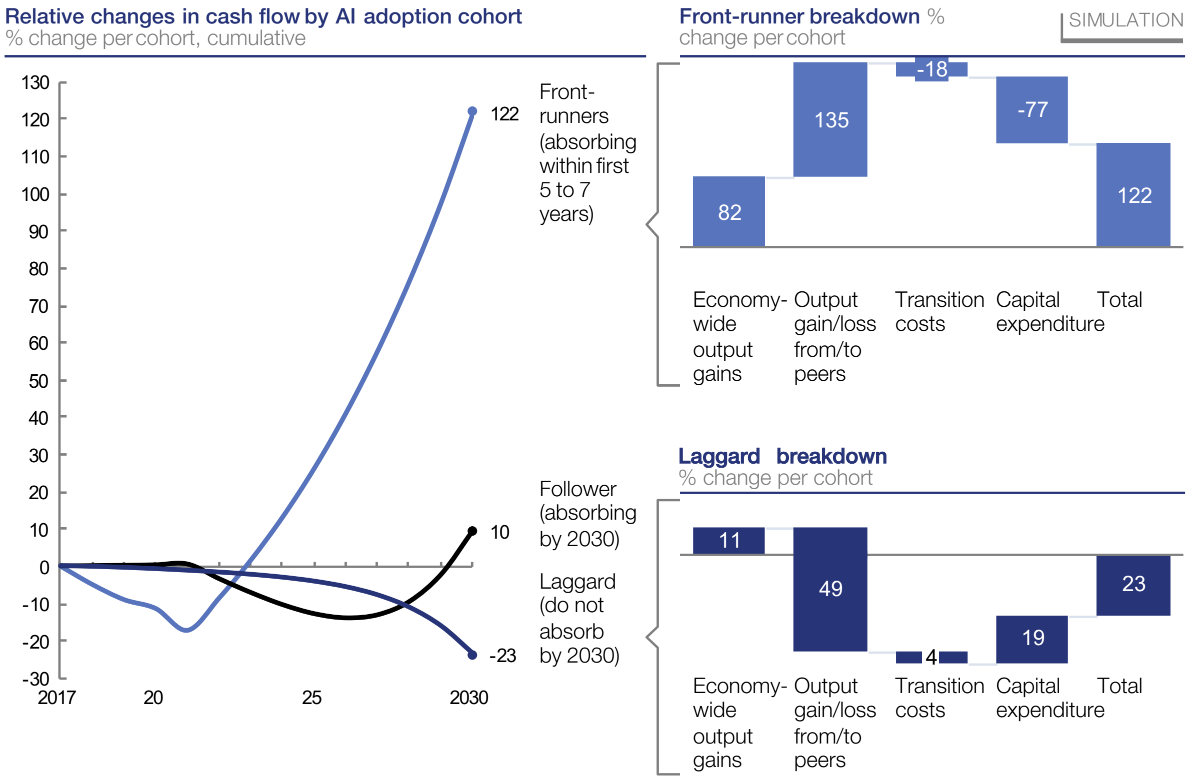
Myths and misunderstandings pose obstacles to the adoption of the Fourth Industrial Revolution. Dispelling these is vital to understanding how accessible the revolution is to organizations of all kinds. With visionary leadership, companies large and small can embark on an innovation journey and realize the benefits of digital transformation. The Forum's analysis of lighthouses has provided meaningful insights that clarify the path to successful adoption at scale of the Fourth Industrial Revolution. These beacons of light cut through the fog and provide clarity to organizations throughout the manufacturing environment.

Figure 1: Key technology megatrends transforming production



** Use-case: application of one or multiple Fourth Industrial Revolution technologies in a real production environment to address a business problem*

Figure 2: Economic gains by AI adoption front runners, followers and laggards[5]



The increasing importance of data and interconnectivity in manufacturing changes the dynamics of technology adoption: Waiting for cheaper and better technology does not pay off, since frontrunners are expected to capture largest benefits.

Note: Numbers are simulated figures to provide directional perspectives rather than forecasts.
Source: McKinsey Global Institute analysis

Figure 3: Global network of lighthouse factories

2. Overview of the Global Lighthouse Network

Site	Change story
Bayer, Division Pharmaceuticals in Garbagnate, Italy	Factory faced increasing demand and volatile OEE[1] – implemented transformation with focused support
BMW in Regensburg, Germany	Highly advanced factory with lean processes leverages digital manufacturing to reach the next performance level
Bosch Automotive in Wuxi, China	Implemented 30+ use cases to meet 200% increase in customer demand
Danfoss in Tianjin, China	Fourth Industrial Revolution technology use cases target quality improvement and cost reduction to meet customer expectations
Foxconn Industrial Internet in Shenzhen, China	Complete organization is transforming from an electronic manufacturing services company into an industrial internet company
Haier in Qingdao, China	Developed digital manufacturing transformation to meet consumer demand and innovate a new business model
Johnson & Johnson DePuy Synthes in Cork, Ireland	Global innovation center focused on material science and technology innovation, with in-house technical capability and knowledge development
Phoenix Contact in Bad Pyrmont and Blomberg, Germany	Market demand shift towards higher level of customization met by deployment of various digital manufacturing use cases

Source: Lighthouse sites
[1] Overall Equipment Effectiveness; [2] Full-Time Equivalent; [3] Business to Consumer; [4] Virtual Reality

Top 5 use cases	Impact		Highlight
Digital performance management	↑ 35%	OEE	A group-wide strategic initiative aims at digitizing the customer experience and internal operations, as well as developing new business models
Mixed reality change overs	↓ 30%	Change over time	
Advanced analytics on deviations	↓ 80%	Deviations	
Advanced analytics on breakdowns	↓ 50%	Breakdown	
Integrated people and asset scheduling	↑ 75%	Batches per FTE[2]	
Data analytics and predictive maintenance	↓ 25%	Unplanned downtime of press	Strategy focused on effectiveness, the right mindset and easy access to improve quality, cost and productivity
Smart autonomous logistics transports	↓ 35%	Logistics cost	
Smart maintenance and assistance	↓ 5%	Rework	
Collaborative robotics and automation	↑ 5%	Efficiency in assembly	
IoT enabled machine condition monitoring	↑ >90%	Benchmark OEE	Big data from connected machines used to improve operations, and agile proofs-of-concept support rapid deployment of new use cases
Digital inventory management	↓ >10%	Total inventory	
Digital value stream mapping	↑ 15%	Unit output	
Digital tool life-cycle management	↓ >10%	Tool inventory	
Real time labor processing and time tracking	↓ >15%	Performance loss	
Digital operator assistant system	↓ 50%	Cost of scrap	Big data from connected machines used to improve operations, and agile proofs-of-concept support rapid deployment of new use cases
AI-enabled quality management system	↓ 57%	Customer complaints	
Real-time machining quality control	↓ 7%	Machining cycle time reduction	
Flexible automation assembly line	↑ 30%	Labor productivity	
Digital R&D and engineering	↓ >40%	Design iteration cycle time	
Cloud-based platform connecting machines	↑ NA	Transparency	Clear top-down strategy, implementation enabled by dedicated team and focus on capability building
Lights-out manufacturing	↑ 31%	Units per hour	
Real-time monitoring and prediction	↓ 60%	Unexpected breakdowns	
Automated testing using artificial intelligence	↓ 50%	Misjudgement	
IoT-enabled nozzle status tracking	↑ 25x	Lifespan of nozzles	
Mass customization & B2C[3] online ordering	↓ 33%	Lead time	Innovated new business model with web-based B2C sales channel for configuration and ordering of air conditioners
Real-time operator performance ranking	↑ 64%	Labor productivity	
Digital quality management system	↓ 21%	Defects per million	
Digital manufacturing performance	↑ NA	OEE increased	
Digital product after sales	↓ 50%	Customer, maintenance staff	
OEE real-time monitoring of critical assets	↑ 5%	Asset utilization	Dedicated Fourth Industrial Revolution space serves as in-house testing ground for the agile testing and deployment of new use case
Additive manufacturing (3D printing)	↓ 25%	Cost of goods sold	
Autonomous process optimization	↓ 10%	Scrap	
VR[4] training and design tool	↑ 5x	Safety information retention	
Collaborative Robotics	↑ 25%	Labor efficiency	
Digital replicas of physical assets	NA	Highly automated lot size 1 line	Innovated a new business model based on a in-house additive manufacturing start-up which serves both internal as well as external customers
Digitized production performance tools	↓ 30%	Production time	
Mixed reality maintenance	↓ NA	Time and errors	
Building energy management	↓ ~7.5%	Energy costs	
Additive manufacturing (3D printing)	↓ 60%	Cycle time	

Site	Change story
Procter & Gamble in Rakona, Czech Republic	Changing product mix and desire to remain operational over the next 140 years
Rold in Cerro Maggiore, Italy	Leverage digital manufacturing to remain competitive and increase production volume
Sandvik Coromant in Gimo, Sweden	Digital manufacturing and smart automation enable the site to produce a large volume of cutting tools in smallest lot sizes at a competitive cost
Saudi Aramco in Uthmaniya, Saudi Arabia	The site is leveraging digital technologies to introduce a more efficient, greener and safer way of working
Schneider Electric in Le Vaudreuil, France	50 year old plant that recognized the need to stay price competitive for the next 50 years through deployment of digital tools
Siemens Industrial Automation Products in Chengdu, China	Consumer demand growth required digital transformation to improve quality performance
Tata Steel in IJmuiden, the Netherlands	End-to-end at scale transformation with clear digital roadmap to improve EBITDA[1]
Fast Radius with UPS in Chicago, United States	Greenfield site to support new, Fourth Industrial Revolution technology-enabled business models

Source: Lighthouse sites

[1] Earnings Before Interest, Tax, Depreciation and Amortization; [2] Enterprise Resource Planning; [3] Manufacturing Execution System; [4] Product Lifecycle Management; [5] Virtual Reality; [6] Advanced Analytics; [7] Sales and Operations Planning

Top 5 use cases	Impact			Highlight
In-process quality control	↓	NA	Scrap	Capability-building represents a key element of the digital transformation, with a «digital college» and «SMART Lab» leveraged to upskill employees
Automatic changes to products on prod. line	↓	50%	Change over time	
End-to-end supply chain synchronization	↓	35%	Inventory	
Digital direction setting	↑	NA	Reliability and OEE	
Modelling and simulation	↓	NA	Testing time	
Machine alarm aggregation	↓	NA	Reaction time for alarms	Collaborations with universities support skill-building and dedicated events ensure a high level of workforce engagement
Digital dashboards to monitor OEE	↑	11%	OEE	
Sensor-based KPI reporting	↑	NA	Transparency of machine status	
Cost modeling	↑	NA	Accuracy of cost calculation	
Additive manufacturing (3D printing)	↓	NA	Time to market	
Parametric design and manufacturing	↑	41%	Engineering productivity	High level of operator involvement in development of new use cases
Digital thread through production process	↑	38%	Operator productivity	
Business intelligence platform	↑	NA	Quality of decisions	
Real-time process control system	↑	NA	Machine OEE	
Unmanned vehicles for inspection	↓	5%	Environmental waste	Collaborated with universities to develop a dedicated program for specialists in data science and robotics
Asset predictive analytics	↑	2%	Energy efficiency	
Asset Performance Management	↑	3%	Reliability	
Wearables for operators	↑	10%	Workforce productivity	
Analytics and artificial intelligence center	↓	12%	Maintenance cost	
Predictive maintenance through IoT	↑	7%	OEE	Workforce involved in the digital transformation from the beginning, leveraging digital technologies such as virtual reality to communicate vision
Mixed reality for maintenance work	↓	20%	Time to diagnosis/repair	
Energy management through IoT	↓	10%	Energy costs	
Lean digitization	↓	NA	Time for lean analysis	
Smart supply chain- Automated Guided Vehicles	↓	80%	Time for milk runs	
Digital performance management	↓	40%	Defects per million	A scalable IoT architecture supports the deployment of new use cases
Integration of ERP[2]/MES[3]/PLM[4]	↑	100%	C/O[5] quality compliance	
3D Simulation for Production Line	↓	20%	Cycle time	
Digital Assistant System for Operators	↓	100%	Issues from customer claims	
Implementation of Automation	↓	~45%	Labor avoidance	
AA[6]-based image recognition	↓	50%	Cost of yield losses	A digital academy has trained more than 200 employees from all levels of the organization in data analytics and digital tools
AA-based raw material selection	↓	NA	Cost of raw materials	
AA-based product quality optimization	↓	80%	Quality reject rate	
Prediction of weld quality	↓	50%	Reduction of re-welds	
S&OP[7] planning based on artificial Intelligence	↓	50%	Late deliveries	
Rapid design prototyping through 3D printing	↓	89%	Time to market	An agile working mode supports the implementation of new use cases as well as the improvement of products
Advanced analytics platform	↑	95%	First pass yield	
Digital twins – factory network	↓	NA	Lead time and cost	
3D scanning for quality	↓	NA	Quality control labor content	

3. Understanding Lighthouses: Characteristics, Differentiators and Success Factors

Lighthouse characteristics

Injectors of human capital

Contrary to widespread concerns about worker displacement, the lighthouse factories are not deploying Fourth Industrial Revolution technology to replace operators. A McKinsey report suggests that fewer than 5% of occupations consist of activities that are 100% automatable with today's technology, while 62% of occupations have at least 30% of automatable tasks[6] (Figure 4). Consequently, employees in production enjoy a working routine that is becoming less repetitive and more interesting, diversified and productive. Employees at all career stages enjoy new tasks and responsibilities that demand the human skill of dynamic decision-making in a changing environment.

