In collaboration with
McKinsey & Company

WORLD ECONOMIC FORUM

Global Lighthouse Network: Reimagining Operations for Growth

WHITE PAPER

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Contents

Foreword

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The Fourth Industrial Revolution is accelerating as a combination of forces that include global disruptions and instabilities, supply chain breakdowns and heightened customer demand for digital-first experiences. Amid the challenges that these forces impose, leading manufacturers are revising their growth strategies, which can serve as beacons for others. In many respects, the Fourth Industrial Revolution is now building upon the achievements of the past decade, when organizations sought to improve productivity and minimize cost. But in today's increasingly complex environment in which customers demand one-to-one, personalized experiences, productivity improvements are table stakes; the ongoing revolution demands that companies achieve growth beyond productivity to remain competitive.

Lighthouses have always held a storied place in the history of maritime tradition. These aids to navigation have served as guides and beacons, ensuring the access so crucial to commercial and industrial growth in untapped territory. Their powerful beams pierce the densest fog, enabling passage and empowering progress. When the World Economic Forum began the Global Lighthouse Network initiative in 2018 in collaboration with McKinsey & Company, leading-edge manufacturers were illuminating exciting possibilities that lay ahead for the future of industry. To be sure, though, in the wake of global market disruption certainly akin to the stormiest of seas, the lighthouse is now an even more compelling image. Recent global events are changing the very nature of navigation, and powerful beacons are more essential than ever. The fog is getting thicker and only the brightest lights can shine through.

This is a time of unparalleled industry transformation; the future belongs to those companies willing to embrace disruption and capture new opportunities. Ever more manufacturing companies are showing that it is possible to unlock unprecedented capacity, realize entirely new revenue streams and gain market share. Workers are finding that new skills can expand capabilities and the chance to collaborate in new ways using state-of-the-art technology. Consumers, who are driving the market transformation towards rapidly delivered tailored products, are finding that their preferences are being met by innovative competitors in this redefined marketplace.

It is companies like this that comprise the Global Lighthouse Network: organizations with the courage to invest in new ideas, new approaches and altogether new methods that are collectively transforming the very nature of operations. Despite growing complexities and disruptions, these companies continue to show signs of sustained strength, keeping the momentum on profit while remaining responsible corporate citizens. They are realizing productivity improvements, gaining market share, redefining customer centricity and ushering in a cleaner future in which boosted productivity and sustainability measures are not mutually exclusive but intrinsically intertwined.

These pioneering companies stand as beacons and leaders. Not only are they surviving; they are thriving as they engage the full power of the Fourth Industrial Revolution to drive growth in ways and at levels unseen before. These companies make clear that growth is possible with little or no capital expenditure, proving false the notion that Fourth Industrial Revolution investment is fruitless. They have written a new growth narrative, with digital as the pen. Whether ahead of the digital curve or lagging behind, no company is immune to the digital revolution that COVID-19 is accelerating. Organizations unwilling or unable to respond quickly face perilous waters indeed.

Today's disruptions, despite their challenges, are a powerful invitation to re-envision growth. The lighthouse companies described in this White Paper have responded, and they illuminate the future of manufacturing – indeed, of industry writ large. They are the leaders, and their ranks are growing to form a dynamic collaborative. Read on, learn about their stories and imagine a future in which this network of beacons continues to grow. After all, their light is both an inspiration and an invitation. There is strength in numbers: as the Global Lighthouse Network grows, the collective light grows brighter, reaching further to an expansive future.

Executive summary

“ Lighthouses are driving business-model innovation through Fourth Industrial Revolution technologies, and ushering in new levels of customer-centric value.

Digital innovation is no longer optional. Global disruptions and instabilities impose a pressing need and opportunity for quantitative and qualitative growth amid shifts in supply, demand and customer expectations for digital-first experiences. Companies must find pathways to extend value through novel customer experiences to remain competitive; indeed, scalable technology that supports business goals is a requirement to become an industry-leading digital organization.

The Global Lighthouse Network welcomes 15 new lighthouses to an inspiring group of organizations that exhibit the essential characteristics of the Fourth Industrial Revolution. Lighthouses show the way amid these challenges, demonstrating how digitally infused operations go beyond productivity gains to create a base for sustainable, profitable growth. Through efforts that deploy Fourth Industrial Revolution technologies at scale, they are creating new revenue streams. Their use of flexible production systems yields increased speed to market through customizable product development, which is informed by a better understanding of customer demands; meanwhile, it boosts productivity of both assets and people.

It is now clear that lighthouses are driving business-model innovation through Fourth Industrial Revolution technologies, and ushering in new levels of customer-centric value. By shifting to models that leverage greater transparency into customer needs, advanced companies are implementing new use cases, such as those enabling mass customization with unprecedented speed to market. Through these efforts, they are positioning themselves at the forefront of a competitive marketplace where customers are looking for individualized products tailored to specific preferences.

While conventional wisdom might presume this kind of transformation would come at exorbitant cost, lighthouses are showing the opposite. They are achieving growth and higher productivity rates by unlocking capacity through Fourth Industrial Revolution technologies, with little to no capital expenditure. By coupling state-of-the-art digital tools with flexible production systems, they achieve measurable growth without the costly physical facility expansion and infrastructure investment such growth might have required in the past. Put simply, leading companies are discovering new ways to achieve growth without a larger footprint.

Accordingly, these forerunners are discovering, furthermore, that this growth need not come at the expense of environmental responsibility – in other words, growth (including higher productivity) and eco-efficiency are not mutually exclusive. In fact, the opposite is taking place: productivity improvements often drive resource efficiency gains and are tied to environmentally-conscious impact. This conveys the dual benefits of cost-reduction coupled with increased sustainability.

Implementing Fourth Industrial Revolution technologies at scale is key to long-term growth. But what is the secret to scaling? The great majority of companies remain in pilot purgatory, held back by outdated working modes or insufficient innovation. How have lighthouses successfully scaled the Fourth Industrial Revolution? The answer is twofold: agility and workforce development.

First, these companies have fully embraced agile ways of working. This has enabled them to scale Fourth Industrial Revolution technologies quickly across their production network and value chains. By transforming their operations to maximize flexibility and adaptability, lighthouses allow for innovative thinking and dynamic approaches. This supports close attunement to shifts in supply, demand and customer expectations.

Second, lighthouses take a keen interest in workforce development. Training, reskilling and upskilling – teaching new skills for future jobs – keeps their workforces prepared and optimized in a Fourth Industrial Revolution environment. They keep people at the centre of their Fourth Industrial Revolution transformation with a focus on inclusive growth, thus ensuring operators have the opportunity to realize their full potential to build the innovative, creative future at the heart of reimagined industry. This workforce engagement is essential to successful scaling. Scaling is a team effort, and people are the team.

The Global Lighthouse Network comprises a steadily increasing group of leaders – beacons that can inspire other companies striving to deploy Fourth Industrial Revolution technologies across their entire operations. By embracing agile working modes to scale across the production network and value chains, as well as prioritizing workforce development for scaling, lighthouses demonstrate what is possible as they achieve sustainable growth. Other companies willing to make similarly bold, courageous decisions can become beacons themselves.

1 Catch the digital shift: The Global Lighthouse Network expands

The Global Lighthouse Network is a community of manufacturers using Fourth Industrial Revolution technologies to transform factories, value chains and business models.

Aiming to close the gap between frontrunners and laggards while accelerating the widespread adoption of advanced manufacturing technologies, the World Economic Forum, in collaboration with McKinsey & Company, launched the Global Lighthouse Network in 2018. The network comprises a community of manufacturers showing leadership in using Fourth Industrial Revolution (4IR) technologies to transform factories, value chains and business models to generate compelling financial, operational and environmental returns. The Global Lighthouse Network welcomes 15 new lighthouses as of the date of this White Paper, bringing the total to 69 lighthouses across different industry sectors (Figure 1).