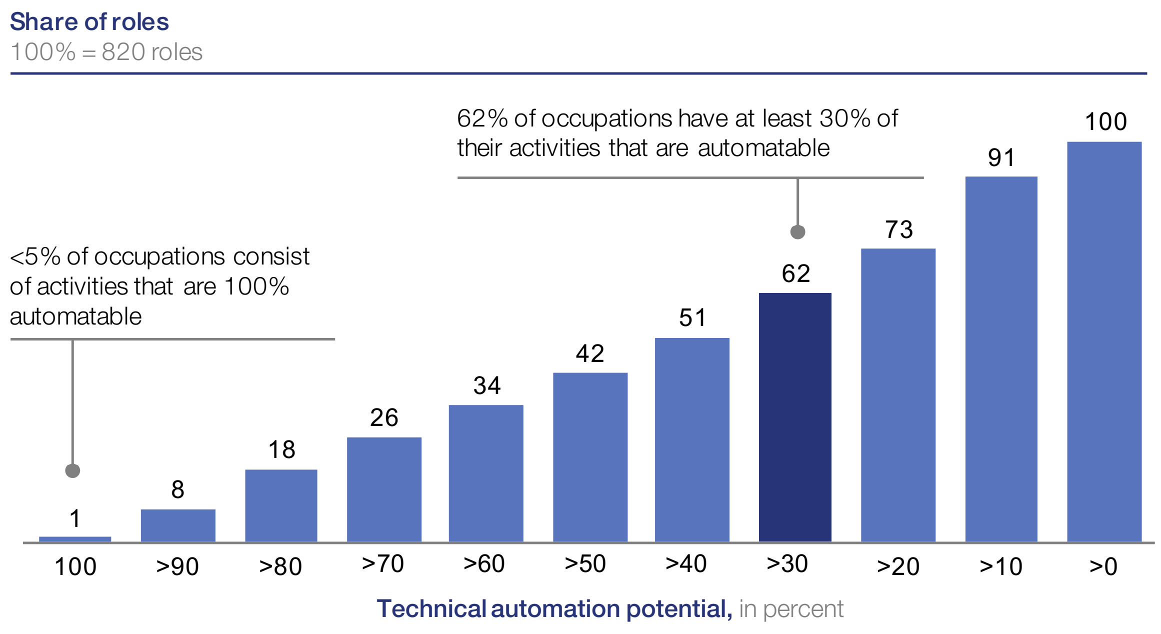
Industry leaders that are resetting benchmarks

The Fourth Industrial Revolution differs from the continuous improvement efforts that have characterized factories for decades. It is not incremental; rather, it involves a step change – it is resetting benchmarks. Lighthouses employ different Fourth Industrial Revolution use-cases to transform their operations. They have, on average, 10–15 use-cases at an advanced stage and are working on the development of an additional 10–15. Accordingly, lighthouses are resetting industry benchmarks for operational and financial key performance indicators (KPIs). Some lighthouses even outperformed their internal expectations by a factor of two. With this transformative approach, lighthouses radically alter their operations and achieve a step change in performance increase – thereafter, they can engage in accelerated continuous improvement efforts, using new Fourth Industrial Revolution technologies and capabilities (Figure 5).

Open innovators and collaborators

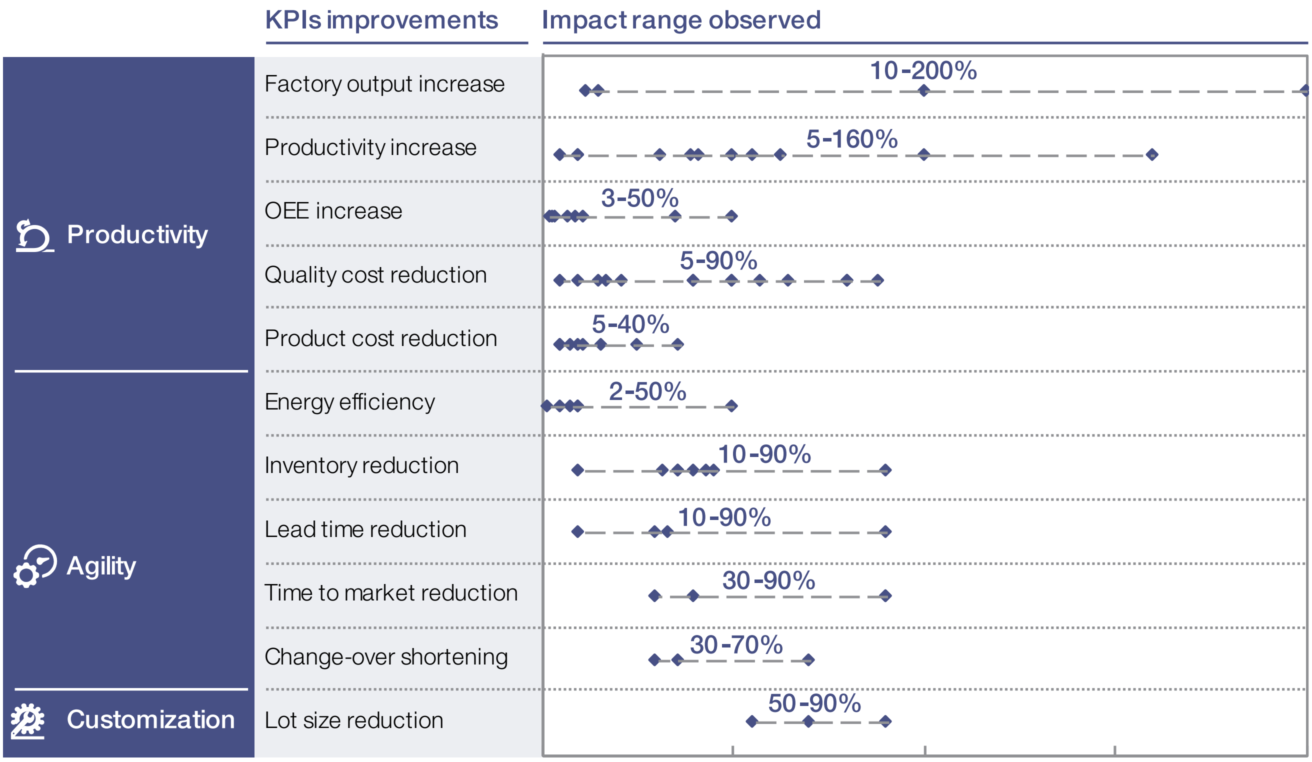
The lighthouses demonstrate that the Fourth Industrial Revolution journey need not be solitary – beacons can guide the way. Indeed, lighthouses are part of an innovation environment that involves universities, start-ups and other technology providers. Lighthouses have worked through the process of discerning amid thousands of technology providers – they have narrowed the options to a system with which they collaborate closely and develop their Fourth Industrial Revolution solutions on the shop floor.

Figure 4: Automation potential of manual activities[7]



Source: McKinsey & Company

Figure 5: Impact of Fourth Industrial Revolution use-cases on select KPIs in lighthouse factories



Source: World Economic Forum and McKinsey & Company lighthouse site analysis

In an increasingly digital world, companies are justified in being concerned about their proprietary systems and technology. However, lighthouses recognize that the benefits of transparency and growth opportunities far surpass the potential for competitive threats. By developing good IP and cybersecurity policies and protocols, lighthouses have managed to maintain effective security to mitigate risk while enabling collaboration. Not only do they open their doors to close partners, but they also welcome thousands of visitors per year.

Large and small companies

Notably, Fourth Industrial Revolution innovation is accessible not only to large organizations but also to SMEs, which can achieve transformative impact by focusing on pragmatic solutions that do not require large investments. The importance of on-boarding SMEs onto the journey of Fourth Industrial Revolution can be recognized in two contexts. First, from a government perspective, the data suggests that SMEs account for the largest share of jobs. For example, 60–70% of jobs in most OECD countries are in SMEs.[8] SMEs, furthermore, are an essential part of the supply chain. Digitalization among SMEs is vital to optimizing the supply chain for organizations of all sizes.

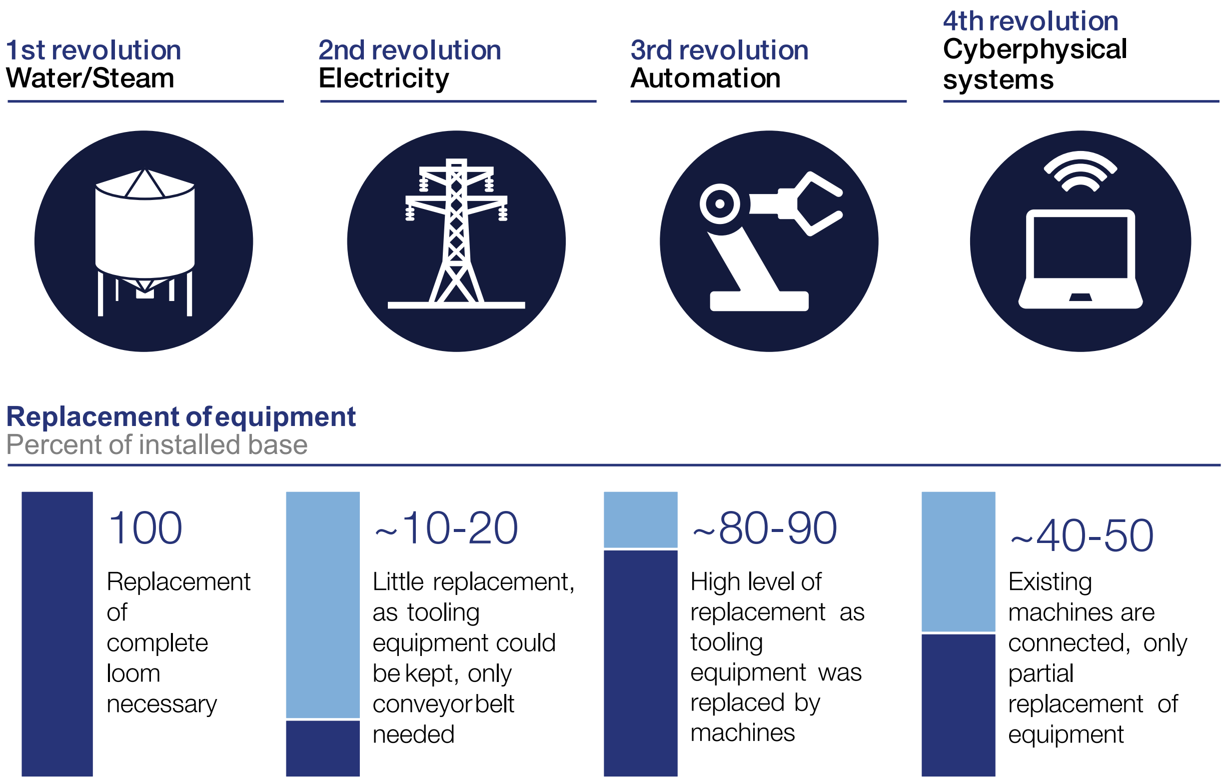
From emerging and developed economies

Additionally, it is apparent that access to Fourth Industrial Revolution technologies is not the exclusive domain of developed economies. In fact, China is one of the leaders, with a high number of lighthouses, and other lighthouses are located in Eastern Europe. This shows that other financial and operational benefits are more relevant than labour-cost reduction.