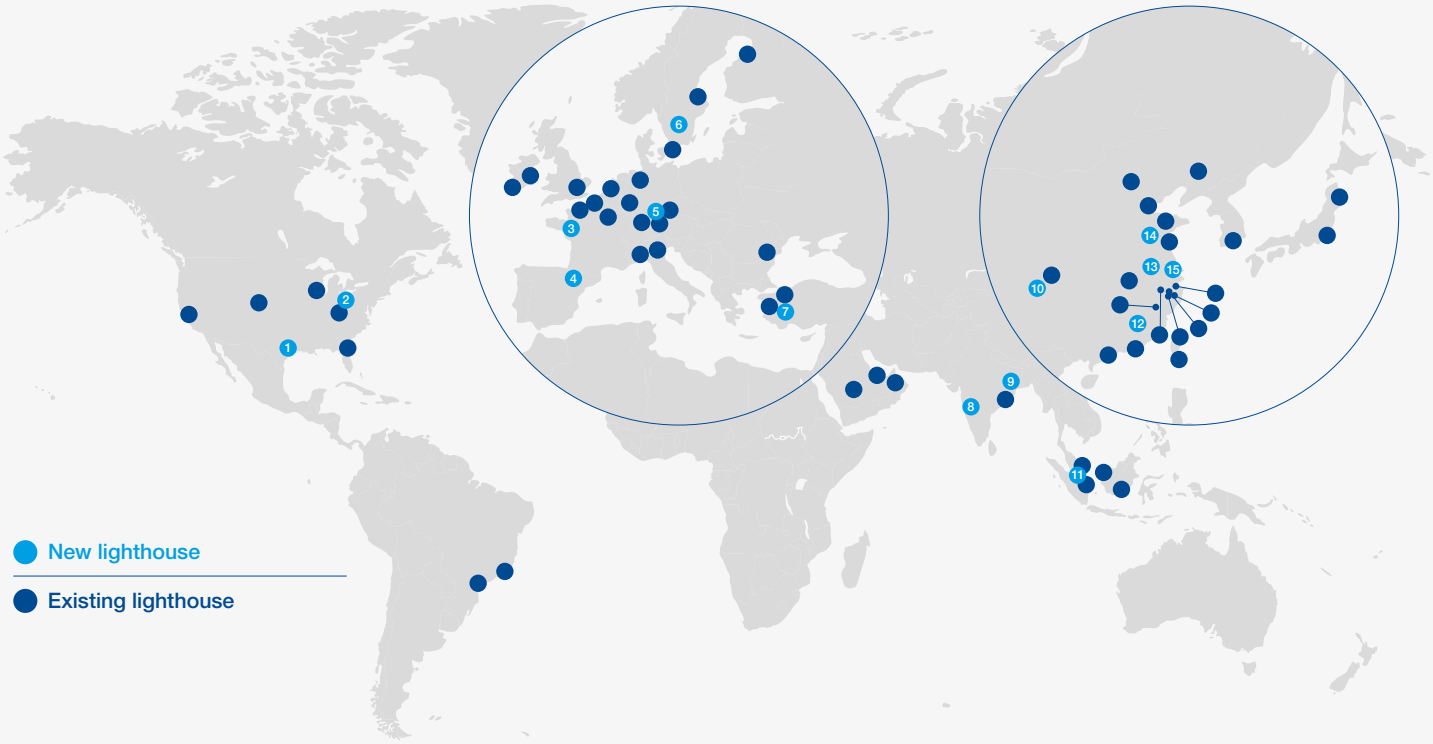
Lighthouses are identified through a comprehensive and independent selection process that has assessed more than 1,000 companies from various industry sectors across the globe on the bases of objective results and use cases. Final selection is delegated to an independent panel of world-leading 4IR experts. Global Lighthouse Network members today are actively engaged on a cross-industry learning journey that finds its core value in developing and sharing insights on top use cases, roadmaps and organizational approaches to deploy advanced technologies at scale while supporting the transition to a more human-centred, inclusive and sustainable future of operations.