High impact with minimal replacement of equipment

Despite the misconception that legacy equipment and older facilities create a barrier to Fourth Industrial Revolution innovation, most of these lighthouses were in fact created by transforming existing brownfield operations. Many of the benefits associated with the Fourth Industrial Revolution can be realized by connecting and optimizing existing infrastructure and augmenting it with select new machinery. In contrast with the First and Third Industrial Revolutions, the Fourth Industrial Revolution will have relatively high impact with comparatively little equipment replacement (Figure 6).

Figure 6: Need for replacement of equipment for each industrial revolution



Source: Statistisches Bundesamt; Deutsche Bundesbank; Prognos; Thomas Nipperdey; McKinsey & Company

4. How Do the Lighthouses Achieve Impact at Scale?

These lighthouses have overcome typical challenges faced by companies, such as engaging in too many proofs-of-concept, scaling too slowly, lacking an integrated business case for Fourth Industrial Revolution technologies, implementing too many isolated solutions and creating countless data silos. How did they overcome these myriad typical challenges to achieve transformational impact and agile, continuous improvement? Amid a range of characteristics and qualities, we observed that the lighthouses follow two distinct yet complimentary routes to scale, and that five specific value-creation differentiators and four capabilities stand out. These routes, differentiators and capabilities are introduced here, but the annex of this white paper will provide an in-depth look at examples from advanced factories.

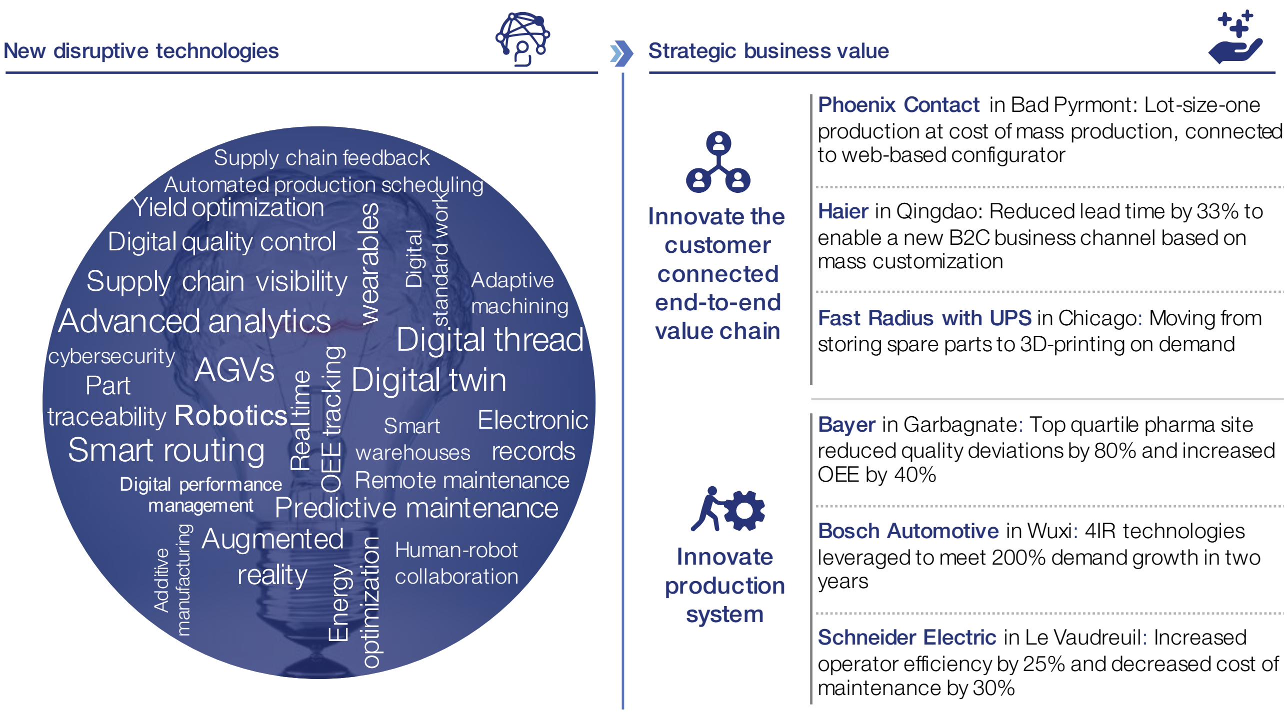
Charting a course for scale: Two routes

The lighthouses prove that there is more than one way to embrace the Fourth Industrial Revolution: there are two principal "routes to scale" by which manufacturing pioneers can chart their course. These routes are not mutually exclusive; they can complement one other as companies navigate the journey to scale (Figure 7):

- **Production system innovation.** Companies expand their competitive advantage through operational excellence. They aim to optimize their production system, increasing their operations' productivity and quality performance. Typically, they start to innovate in one or a few manufacturing sites and then roll out from there.

- **Innovation in the end-to-end value chain.** Companies create new businesses by changing the economics of operations. They innovate throughout the value chain, offering new or improved value propositions to customers by way of new products, new services, more customization, smaller lot sizes or significantly shorter lead times. Companies stay focused on innovation and transforming one value chain first, then scale their findings and capabilities to other parts of the business.

Figure 7: Two methods of strategic business value generation from new disruptive technologies



Source: McKinsey & Company; lighthouse sites

Value drivers for impact at scale

The lighthouses exhibit five ways in which they create value from Fourth Industrial Revolution technologies. These value-creation differentiators transform how technology is implemented, how people interact with technology and how it affects business decisions, as well as results.

Big data decision-making

Decisions are not hypothesis-driven, but rather are based on big data deciphered by pattern recognition – and not by humans. (See annex for perspectives from Bosch Automotive and Maana.)

Democratized technology

Technology on the shop floor is transforming ways of working, as operators develop their own apps and solutions to facilitate and automate their tasks. (See annex for perspective from Tulip Interfaces and Fetch Robotics.)

Agile working mode

The lighthouses implement new Fourth Industrial Revolution use-cases in an agile working mode, which allows them to do proofs-of-concept in a short time period, improve the solution based on findings and go quickly from pilot to scale-up. This is a matter of weeks versus years. In some cases, a model factory or an experimental Fourth Industrial Revolution technology department serves as an incubator. (See annex for perspectives from Fast Radius and Bosch Automotive.)

Minimal incremental cost to add use-cases

Fourth Industrial Revolution use-cases can be deployed at minimal additional cost, allowing factories to work on multiple areas at once. (See annex for perspectives from Microsoft and Fetch Robotics.)

New business models

Fourth Industrial Revolution technologies enable the lighthouses to develop new business models that complement and/or disrupt the traditional business and value chain. (See annex for perspective from an undisclosed European consumer electronics manufacturer.)

Scale-up enablers

The lighthouses exhibit four distinct capabilities, which represent important success factors for their Fourth Industrial Revolution implementation journey. These capabilities are developed deliberately during a Fourth Industrial Revolution transformation effort and often represent a top priority for senior management.

Fourth Industrial Revolution strategy and business case

The lighthouses have a Fourth Industrial Revolution strategy linked to the creation of fundamental business value that is clearly articulated and communicated and has enterprise-wide validity. (See annex for perspective from BMW.)

IoT architecture built for scale-up

The lighthouses have an IoT architecture built for scale-up and interoperability. All information flows into one central data lake and interfaces between applications are standardized. According to a survey from Digital McKinsey, standardized integration opportunities and the use of open standards are essential selection criteria for IoT platforms.[9] (See annex for perspectives from Hewlett Packard Enterprise and Precognize.)

Capability-building

The lighthouses have a very strong focus on capability-building. Digital academies and smart factories allow all employees to learn the basics of new digital use-cases and a smooth, efficient way of implementing them. Moreover, lighthouses invest in the capacity of their workforce, ensuring that their teams have digital translators, IT/OT integrators and change managers. The workers are trained for these duties, or new people are recruited. (See annex for perspectives from Tata Steel.)

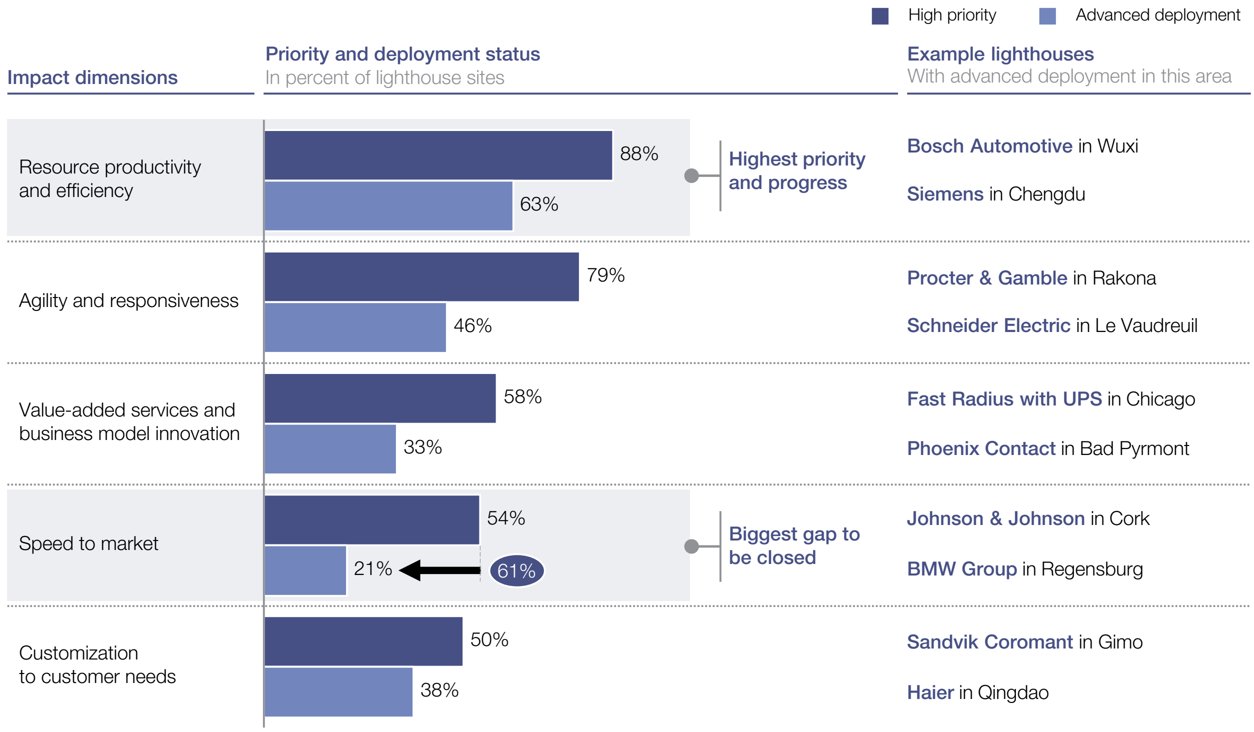
Workforce engagement

In the lighthouses, the leaders act as role models for the change, communicating a clear change story through various channels and ensuring that all employees feel part of the journey. Workers are actively involved in the development and deployment of use-cases. (See annex for perspectives from Schneider Electric.)

The current state of lighthouses

Where are lighthouses on their own process of Fourth Industrial Revolution innovation? It is notable that while these sites are at the forefront of the Fourth Industrial Revolution, their transformation is ongoing and they recognize the potential to improve even more. Survey data indicates a gap between their aspirations and achievements in various business drivers, with the largest gap in speed to market. For example, Figure 8 shows that only 21% of lighthouses have an advanced "speed to market" deployment, while 54% indicated that this impact dimension has a high priority. Further advances in these contexts, then, are likely on the horizon.

Figure 8: Priority vs. deployment status of different impact dimensions



Source: World Economic Forum and McKinsey & Company lighthouse site analysis[10]

Three tools to scale Fourth Industrial Revolution technologies in production and overcome pilot purgatory

The World Economic Forum, in conjunction with McKinsey & Company, published a report entitled *The Next Economic Growth Engine – Scaling Fourth Industrial Revolution Technologies in Production* in January 2018. It provided essential insights into the benefits of and struggles associated with deployment of Fourth Industrial Revolution technology in manufacturing. The report presented three tools to accelerate adoption: the Value Delivery Engine, the Scale-Up Engine and the Government Framework. The Value Delivery Engine, shaped by 39 production use-cases of the Fourth Industrial Revolution in manufacturing, emphasizes intelligence, connectivity and flexibility. The Scale-Up Engine describes the best methods of scaling technologies, including elements of mobilization, strategy and innovation. The Government Framework identifies action areas for stakeholders to accelerate adoption of technology.

Manufacturing, if transformed through enhanced productivity and agility, can generate inclusive economic growth and global benefits. However, achieving these benefits represents a significant challenge for most organizations. Findings from our previous work show that adoption of Fourth Industrial Revolution technology in production remains slow, with more than 70% of industrial companies still in “pilot purgatory”. Only 29% are actively deploying Fourth Industrial Revolution technology at scale, while a greater number, 30%, had yet to pilot or were only just about to begin.

Among companies piloting, it is evident that pilots are often too long and/or complex. Only 15% of respondents indicated pilots of less than one year; 56% of respondents indicated one-to-two-year pilots; 28% described pilots of more than two years. Most companies struggle to scale up due to the difficulty of aligning in terms of value and return on investment (ROI), the uncertainty of digitals’ value to performance and the cost required to implement and scale.

Clearly, emerging from “pilot purgatory” remains a challenge for companies seeking to achieve the transformational impact of the Fourth Industrial Revolution. The tools provided by the Forum can help organizations forge ahead and realize the tremendous benefits of Fourth Industrial Revolution adoption at scale.

5. Successful Deployment at Scale: A Close Look at Two Lighthouses

This section will offer detailed introductions to two lighthouses that represent how successful deployment of Fourth Industrial Revolution technology at scale can be achieved at very different sites. A detailed look at sample factories helps garner a deeper understanding of the broad changes occurring in the manufacturing environment. These close looks can help industry leaders educate themselves about how the Fourth Industrial Revolution plays out, with a solid grasp of the rewards, opportunities and challenges involved. Procter & Gamble's Rakona plant is representative of a large multinational corporation (MNC) deploying Fourth Industrial Revolution use-cases developed at both the site and group level, whereas Rold, an SME, has executed successful deployment in a single-site context engaging different use-cases.

Procter & Gamble (P&G) Rakona, Czech Republic: Growth through cost leadership

Procter & Gamble's Rakona plant provides an example of how driving productivity through Fourth Industrial Revolution adoption secured jobs by maintaining a site's relevance in the face of shifting customer demands and increasing market pressure.

Site history

Located 60 kilometres from Prague and founded in 1875, Rakona is Procter & Gamble's second-oldest plant. The facility became state-owned during the communist era and was acquired by P&G in 1991. It produces around 4 million cases of dish-washing liquids and powder along with fabric enhancers daily. Market shifts from dry to liquid washing products effected a significant drop in demand between 2010 and 2013. Facing this challenge, the site triggered a programme to cut costs significantly in order to attract new business. This programme turned the site into a cost benchmark, which then led to demand for more volume and ultimately the need for expansion over 2014–2016. To implement such expansion successfully, anticipating and addressing the emerging needs required embracing digitization and automation and full use of Fourth Industrial Revolution capabilities.

An inclusive vision

Having faced the challenges it did, Rakona aimed to secure a resilient, sustainable future despite economic uncertainties and pressures. This led to a clearly articulated vision: "We Are Rakona, We Create the Future". According to plant manager Aly Wahdan, "This vision was developed hand in hand with all employees. It combines the pride in our Rakona organization with the need for attractive solutions for our company and our customers. This organizational vision remains actively communicated throughout the site and includes all employees in an innovative journey to improve competitiveness through minimizing losses." Guided by this vision, two essential enablers have supported Rakona's successful Fourth Industrial Revolution innovations:

– **Exploit the external digital environment**: Rakona's leadership team recognized among internal staff a lack of the skills necessary to enable Fourth Industrial Revolution innovation, and acted accordingly. They benefitted from external knowledge on digitization and automation in a variety of ways: direct connection with Prague universities, and cooperation with start-ups and student exchange programmes in which digitally educated students worked alongside Rakona employees.

– **Improve people's skill levels, shape the jobs of the future.** The site developed a capability programme open to all employees, which deepened understanding of and affinity for new technologies such as analytics, smart robotics and additive manufacturing. This developed specialized skills while guiding the creation of new roles such as "cybersecurity leader".

The nature of this "pull" approach – which differs from a top-down "push" mentality – is intrinsic to the inclusive culture of innovation. The goal is to involve 100% of the organization in digital transformation.

Top five use-cases

Lighthouse sites vary in their applied use-cases, but all are reaping benefits. For P&G Rakona, the top five use-cases were digital direction-setting, in-process quality control, a universal packing system, end-to-end supply chain synchronization and modelling and simulation.

– **Digital direction-setting** is a digital performance management system, which created impacts in both technical and management systems. This addressed problems including a difficult, time- consuming data-collection process and decisions based on inaccurate data points. The digital direction-setting tool shows live KPIs on touchscreens directly on the shop floor, which allows users to explore the data at multiple levels in order to understand performance drivers and identify the root causes of deviations. Additionally, the system is used for operator task scheduling and tracking. This created more rigorous execution leading to increased process reliability and overall equipment effectiveness (OEE). An agile development approach with frequent tests and iterations led to successful implementation throughout the factory

– **In-process quality control** has addressed the problems of a manual sampling process that did not ensure the 100% quality of each batch, thus requiring the scrapping and reworking of an entire batch if a deviation was detected after production. Additionally, it has addressed delays in product release related to lab analysis. Quality control is now based on real-time analytics applied on data collected by various sensors that monitor pH value, colour, viscosity, active level, etc. The line can be stopped if a deviation is detected, and reports allow operators to ascertain batch quality for release. This system, which was developed by P&G, is the first of its kind in the industry. Enabled by IT/OT integration, it was first tested with a new production line and then rolled out to legacy systems. The reduction of manual, repetitive tasks benefits employees. On an impact level, reworking and complaints have been cut by 50%, scrap is down and quality inspections have been reduced significantly. There is now zero time to release the product, which has led to a throughput time reduction of 24 hours. This use-case has been deployed for all production lines.

– A **universal packing system**, known as UPack, allows for recipe change propagation through the packaging line while the line is running. Previously, a complete stop of the line was required to perform changeover, which led to wait time for operators and long durations involving manual setup of machines. This system, developed by P&G at the group level, has been deployed on all packaging lines. The fully integrated sensor, camera, scanner and wrapper system detects and verifies the current status of each zone. Along with automatic line clearance instead of paper-based data records, UPack enables each zone of the packaging line to be in a different phase (e.g. start-up, production, empty or changeover). It also features automatic setup of machines based on system-stored recipe data and in-process quality inspection. UPack, in addition to reducing the number of unpleasant changeover tasks for operators, has cut changeover duration by 50%, enabling a 40% reduction of minimum order quantity.

– **End-to-end supply chain synchronization** has addressed several problems, including the scrapping of excess products at the end of a campaign, capital bound in inventory, slow speed to market and difficult, time-consuming manual supply chain analyses. This global P&G tool, which benefits from continuous improvement based on user requirements, is applied at the site management level, in each department and for coordination with the central planning team. The web-based tool uses analytical modelling and simulation to provide end-to-end visibility of the supply chain. It allows simulation of supply-chain synchronization under different conditions – this enables identification of tension points to improve agility. It displays information on supply chain synchronization in each node, with the option to deep-dive and optimize on the level of each product and production line. It provides benchmarking and comparison among different P&G factories and lines. Used for all products and production lines, the tool has reduced inventory by 35% in three years and increased inventory efficiency by 7% during the previous year. It has also reduced the number of returns and stock-outs and improved speed-to-market of new product introductions.

– **Modelling and simulation** address problems associated with the difficulty of understanding implications of changes to production lines, the high cost of testing in production setup and expensive corrections of new product failures when those failures are detected only in operations. This use-case involves various descriptive and diagnostic modelling applications in use at scale – as well as ongoing pilots of predictive modelling applications – all with a vision to reach prescriptive modelling capabilities. Sample modelling applications include manufacturing outputs related to new product introductions (e.g. recommending SKU allocation to production lines, number of storage tanks etc.), selection of optimal conveyor speed, determination of ideal packaging dimensions, simulation of changes to the production line before actual execution, prediction of failures before occurrence and failure of root cause identification. Intuitive models and accessibility by engineers are important enablers. The "learn early, fail small" benefits of this approach have led to improved product design, refined problems statements and optimized testing.

Achievements, impact and the road ahead

Rakona's innovation experience showcases the kind of substantial impact that can be achieved by a lighthouse facility embracing Fourth Industrial Revolution approaches and technology. In three years:

– Productivity has increased by 160%.
– Customer satisfaction has increased by 116%.
– Customer complaints have been reduced by 63%.
– Full plant cost has been reduced by 20%.
– Inventory has been reduced by 43%.
– Off-quality products have been reduced by 42%.
– Time for changeover has been reduced by 36%.

Even with these notable achievements and energized by the progress to date, the site has targets for future development. These include "lights-off" operation, automated condition-based maintenance, automation with affordable collaborative robots and end-to-end synchronization of the supply chain. According to Yannis Skoufalos, Global Product Supply Officer, "Our objective is to create an end-to-end synchronized supply network where retail customers, P&G and suppliers efficiently operate in a seamless manner, often delivering P&G brands from the point of manufacture to the store shelf in 24–48 hours." Rakona's vision demands a continuous commitment to innovation and improvement. This lighthouse is constantly striving to live up to its motto: "We Create the Future."

Rold Cerro Maggiore, Italy: Fourth Industrial Revolution implementation in SME

Italian company Elettrotecnica Rold Srl is an SME with 250 full-time employees producing door locks for washing machines. The company's Cerro Maggiore factory has applied digital manufacturing technology at scale to increase productivity and quality in the context of a small organization. It demonstrates that Fourth Industrial Revolution innovation is possible even with limited investment by using off-the-shelf technology and collaborating with technology providers and universities. In Rold's case, for example, only three programmers were hired.

Before and after: Transformational changes

Prior to its digital transformation, Rold faced external pressure in the form of increased international customer demand, which exceeded the site's capacity. Additional problem factors included poor visibility of actual plant performance and non-centralized, paper-documented data. Operators spent significant time on manual reporting, and efficiency was limited by hypothesis-driven decisions. According to Rold President Laura Rocchitelli, "The reasons why we introduced digital manufacturing technologies are different: first of all, it was to become more efficient in our production performances. The opportunity to monitor in real time our manufacturing processes turned out to be essential to reach better results both in terms of machine utilization and performance of each machine."

Workers on the shop floor echo her sentiments. Stefano Bosani, Head of the Moulding Department, offered this observation: "The digital platform lets the supervisor and the workers have a constant eye on the process, with the opportunity to reach higher levels of efficiency to optimize the moulding process. The platform is flexible and continuously improving, introducing new features based on users' requests and suggestions. Workers at all levels participate proactively into the generation of new functionalities." According to a worker in the Moulding Department, "With the platform, the worker can see, in real time, when the production is planned to end and therefore prepare for the subsequent production order. Moreover, the opportunity to input motivations for slowdowns and downtimes grants visibility on the process, enabling operators to define activities for production improvement based on objective data rather than subjective perceptions."