1.1 New lighthouses bring diversity

The scope and variety of sectors (Figure 2) represented within the Global Lighthouse Network, including among its newest members, makes clear that the decisions, shifts and strategies that enable companies to succeed in scaling 4IR innovations are relevant in both traditional manufacturing and other sectors. These strategies are not sector specific. Whether companies are focused on customized consumer goods, advanced electronics, energy production or biopharmaceuticals, they are committing to the same principles to succeed in scaling, leading to sustainable growth. Furthermore, because the network represents manufacturing locations and value chains of all sizes, from plants exceeding 10,000 employees to others with 100 or fewer, it demonstrates that the adoption of 4IR technologies is critical and achievable for manufacturers large and small.

FIGURE 1 | **Global Lighthouse Network: 69 lighthouses**

An expert panel has added **15 new lighthouses**, bringing the total to **69 lighthouses** identified across various industry sectors.



1 **Ericsson**
Electronics, USA

2 **Procter & Gamble**
Consumer goods, USA

3 **Procter & Gamble**
Consumer goods, France

4 **Henkel**
Consumer goods, Spain

5 **Siemens**
Industrial automation products, Germany

6 **Johnson & Johnson Consumer Health**
Self-care products, Sweden

7 **STAR Refinery**
Oil and gas, Turkey

8 **ReNew Power**
Renewable energy, India

9 **Tata Steel**
Steel products, India

10 **Foxconn**
Electronics, China

11 **HP Inc.**
Electronics, Singapore

12 **Midea**
Home appliances, China

13 **Wistron**
Electronics, China

14 **Tsingtao Brewery**
Consumer goods, China

15 **Bosch**
Automotive, China

Note: Details on previously selected lighthouses are available in World Economic Forum, "Four Durable Shifts for a Great Reset in Manufacturing", White Paper, 2020.

Source: World Economic Forum and McKinsey & Company.