Apart from the internal improvement, Rold's digital transformation enables its customers, washing-machine original equipment manufacturers (OEMs), to improve the digital integration of their supply chain through an automatic order and traceability data exchange. This increases transparency and reduces manual effort. In addition, the new digital capabilities enable Rold to innovate smart, interconnected products that allow washing-machine OEMs to offer new services to their customers.

Key enablers

Rold exemplifies the lighthouse characteristic of enabling improvement through change management and communication. Through initiatives aimed at transforming the organizational mindset and improving skill levels, the company has invested in its people and facilitated their digital journey alongside the technology. Rocchitelli described some of the challenges: "First, we had to create awareness among workers of the opportunity to use digital technologies at shop-floor level with an inclusive rather than exclusive approach."

Other initiatives have included industry-related events with suppliers, customers, C-level executives and first-line managers. Rold has also carried out coaching engagements with varied groups, from designers to engineers, employees and outside researchers focused on problem-solving, creativity, change management, communication and innovation. The company has developed relationships with industrial and innovation partners and connected with delegations from international universities and associations. A commitment to talent management is visible in its promotion of technical internship models with secondary and post-secondary institutions, partnerships with international and national universities and the engagement of employees with international training and meetings.

In terms of organization and governance, the company has committed to personnel with the capability to drive Fourth Industrial Revolution innovation, including software developers and electrical engineers to model, develop and implement IoT applications and industrial engineers with digital integration skills. These efforts complement digital transformation initiatives sponsored by the Board of Directors, along with extensive training on Fourth Industrial Revolution topics for workers at various levels of the organization. Rocchitelli commented, "In order to complete this shift, everyone needs to be aligned on expectations and resilient in delivering results."

Top five use-cases

– **Machine alarm aggregation, prioritization and analytics-enabled problem-solving** has supported improvements in overall equipment effectiveness (OEE) by providing notification of specific machine and custom alarms to operators on smartwatches and interactive displays.

- **Digital dashboards to monitor OEE** have facilitated real-time monitoring of production resources distributed in different plants. These have provided the ability to input reasons for stoppages of faults.

- **Sensor-based manufacturing reporting of KPIs** has allowed for digitization of any kind of production machine along with real-time collection of production data, which is used to build dynamic, interactive dashboards.

- **Cost modelling to support make-versus-buy decisions**, which is in ongoing development, uses granular data collection based on IoT devices on the shop floor combined with business intelligence tools to increase the accuracy of Rold's cost models.

- **Rapid design prototyping through 3D additive manufacturing** has shortened time to market for new product introductions and contributed to several innovations. This has strengthened university relations and seen the awarding of funded research projects. Rold's progress in this area made them the recipient of the 2018 Electrolux Innovation Factory (EIF) award.

Achievements, impact and the road ahead

The implementation of the first Fourth Industrial Revolution use-cases has helped Rold realize substantial financial and operational impacts. Rold reported a financial impact of 7–8% growth of total company revenue from 2016 to 2017, driven by an overall equipment effectiveness (OEE) increase of 11%.

Rold envisions a factory in which digital solutions and automation provide the best possible support for operators to maximize production output while increasing worker satisfaction and empowerment. Laura Rocchitelli explained, "Eventually, the adoption of digital technologies at the shop-floor level let Rold design a platform with humans at the centre." The company hopes to use its accumulated knowledge and expertise to support the digital transformation of its own supply chain. Moreover, Rold aims to continue growth and development through regular best-practice exchange, both with other production sites and with universities at the forefront of Fourth Industrial Revolution innovation.

6. Call to Action

Why act?

The Fourth Industrial Revolution is essential to breaking out of productivity stagnation

Manufacturing has experienced a decade of productivity stagnation and demand fragmentation, coupled with an ageing workforce in OECD countries. The time for innovation is long overdue. Where organizations have taken Fourth Industrial Revolution innovation to scale beyond the pilot phase, they have rapidly achieved a tremendous impact. These cases of successful scaling up have delivered unprecedented increases in efficiency, with minimal displacement of workers. However, most companies appear to be stuck in “pilot purgatory”. Widespread adoption of the Fourth Industrial Revolution at scale, through the combined efforts of companies and governments, can lead to sizeable increase in global wealth production, benefitting people throughout society.

The world is under stress

A burgeoning global population, combined with the challenges of environmental sustainability, have put the world under great stress in the 21st century. As World Economic Forum Founder and Executive Chairman Klaus Schwab explained, “The challenges associated with the Fourth Industrial Revolution are coinciding with the rapid emergence of ecological constraints, the advent of an increasingly multipolar international order and rising inequality.”[11] A report from the United Nations Intergovernmental Panel on Climate Change (IPCC) states that rapid, far-reaching and unprecedented changes in industry are required to limit global warming to 1.5°C, to avoid challenging impacts on ecosystems, human health and well-being associated with a higher temperature rise.[12] Similarly, a study from the Global Footprint Network highlights that current global resource consumption is exceeding available resources by a factor of 1.7.[13]

The Fourth Industrial Revolution presents multifaceted opportunities and challenges

The significant benefits of the Fourth Industrial Revolution in manufacturing are well understood by many leaders from the private and public sector: 70% of industrial organizations are either piloting Fourth Industrial Revolution technology in manufacturing or deploying these technologies at scale. Strategies, initiatives and programmes have been put in place at all levels to ensure these benefits are realized. Countries have invested in, for example, national platforms to raise awareness for the Fourth Industrial Revolution in manufacturing, support the development of new use-cases and enable collaboration between research institutes and private organizations.[14]

However, the Fourth Industrial Revolution also brings risks, which require attention from the beginning. If not managed properly, the Fourth Industrial Revolution could accelerate the creation of a two-speed world. The gap between Fourth Industrial Revolution leaders and laggards has the potential to exacerbate inequality in wealth production. It can, potentially, lead to significant displacement of workers in manufacturing, make critical assets vulnerable to cyber-attacks and create a dominant market position for very few artificial intelligence providers.

Companies and governments can work in partnership to ensure diffusion of technology and the benefits it can bring. Essential to this is upskilling. With 62% of existing occupations having 30% of activities that are automatable,[15] training and preparing workers for these changes is an important step to successful Fourth Industrial Revolution implementation. The Fourth Industrial Revolution has the potential to transform factories into creative, entrepreneurial and exciting places to work. If appropriately trained and upskilled, today’s line workers will play valuable roles as problem-solvers and innovators. This presents the opportunity to create a future workplace that attracts and excites the best and brightest of the next generation.

What needs to be done?

To ensure the manufacturing environment transitions as smoothly as possible through the Fourth Industrial Revolution while avoiding increased inequality and a “winner-takes-all” outcome, public and private leaders need to act responsibly. They have the power to influence the outcome of the Fourth Industrial Revolution and mitigate these risks with a proactive approach. The World Economic Forum proposes a set of value-based actions that support “fair” technology diffusion globally:

Augment, instead of replace, the operator

Factories should deploy technologies that allow the human operators to focus on the most value-adding activities, where the human skills of decision-making and adaptability to new situations brings most value – and, at the same time, create a more attractive workplace.[16]

Invest in capability-building and lifelong learning

The Fourth Industrial Revolution in manufacturing will change many job profiles and displace workers within and between organizations. The private and public organizations must prepare the workforce for this transition, retool the education system and invest in training as well as lifelong learning to create a mobile workforce that can benefit from the opportunities related to the Fourth Industrial Revolution. This will not only help workers, but also provide benefits to the companies since a shortage of skills is the most frequent barrier preventing scale-up of technologies.

Diffuse technologies throughout geographical areas and include SMEs

The full benefit of the Fourth Industrial Revolution in manufacturing can be realized only if complete value chains and production systems are transformed, including all geographical areas and SMEs, which are contributing 50–60% of value add in OECD countries.[17] Therefore, companies should diffuse Fourth Industrial Revolution technologies through their entire production network and include developing economies as well as suppliers of all sizes. This will not only lead to improved overall results, but also ensure knowledge is spread more equally. Accordingly, government leaders must ensure they support large and small companies in adopting technologies, provide incentives and collaboration opportunities with universities as well as technology providers.

Protect organizations and society through cybersecurity

The US government identified cybersecurity as “one of the most serious economic and national security challenges”.[18] With 50 billion new devices added to the internet due to IoT,[19] the threat becomes even more severe. To prevent hackers shutting down factories or misusing critical assets,[20] which could slow down the further advancement of the Fourth Industrial Revolution, private and public organizations must ensure the cybersecurity infrastructure meets the highest standards. Companies should engage in cross-organizational initiatives to learn and develop cybersecurity further, not only to ensure their economic future but also to protect employees, customers and local communities.

Collaborate on open Fourth Industrial Revolution platforms and handle data carefully

Building open Fourth Industrial Revolution platforms in collaboration with multiple private and public organizations reduces dependency on a few large providers and avoids vendor lock-in, while ensuring access to a large data pool required to improve analytics algorithms and generate insights. Data ownership can be shared among collaborators, with clear rules and a high level of transparency in place to avoid data misuse. Also, companies should have a centralized data storage and avoid the creation of additional data silos that hinder integration and new use-case deployment.

Address the climate change challenge with Fourth Industrial Revolution technologies

The world faces a significant challenge with regard to climate change, with a recent report from the IPCC stating that emissions must be cut by 45% by 2030 to keep below 1.5°C warming.[21] Factories should employ Fourth Industrial Revolution technologies to improve their energy efficiency, increase yield and reduce waste and emissions while enhancing overall competitiveness.

Who needs to act?

Adhering to the principles presented above, the Forum encourages public and private organizations to engage in the network of lighthouses and be part of a learning journey. They provide valuable insights on how to scale technologies.

Organizations with a lighthouse

They can use this asset to accelerate technology diffusion through the production environment and value chains by sharing findings and best techniques. Trisector collaboration with governments and academia can enable and support this diffusion.

Organizations without a lighthouse

They should define which factories will be developed to become a lighthouse in one to two years, set ambitious targets, define which support is required and track the progress. The lighthouse network can provide relevant learning as well as a tool for potential lighthouses to assess their maturity. Also, to accelerate this journey, these organizations can collaborate with governments and academia.

Technology providers, start-ups and universities

They can partner with the lighthouses to develop and test new Fourth Industrial Revolution use-cases while learning about trends and business challenges that require new solutions.

An opportunity to form a new, global learning platform for the Fourth Industrial Revolution

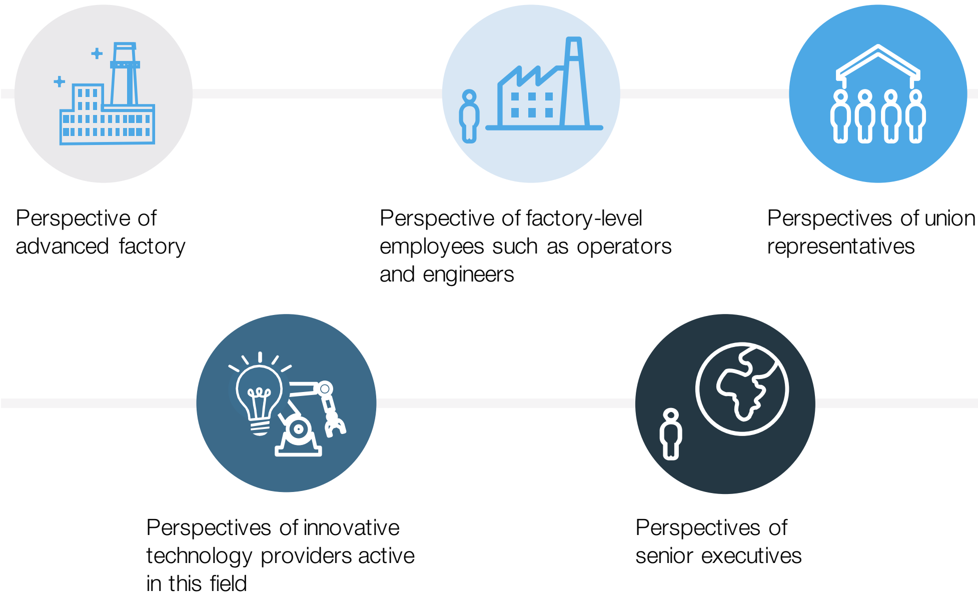
Private and public organizations face significant challenges when it comes to adapting to the Fourth Industrial Revolution, such as scaling of technologies through environments, increasing workers’ skills and cybersecurity. The identified lighthouses serve as a first point of orientation. But more is required: the world needs a place to go to learn about the Fourth Industrial Revolution, which goes beyond individual efforts.

Upon the call of stakeholders, a new public-private partnership could build a global, scalable learning platform to provide guidance and orientation for public and private organizations and for society. It would enable a dialogue about Fourth Industrial Revolution technology diffusion and the related challenges. This global learning platform can build on available assets from country-level programmes, on networks for technology development and testing, on programmes that work on standards and on the new network of lighthouse factories. This is an opportunity to bring the different efforts together on a global level and to create a true “go-to place” for any aspect related to the Fourth Industrial Revolution in manufacturing.

Annex: A Look Inside the Lighthouses – Inside Perspectives

This section of the white paper provides perspectives offered by the Fourth Industrial Revolution factories. It takes a close-up look at how the various sites exemplify lighthouse characteristics. Along with summary information, comments by a range of people – from shop-floor operators to senior executives – offer additional insights about the benefits, challenges and opportunities of Fourth Industrial Revolution implementation.

Figure 9: Five different perspectives highlight the value drivers and scale-up enablers of lighthouses



1. Value Drivers

Big data decision-making

Bosch Automotive in Wuxi, China

Bosch Automotive Diesel Systems Co., Ltd. (RBCD) began its journey towards big data analysis in 2015. At the time, operational data from the shop floor, such as machine cycle times or part failure modes, was not readily available. Instead, such data typically required a significant amount of manual collection and preprocessing. As a result, RBCD's continuous shop-floor improvement activities were impacted by delayed data availability, suboptimal data quality and soon-outdated static results covering only a limited period of time.

Wuxi personnel soon realized that real-time data and the insights from its analysis would provide a path to better and faster decision-making. This in turn would improve their business agility, considered vital to competitiveness in the Chinese market. In order to pilot this approach in RBCD, the company decided to first apply it to machining, a process essential to many of its products. Deployed in more than 100 machines, it came with a significant roll-out potential.

Using standard tools and based on best practice already explored by other Bosch plants, the Wuxi site set up an industrial IoT framework connecting newly installed machine-condition sensors and individual cutting tool information within six months. At this point, bringing together a data analyst with a machining expert was essential. Together, they were able to visualize the data and develop customizable reports with increasingly powerful analyses, including diagnostic, predictive and prescriptive functions. For instance, plant personnel now deeply understand cutting tool cost drivers, automatically identify tool types likely to sustain extended life quantities and are able to automatically adjust inventory to future demand.

Wuxi prioritized holistic thinking beyond the classical divisions. Right from the start, therefore, they made these reports available to associates and managers from all stakeholder departments in order to collect and integrate their user experience. By mid-2017, this approach had not only led to double-digit tool cost improvements but also, by setting an example, had inspired the organization to come forward with further big data applications, e.g. predictive maintenance or bottleneck analysis. Over the past two years, during a critical high-demand situation, these activities contributed to more than 10% output increase in selected areas and, therefore, played a role in ensuring delivery and customer satisfaction. Wuxi has also been enabling engineers to master basic data analytics in their respective domains. As a consequence, today big data analyses are supporting decision-making throughout the entire RBCD organization, including manufacturing, logistics, quality management and controlling.

Christophe Chapdelaine, Senior Vice President Manufacturing and Quality Management, Bosch Automotive Diesel Systems Wuxi

"Data analytics provides us with new methods and insights to improve quality, productivity and delivery. In our very dynamic and competitive business conditions, the resulting speed and agility further enhances our customers' satisfaction.

"We are applying these methods in both the technical and commercial areas. This demands development of new competencies to maximize benefit. Moreover, the organization and leadership need to evolve in order to support this transformation. This is an exciting development for our associates and enhances our reputation as an attractive place to work. Introducing innovative solutions with speed across our business gives us the edge in delivering products and services 'Invented for Life'."

Babur Ozden, Founder and CEO, Maana

"Over the last six years we at Maana have been working with the world's largest industrial enterprises to help accelerate their digital transformation.

"An enterprise on a digital transformation journey quickly learns that big data is not about quantity (volume) or speed (real time) of data; neither is it about (more) sensors, robots or automation. With that learning comes the recognition that return on investment in big data cannot be justified by mere insights.

"Industrial companies utilizing big data in a truly successful manner do so for the pursuit of dramatic improvements in operational decision-making. It enables enterprises to do something that they could not do easily and/or inexpensively before: that is, it allows for 'globally optimizing local decisions'.

"Take, for example, decisions at a single plant to reduce rework, bottleneck and waste. Can a local decision (i.e. about rework at a single instance at single plant) be optimized at the plant level (considering that plant's overall goals) and even, if the company has multiple plants, at the broader company level? Let's take this 'globally optimizing local decisions' concept one step further: for example, should the plant start on an order received or wait, if there is a likelihood of a more lucrative order?

"Globally optimizing local decision-making is not new. What is new is that big data makes building an analytical capability at scale that is, by orders of magnitude, easier, faster and less expensive than before. Big data decision-making is for globally optimizing each local decision across the plant – and across all the plants and the enterprise."

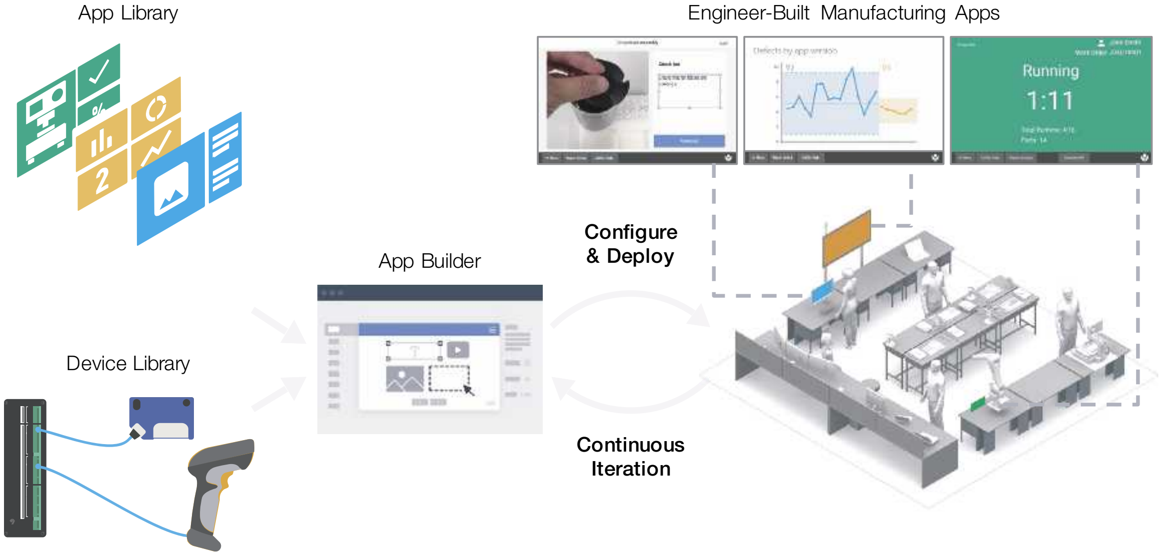
Democratized technology on the shop floor

Natan Linder, CEO and Co-founder, Tulip Interfaces

"In recent years some of the world's largest manufacturers have made significant strides in improving shop-floor productivity and yield by democratizing access to shop-floor technology. Manufacturing app platforms have emerged as an important tool in manufacturers' journey towards digital transformation. They allow manufacturing engineers to easily build shop-floor apps without the need to write code. This enables an organization's manufacturing problems to be addressed by engineers, the stakeholders that actually understand these problems.

"These platforms relieve IT from having to custom-code applications for the shop floor, and instead focus on empowering engineers to create their own apps. The role of IT in such a world is to shepherd the bottom-up adoption of the manufacturing app platform. For shop-floor operators, the benefits are immediate. Manufacturing apps augment operators and guide them through work. In addition to improving productivity and yield, apps enable manufacturers to bridge the skill gap. Operators are given detailed guidance and real-time performance feedback through manufacturing analytics. In this way, experienced and new operators can work side by side with manufacturing apps, guiding each operator according to their skill level."

Figure 10: App building platforms enable democratization of technology on the shop floor



Melonee Wise, CEO, Fetch Robotics

"A key element of Fourth Industrial Revolution technologies is their ability to empower workers and staff on the shop floor to identify opportunities for improvement and take local action. In one example, a large manufacturer had deployed autonomous mobile robots (AMRs) for a point-to-point material transfer workflow moving parts from kitting stations to an assembly cell. Workers in another cell noted that their colleagues experienced fewer delays waiting for parts, and they also noticed that the robots would wait in an idle queue between tasks. They approached the floor supervisor and requested that the robots also be assigned to support their cell.

"The AMR system employed cloud robotics technology, so it provided a simple interface that enabled the floor manager to set up and schedule the additional workflows between the kitting area and the new cell with a few clicks, without any programming or support from the IT staff. As a result of their independent and collaborative action, the workers and local staff were able to increase their productivity and also increase the utilization of the robot, making it a win for all involved."

Agile working mode

Fast Radius in Chicago, USA

Creating an agile working environment requires building out nimble and smart teams, processes and technologies optimized through learning. Fast Radius, an additive manufacturing company based in Chicago, IL, understands how important agility is to the future of manufacturing. This is especially true for the additive manufacturing industry, where evolving environments and disruptive technologies necessitate the need for teams to become more adaptive.

To that end, Fast Radius set out to enact **an agile working mode that would enable its team to constantly iterate and optimize for efficiency.** The agile working mode is comprised of two engines: a flexible, flat organizational structure and a technology platform that allows for scalable organizational learning. Combined, these engines have ensured that Fast Radius can adapt for flexible working environments in the following ways:

Network of empowered teams: Fast Radius opted to make its organizational structure very flat. On the client-service side, the team is organized in flexible, rapidly changing client-service teams. On the operations side, the team is structured atypically for a manufacturing company. Operations is built around value streams instead of separated functions, with value-stream leaders who own end-to-end decisions in the quality of designs, engineering, machine use and production. These cross-functional teams implement new technologies and improvements in short sprints, with a strong focus on developing a minimal viable product first and then adding additional functionality iteratively, while always incorporating findings and operator feedback.

Software-enabled rapid decision and learning cycles: The critical enabler of Fast Radius's ability to be agile is its proprietary technology platform. The platform enables the entire team to bring the principles that have revolutionized software development via agile to the physical product development world. In this instance, the software collects data and findings from every part design that is stored and manufactured in the Fast Radius virtual warehouse. The data derived from this technology is centralized, industrialized and disseminated to teams to help members iterate and scale quickly, based on performance. This has allowed them to cut traditional product-development cycles by up to 90 percent.

Lou Rassey, CEO, Fast Radius

"From day one, we understood that an agile working model would be critical to our business. Today's manufacturing is becoming increasingly intertwined with the design and supply chain. And when it comes to additive manufacturing specifically, there is constant disruption that needs to be understood and navigated in order to get to quick, achievable solutions.

That's why we combined agile technology with agile team structures. We can accelerate new products to market for our clients by creating hundreds of designs and prototypes within weeks instead of months. We are also able to make and deliver critical parts faster than ever, with end-to-end cycle times that used to take 45 days now taking just 45 hours. All of this is made possible by stitching an agile working mode into our business – in our software and technology, in our factory designs and in how we organize our teams."