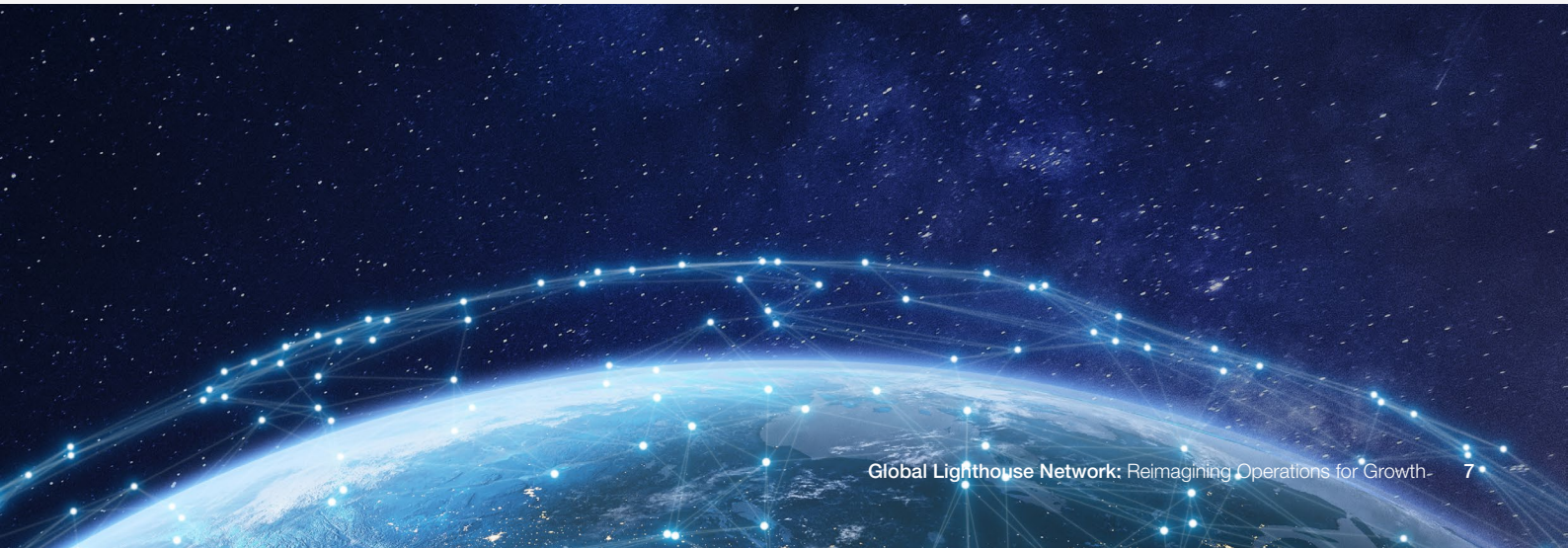


FIGURE 2 | **Global Lighthouse Network: A diverse network in all industry sectors**

Consumer packaged goods

Alibaba
Apparel, China

Henkel
Consumer goods, Germany

Henkel
Consumer goods, Spain

Procter & Gamble
Consumer goods, Czech Republic

Procter & Gamble
Consumer goods, China

Procter & Gamble
Consumer goods, USA

Procter & Gamble
Consumer goods, France

Tsingtao Brewery
Consumer goods, China

Unilever
Consumer goods, China

Unilever
Consumer goods, United Arab Emirates

Process industries

Baoshan Iron & Steel
Steel products, China

DCP Midstream
Oil and gas, USA

MODEC
Oil and gas, Brazil

Petkim
Chemicals, Turkey

Petrosea
Mining, Indonesia

POSCO
Steel products, South Korea

ReNew Power
Renewable energy, India

Saudi Aramco
Gas treatment, Saudi Arabia

Saudi Aramco
Oil and gas, Saudi Arabia

STAR Refinery
Oil and gas, Turkey

Tata Steel (2 lighthouses)
Steel products, India

Tata Steel
Steel products, Netherlands

Advanced industries

AGCO
Agricultural equipment, Germany

Arçelik
Home appliances, Romania

BMW Group
Automotive, Germany

Bosch (2 lighthouses)
Automotive, China

Danfoss
Industrial equipment, China

Ericsson
Electronics, USA

Fast Radius with UPS
Additive manufacturing, USA

Ford Otosan
Automotive, Turkey

FOTON Cummins
Automotive, China

Foxconn
Electronics, China

Foxconn Industrial Internet
Electronics, China

Groupe Renault
Automotive, Brazil

Groupe Renault (2 lighthouses)
Automotive, France

Haier
Appliances, China

Haier
Home appliances, China

Hitachi
Industrial equipment, Japan

HP Inc.
Electronics, Singapore

Infineon
Semiconductors, Singapore

Micron
Semiconductors, Singapore

Micron
Semiconductors, Taiwan, China

Midea (2 lighthouses)
Home appliances, China

Nokia
Electronics, Finland

Phoenix Contact
Industrial automation, Germany

Rold
Electrical components, Italy

SAIC Maxus
Automotive, China

Sandvik Coromant
Industrial tools, Sweden

Schneider Electric
Electrical components, Indonesia

Schneider Electric
Electrical components, France

Schneider Electric
Electrical components, USA

Siemens
Industrial automation products, China

Siemens
Industrial automation products, Germany

Weichai
Industrial machinery, China

Wistron
Electronics, China

Pharmaceuticals and medical products

Bayer
Division pharmaceuticals, Italy

GE Healthcare
Medical devices, Japan

GSK
Pharmaceuticals, UK

Johnson & Johnson Consumer Health
Self-care products, Sweden

Johnson & Johnson DePuy Synthes
Medical devices, Ireland

Johnson & Johnson DePuy Synthes
Medical devices, China

Johnson & Johnson Janssen
Pharmaceuticals, Ireland

Johnson & Johnson Vision Care
Medical devices, USA

Novo Nordisk
Pharmaceuticals, Denmark

Zymergen
Biotechnology, USA

Source: World Economic Forum and McKinsey & Company.