Bosch Automotive in Wuxi, China

Bosch Automotive Diesel Systems Co., Ltd. (RBCD) strives to complete the proof-of-concept (PoC) phase very rapidly. In this way, the company is able to focus its resources and to maintain an innovation speed of approximately 10 PoCs per year. In order to achieve this, they have created a Production Innovation Center (PIC) with a small assembly line, exclusively for training and development purposes. While this line is not designed for "real" production, it is fully connected with sensors, radio frequency identification (RFID)-based tracking and enterprise resource planning (ERP) integration. As a result, the site has the advantage of an isolated (and therefore safe) try-out environment for many of its PoCs. By focusing on core functions supported by fast local software suppliers, Bosch finishes more than 80% of its PoCs in less than three months.

Minimal incremental cost to add use-cases

Microsoft's manufacturing site in Suzhou, China

At Microsoft, hardware for technology products is big business. In fiscal year 2017 two well-known company products grew to over $8 billion in business. This level of impact underscores the importance of monitoring and optimizing manufacturing operations – as well as sharing information about them.

To ensure competitiveness of their products and customer services, Microsoft transformed the manufacturing process at its Suzhou, Jiangsu, factory in China in three waves:
- connection of equipment
- prediction using big data
- application of machine learning to create cognitive manufacturing lines

According to Microsoft, one of the most important benefits of connected equipment is the ease of setup of new use-cases with minimal investment. In the past, program managers and teams of developers wrote code and backend queries to bring a new data source into the process, which could take days, weeks or even months of work. Now, the company says, it takes one person about 15 minutes to attach a new data source to the solution.

Using the connected equipment and the capability to add new use-cases in a short time period, the company added machine learning algorithms for predictive yield improvement based on production process data of individual components. These predictive patterns highlight defects, material waste and other factors. This enabled a significant yield improvement of 30% with the completion of one use-case.

Microsoft explained that the new solution has already provided manufacturing processes with many benefits, including easy initial setup, customizability, quick access to data insights, significant time savings, cost savings and increased productivity. Their factories and suppliers are integrated at an unprecedented level and personnel are constantly amazed at how quickly they can discover important trends and issues within the facilities. With nominal investment, the company expects these benefits to increase as it moves further towards completing its cloud solution.

Darren Coil, Director of Business Strategy, Microsoft

"This digital transformation has been the largest change in manufacturing technology in 30 years, and it was one of the easiest changes to bring to flourish. The physical connection of machines took only a couple of weeks. And once the data was available, within hours of implementing the machine learning at minimal cost, we uncovered inventory that was headed towards obsolescence. The data was always there, but we weren't seeing it until IoT highlighted it for us. The factory has saved countless units from being scrapped by using data to make line improvements and identify quarantines. Ultimately, it saved upwards of $5 million in a 12-month period just based on what our five-man team accomplished. And finance is reporting that we've reduced inventory costs by $200 million."

Melonee Wise, CEO, Fetch Robotics

"Industry leaders are seeking new automation technologies that can support new use-cases in digital manufacturing with minimal investment. In response, a new generation of on-demand automation technologies are emerging that bring to factory floors and warehouses the kind of speed, agility and incremental cost advantages that cloud computing has brought to IT.

Figure 11: On-demand automation is described by six basic principles

"In one example, a robotic material-handling system was deployed in a large facility to address a congestion and dwell time issue that was reducing output and increasing labour costs. Because the system was collaborative, autonomous and cloud-based, no changes to the facility or processes and no installation or integration of IT hardware and software were required. The pilot was deployed and operational in days, and completed in under two weeks. Based on the quick success and compelling ROI, the initial use-case was approved for full scale-up, and an additional use-case was added as part of the scale-up."

New business models

European consumer electronics manufacturer (company name undisclosed)

Because new business model innovations are typically self-induced business model disruptions, company leaders anticipate some turbulence as they adopt the changes. Therefore, it is understandable that company leadership may desire to retain levels of confidentiality until the new business model has reached a significant size. For this reason, a European consumer electronics manufacturer, which has demonstrated success in innovating a new business model, has elected to remain anonymous at the time of this white paper's publication. The company is included anonymously as its experience can provide valuable insights and findings in this context.

It is notable that in the digital era, customers are accustomed to 24/7 online availability from vendors, along with a streamlined, customizable ordering experience enhanced by free shipping and hassle-free return policies. To remain competitive, therefore, traditional manufacturers must be able to engage customers in the design stage, lower the lead time from weeks to hours and execute an order size of one at the price of mass production, all while presenting a fluid interface complete with hassle-free shipping and returns. These capabilities are difficult or impossible to meet without employing digital technologies.

Facing these market demands, this unnamed organization found itself faced with challenges associated with traditional products and supply chains. Production of components with injection moulding required high investment in tools and long lead times for the production of new manufacturing tools. Consequently, long delivery lead times, with much capital bound in inventory, made for a high risk of inventory excess or shortage. The product design system was optimized for traditional manufacturing processes, limiting design freedom and leading to many parts requiring assembly. All of these factors combined to create a long time to market for new designs.

In order to overcome these challenges and offer the consumer a new value proposition, the company founded a new venture that produces fully customizable products down to a lot size of one at a unit cost below that of legacy products. It distributed an additive manufacturing production network, with the vision to produce directly in logistics hubs enabled by additional digital manufacturing use-cases. An integrated digital manufacturing backbone ensures fast scalability of manufacturing operations. Quality control is harmonized and automated by machine learning. A web-based configurator allows the customer to order a fully individualized product with infinite design possibilities, while production near to the end customer reduces both shipping cost and delivery lead time.

The results of this initiative have included a complete disruption of the existing value chain and the creation of a new business with several million euros worth of sales after one year. It has also effected a significant shift in current operating boundary conditions for the company, including:

- Time for new product introduction: -90%
- Capital bound in inventory: -75%
- Manual assembly time per product: -80%
- Investment in design-specific tools: -100%
- CO2 output: -50%

This unnamed organization provides demonstrated insights into how new business models emerge in response to market changes. Many disruptive digital technologies have emerged in recent years that have affected, and will continue to affect, supply chain, product design, manufacturing and marketing. Successful implementation that captures the value of these changes, especially in a large corporate environment, involves travelling a road with many opportunities and pitfalls. Some specific insights from the manufacturer include:

- Managing expectation is important at all levels in the company. Meaningful short-term results that fit the end-goal are preferable to overambitious goals that will lead to disappointment.

- Experience shows the benefit of forming an autonomous team initially separate from the rest of the company. This autonomous team should have access to the company's assets that best serve the purpose of success (e.g. brand, investment money, talent, sales channels).

- Because corporate culture must change for these kinds of disruptions to be successful, embedded executive sponsorship at the highest level is mandatory to resolve any potential conflicts and ensure access to necessary resources until maturity is established.

2. Scale-up Enablers

Fourth Industrial Revolution strategy and business case

BMW Group

BMW's digital manufacturing strategy is based on three pillars: focus on effectiveness, the right mindset and easy access. All digital use-cases deployed must serve to further improve its production processes in terms of quality, cost and productivity, benefitting from easy access to technology while adhering to a culture of cooperation.

Effectiveness

BMW-defined implementation clusters, each with its own clear strategic trajectory, determine the framework: smart data analytics, innovative automation and assistance systems, smart logistics and additive manufacturing.

With its consistent IT architecture from the top group level to the shop floor, the BMW Group's IoT platform provides the backbone for all digital applications. The connection of facilities and sensors with the cloud is more than just a goal in itself: each new use-case implementation funds the setup of this infrastructure with a positive ROI. An important advantage of the company's IoT infrastructure is that it allows plug-and-play setup of various use-cases, with a negligible installation effort. Staff members have access to a digital toolbox of resources they can combine and apply as they see fit. The best outcome of this system is speed.

Mindset

The BMW Group operates production sites at 30 locations in 14 countries worldwide. All of the company's vehicle plants work in keeping with the BMW production system. Consequently, the most effective innovations are those that can be applied in all plants. However, many innovations emerge at an individual plant, solving a particular issue at that location. Therefore, it is essential to promote a culture of cooperation across locations and continents. Each location contributes to the centrally coordinated production network, and solutions are implemented once at a single plant for all locations. This way, valuable and effective innovations can be adopted swiftly for all locations. The company has a term for this approach: "sharing is caring".

Easy access

Digitalization in production can be highly effective if this third principle is met. Software development can be highly complex with regard to the underlying technology. However, all applications – from artificial intelligence-supported image recognition to the analysis of sensor data or autonomous transport systems – have one requirement in common: access to data and the design of the user interface must be as simple as possible. If this criterion is not met, isolated solutions are created that require expensive training and may complicate operations.

Control logics and analyses can be generated directly at the plants, using self-service solutions that require very little effort. This principle of open systems and interfaces applies to the entire BMW production system.

Any connected facility or machine is always integrated into an overall system, in which it has to work – preferably at the least cost and effort possible. Ultimately, a digital solution must present a benefit to the process and not cause any additional cost or effort.

Christian Patron, Head of Innovations and Digitalization in Production System,
and Marcel Eigner, Strategy Digitalization and Smart Data Analytics Production System, BMW Group

According to Christian Patron, Head of Innovation, Digitalization, Data and Analytics at BMW Group, "Not everything that's technically feasible also makes sense: The more effectively a technical solution supports and frees up staff, the better people can apply their strengths in a productive manner. Consequently, one of the main tasks in the Fourth Industrial Revolution environment is to identify highly effective applications and to standardize and scale these rapidly within an international production system. Nobody has a better take on a solution's effectiveness than the people in the process.

"To roll out scaled projects quickly across the board, we need fundamental enablers. This is why our strategy at the BMW Group focuses on a comprehensive IoT platform and training for our staff. This combines local process expertise with a group-wide rollout strategy. In the future, artificial intelligence solutions will allow us to support people even more effectively.

Deep learning models pool the knowledge of experts and make it available around the globe within a matter of seconds. Nevertheless, people will always continue to be at the centre of value creation, with their scope of creativity actually expanding further."

Marcel Eigner, from the company's Strategy Digitalization and Smart Data Analytics Production System, echoed Patron's emphasis on this comprehensive approach: "When it comes to smart data analytics, we pursue a clear strategy of getting the data as closely to the people in the operational process as possible. This is primarily about data lakes that are fully accessible to the specialist departments, analytics tools in self-service solutions and hands-on data visualization. Analytics can only be effective if we have actionable insights."

IoT architecture built for scale-up

Hewlett Packard Enterprise

Texmark Chemicals, a customer of Hewlett Packard Enterprise, operates a petrochemical refinery in Galena Park, Texas. The site is one of the world's largest producers of DCPD (dicyclopentadiene). Additionally, they are a tolling manufacturer, producing specialty chemicals for their contract customers.

Texmark is an important link in the petroleum product supply chain, and because it works with regulated hazardous materials, safety is a top priority. Texmark's vision for next-generation worker safety, production and asset management hinges on the emerging promise of the industrial internet of things (IoT). This involves sensored devices combined with advanced analytics software to generate insights, automate the environment and reduce the risk of human error. One of Texmark's goals with IoT was to reduce planned maintenance costs by 50%.

IoT has the potential to benefit Texmark's production streams in many ways. But specialized manufacturing needs more than one-size-fits-all solutions. IoT requires robust connectivity, architectured to support gathering data from a range of IoT devices. That connectivity must be cost-effective, however – and hardwiring a manufacturing plant can be prohibitively expensive. In addition, any technology installed in Texmark's plant must be ruggedized and meet the company's operational standards for safety: equipment operating at Texmark's edge must be designed to ensure it cannot be a source of ignition. Another important IoT challenge Texmark must address is data latency. Transmitting data takes time, and in IoT seconds often count. Therefore, an IoT architecture is required that eliminates the need to transmit device data.

In order to meet these challenges and realize the benefits of IoT architecture, Texmark launched a multiphase project to implement an end-to-end IoT solution.

Phases 1 and 2 established the digital foundation by enabling edge-to-core connectivity. A wireless solution was deployed that costs approximately 50% of deploying a hardwired network.
For its edge analytics, Texmark deployed an industrialized solution that provides enterprise-grade IT capabilities at the edge. In addition, Texmark's plant control room was upgraded to enable seamless edge-to-core connectivity and to integrate its operations technology and IT into a single system.

Phase 3 (ongoing) builds on the foundation established by these technology solutions to support Texmark's use-cases: predictive analytics, advanced video analytics, safety and security, connected worker and full life-cycle asset management.

According to Plant Manager Linda Salinas, this IoT architecture is vital to developing advanced Fourth Industrial Revolution manufacturing in the chemical industry. "We're building a refinery of the future that combs through data and reveals how the entire plant is interconnected. It becomes like a living, breathing organic plant that knows how it should operate; if any part falls out of line, it flags for intervention."

Chen Linchevski, Co-Founder and CEO, Precognize

Chen Linchevski is the Co-Founder and CEO of Precognize, an Israel-based software company specializing in predictive analytics for the process industry. Linchevski explained that the lessons of implementing IoT architecture in process industry plants, which collect data from thousands of sensors, are relevant and applicable to any industry implementing IoT. Based on his experience with analytical predictive monitoring software, Linchevski shared three important recommendations for building IoT architecture for scale-up.

Accessibility of data. The first recommendation is that when selecting an architecture for IoT scale-up, accessibility of the data is essential. “Have an architecture that makes the data available for everybody to analyse,” said Linchevski. This “democratizing” is best achieved when barriers to the data are removed. Some equipment vendors, for example, have charged a premium to manufacturers in order to use a connector to the data collected by their machines. Linchevski suggests this presents “a call for manufacturers in the digital age to ensure the data gathered by the equipment they purchase is available to them, even if it means setting this as a criterion when selecting an equipment or sensor provider”.

Fast trial and error. The second recommendation is that IoT architecture should support fast trial and error. According to Linchevski, digital initiatives are generally implemented rapidly, which makes them distinct from the long lead times associated with more traditional industry. He explained that in the process industry, implementation is usually finished within two weeks, with the pilot running an additional three months. “Expediting this process requires availability of all the data, as mentioned above, but also APIs or other connectivity means to the data. The architecture should clarify the cybersecurity requirements and make sure that the environment is planned to allow moderate security requirements, because strict security requirements will slow down projects. Sandboxes, read-only means to the data and standalone applications (for the pilot phase) should be allowed,” Linchevski commented.

Agile architecture design. Linchevski’s third recommendation is that the design of the architecture should be agile to account for the differences in manufacturing sites, and to allow for expansion and adaptation as needs are clarified. The value should be apparent in the first application, which can then justify the next steps in building the architecture. “Trying to design every part of the architecture from the beginning will be costly and long.” Instead, Linchevski suggests, “Agree on the principles. Then start piloting applications in order to clarify the needs and expand your architecture.”

Capability-building through acquiring new skills

Tata Steel in IJmuiden, Netherlands

When Tata Steel began its roll-out of advanced analytics (AA), it quickly became clear that there was no silver bullet, and that building up the skills of employees would be essential to success. Rather than seeking to achieve a limited number of very large use-cases (EBIBTA impact of more than €20 million), the approach would focus on many smaller projects. This important determination would shape the nature and structure of the programme. The sheer number of projects required many workers with specialized skills. External hiring was impractical due to the lack of capable candidates, and outsourcing would be unsuitable due to the continuous nature of this activity. Thus it proved necessary to train a significant number of Tata Steel employees. This gave rise to the internal Advanced Analytics Academy, which has now trained more than 200 people.

The academy was designed for versatility, and its dedicated curricula have been built to train for a number of roles, including data scientists and data engineers. Data scientists develop the skills to create the optimal model from a given dataset and for a given target function, which requires a solid understanding of statistical methods. Data engineers must make the raw data available in such a form that it can be understood and used repeatedly by the data scientists. This demands training in skills such as data preparation and data cleaning.

Along with these AA specialists, there are two groups requiring a sound level of AA understanding: digital translators and management. Translators ensure that the right business problem is communicated to the AA team and that the result of the AA team fits with the implementation constraints of the business area. They also have the important role of spotting spurious (or even faulty) correlations that typically emerge in the early phases of AA projects. It became clear that dedicated training modules were also important for the management of Tata Steel. These provide a basic understanding of AA along with the preferred style of directing AA projects. Due to significant ambiguities present in the beginning of AA projects, their management requires questions, checks and balances that differ from more conventional approaches.

Most training is delivered through conventional classroom teaching, as face-to-face interaction between students and the teachers is a vital component of the educational process. Rather than relying on generic examples, curricular material has been tuned to the Tata Steel environment, as experience has taught the company that contextualized examples are substantially more effective in conveying the underlying message or statistical method. In addition to classroom teaching, other hands-on learning applications are used. For example, the academy’s “hackathon” is part of data scientist training. In this 36-hour assignment, teams of new scientists are tasked with developing a model for a pre-engineered dataset from a real-life Tata Steel situation.

Hans Fischer, CEO, Tata Steel in Europe

"Advanced analytics forms a key part of our Industry 4.0 strategy. We have chosen to train our domain experts to become skilled in data science, rather than hiring pure data scientists. Our AA Academy has been instrumental. However, it must be noted that training data scientists is not enough; we needed to educate the management as well to ensure their ability to spot future AA opportunities and direct the projects that run in their areas. Recently, I followed the management training on advanced analytics myself. It was a true learning experience in the sense that it gave me deeper insight into the opportunities of AA. I was already convinced about the application of AA in our industry, but now I've experienced this first hand."

Daiane Piva, Improvement Consultant Energy Efficiency, Tata Steel

"I joined the Advanced Analytics Bootcamp shortly after being hired as an energy consultant at Tata Steel Europe. After completing the AA Bootcamp, I was engaged with a relevant project. This combination of theoretical background and practical work was pivotal in setting me up for success. I believe the true power of advanced analytics, besides the algorithms, is its agile-yet-well-structured aspect. We fail fast and we learn fast. Projects are organized in a way that leads to clear end products divided into very specific intermediate steps, which makes it much easier to track progress. It was stunning to see how many extra insights we can get just by looking more closely at the data."

Workforce engagement

Schneider Electric in Le Vaudreuil, France

In a digital transformation, innovation must be open, but also organized, to ensure it is adopted holistically throughout a business. Schneider Electric is implementing, testing and rolling out ideas for innovation in an organized approach in a "Smart Factory Programme". A strong focus on workforce engagement ensures that the changes and new technologies are supported by employees and therefore adopted quickly.

For example, at the company's Le Vaudreuil site in France, it has created a 3D virtual reality model of the entire factory to use in testing and validating innovative ideas. This is then used to engage operators so they can see how their day-to-day work will change.

To promote collaboration, it is essential to devote time to access and discover new technologies, answer questions and engage discussion. Schneider uses a web-based social network that allows operators to share best methods, post and answer questions and contribute to a shared community space.

One of the main transformations the company has observed is a shift in factory management practices. The role of plant manager has traditionally been to check execution and correct issues, and to drive the workforce to achieve the plant's KPIs. However, this is evolving as operators become empowered to make decisions using more sophisticated data and information obtained directly from machines and process. Plant managers can focus on benchmarking and analysis to drive improvements to the factory. This change is additionally supported by the interconnection of more and more smart factories, whereby each plant manager can benchmark and compare the performance of their own factory against others.

Lilian Aube, Le Vaudreuil Plant Union Representative, Schneider Electric

"Digital transformation demands the combined efforts of people at all levels of the company to ensure changes are made in a sustainable manner. At Le Vaudreuil, we have seen our work practices evolve quickly and have had many new tools appear in our working environment including AGVs, tablets, cobots, predictive software and an explosion of data.

"Today, our business requires new skills, and employee perception is very positive, thanks to training and opportunities to work differently. We see fewer repetitive and more interesting tasks, better safety with hyper-secured AVGs and the ability to see production information on a mobile device in real time but away from the machines. Early involvement in new technology deployment is valuable for employees, enabling them to feel engaged in the transformation. We also expect an increase in internal promotion for our factory staff who, as they upskill, will become more valuable to the organization.

“These small evolutions are showing already that, with digitization, we will be able to reduce risk, be more responsive and work differently at the plant level. At the company level, we will be more efficient and effective with our manufacturing methods.”

Sophie Grugier, Senior Vice President,
Global Supply Chain Operations, Schneider Electric

“Adoption of 4IR technologies in supply chains represents a new way for humans and machines to work together. Digitization of manufacturing and warehousing processes helps improve both efficiency and sustainability. Human expertise remains significantly needed for interpretation and guidance, but can be combined with artificial intelligence applied on machine and process data to generate deep insights and solve complex problems. This coexistence of people and technology is what brings to life the true value of digital transformation.

“One of the key factors in successful and widespread adoption of digitization lies with how companies manage and communicate the changes brought about by digital transformation. At Schneider Electric, involving our people in the process of digital transformation from the beginning ensures that new technologies fully support them in their day-to-day work.

“It is not obvious for all operators to handle a tablet to check the status of a machine, where they would have previously leveraged another human-machine interface. We have found through our own digitization journey that peer-to-peer learning and cross-site collaboration have been quite effective in allowing suitable change management. This accelerates the adoption and increases the efficiency of change, and demonstrates that smart and green manufacturing is possible – delivering on the global promise of a sustainable production.”

Contributors

The World Economic Forum would like to thank the following contributors, particularly the representatives from the "lighthouses" presented in this report.

Sergey Chebotarev, Vice President of Energy, NLMK
Loic Regnier, Strategic Thought Leadership, Schneider Electric
Shwetha Shetty, Senior Director Corporate Strategy, SAP
Majid Gwaiz, General Sup., Advanced Process Solution, Saudi Aramco
Christian Haecker, Head of Additive Manufacturing Industrialization, Oerlikon
Steffen Lang, Global Head Technical Operations, Novartis
Dr. Ravi Kumar, Associate Vice President and Head, Advanced Engineering Group, Infosys
Bart Talloen, Vice President Supply Chain Strategy and Deployment, Johnson & Johnson
Jeffrey Wilcox, Vice President Digital Transformation, Lockheed Martin
Renee McKaskle, Senior Vice President and Chief Information Officer, Hitachi
Aly Wahdan, Plant Manager, Procter & Gamble
Ric Fulop, Founder and Chief Executive Officer, Desktop Metal
Andreas Kunze, Chief Executive Officer and Co-Founder, KONUX
Carl Vause, Chief Executive Officer, Soft Robotics
Luca Cremona, Business Development Manager, Rold
Melonee Wise, Chief Executive Officer, Fetch Robotics
Natan Linder, Chief Executive Officer, Tulip Interfaces
Andreas Braun, Department Manager, Bosch Automotive
Lou Rassey, Chief Executive Officer, Fast Radius
Alan Amling, Vice President Corporate Strategy, UPS
Menno Van der WindenGeneral, Manager Advanced Analytics, Tata Steel
John O'Sullivan, Global Head of IT BP Product Supply for Pharmaceuticals, Bayer
Christian Patron, Head of Innovation, Digitalization, Data and Analytics, BMW Group
Marcel Eigner, Strategy Digitalization and Smart Data Analytics Production System, BMW Group
Neal Meldrum, Business Strategy Leader, Microsoft
Matthias Roese, Chief Technologist – Mfg, Auto and IoT, Hewlett Packard Enterprise
Jun Ni, Director Manufacturing Research Center, University of Michigan
Krystyn Van Vliet, Professor, Massachusetts Institute of Technology (MIT)
Jeremy Edwards, Professor, University of Cambridge

Project team

World Economic Forum
Helena Leurent, Head of Future of Production System Initiative, Member of the Executive Committee
Francisco Betti, Future of Production Lead
Jayant Narayan, Project Lead, Future of Production and Global Leadership Fellow

McKinsey & Company
Enno de Boer, Partner, Lead Partner World Economic Forum Tech. and Innovation for the Future of Production
Adrian Widmer, Engagement Manager, seconded to the World Economic Forum
Diego Hernandez Diaz, Engagement Manager, seconded to the World Economic Forum
Katy George, Senior Partner
Varun Marya, Senior Partner
Christoph Schmitz, Senior Partner
Richard Kelly, Partner
Mehdi Miremadi, Partner
Dinu Niculescu, Partner
Forest Hou, Senior Expert

The team would like to thank Paul Cumbo for his support in writing this paper.

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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