1.2 Lighthouses are deploying a variety of use cases

Lighthouses are deploying 110 use cases. While some focus within the context of individual manufacturing sites (Figure 3), others focus on connecting the value chain end to end (E2E) (Figure 4). A variety of use cases are also evident in the newest lighthouses (Figure 5).

FIGURE 3 **Lighthouse use cases: Within manufacturing sites**

Digital assembly and machines

- Additive manufacturing for process tools
- Advanced industrial internet of things (IIoT) process optimization
- Artificial intelligence (AI)-guided machine optimization
- AI-powered material handling system
- AI-powered process control
- Collaborative robotics and automation
- Cycle time optimization through big-data analytics on lines programmable logic controllers (PLCs)
- Digital engineering
- Digital lean tools (e.g. eKanban)
- Digital twin for flexible production
- Digitally enabled flexible manufacturing
- Digitally enabled modular production configuration
- Digitally enabled variable takt time
- Light-guided assembly sequence
- Mixed reality to enable digital training
- Real-time locating system (RTLS) for key manufacturing components

Digital maintenance

- Analytics platform for deviation root-cause identification
- Cost optimization of heavy operations through sensor analysis
- Digitally enabled pipeline leak prevention and detection
- Machine alarm aggregation, prioritization and analytics enabled problem-solving
- Predictive maintenance aggregating data based on historical and sensor data
- Real-time pipeline cost optimization based on edge sensors
- Remote assistance using augmented reality
- Unmanned vehicles for inspection

Digital performance management

- Analytics platform for remote production optimization
- Analytics platform for yield management and root-cause analysis
- Digital dashboards to monitor overall equipment effectiveness performance
- Digital recruitment platform tailored to shop floor
- Digital tools to enhance a connected workforce
- Digital twin for remote production optimization
- Digitally enabled man-machine matching
- Enterprise manufacturing intelligence system to upgrade operations management
- Integration platform to connect machine-level data with enterprise software
- Real-time asset performance monitoring and visualization
- Sensor-based manufacture key performance indicator reporting

Digital quality management

- AI-enabled safety management
- AI-powered optical inspection
- Automated in-line optical inspection to replace end-product manual inspections
- Digital quality audit
- Digital work instructions and quality functions
- Digitally enabled batch release
- Digitized standard procedures for line operations with integrated workflow
- Field quality failures aggregation, prioritization and advanced analytics-enabled problem-solving
- Internet of things (IoT)-enabled manufacturing quality management
- Mixed reality glasses to guide operators in the end-of-line inspection
- Quality improvement by predictive analytics
- Scanning to replace and improve performance for high-cost coordinate measuring machines (CMM)

Digitally enabled sustainability

- Digital twin of sustainability
- Energy optimization by predictive analytics
- IIoT real-time energy data aggregation and reporting dashboard
- Sensor-based data collection for energy management

Source: World Economic Forum and McKinsey & Company.

FIGURE 4 | Lighthouses use cases: Connecting the value chain end to end

Supply network connectivity

- Agile buying through price prediction
- Aggregate demand across E2E supplier network
- Analytics-driven procurement supported by spend intelligence and automated spend cube
- AI to accelerate the scaling of digital applications across sites
- AI-powered contract review for decision-making
- Digital supplier performance management
- Digitally enabled automatic material call-off system
- Digitally enabled negotiation
- Joint data analytics with original equipment manufacturer for process optimization
- Part traceability from unique digital tag based on surface scanning
- Should-cost modelling to support make versus buy decisions
- Supplier and materials quality tracking
- Supplier material delivery by eKanban

E2E product development

- Advanced analytics for performance management across the idea to market
- Big-data/AI-enabled product design and testing
- Crowdsourcing and competitions to develop digital solutions
- Digital thread implementation through product development life cycles
- Product development using robotics
- Rapid outsourced prototyping
- Testing automation
- Virtual-reality-supported prototyping
- 3D printing for rapid design prototyping
- 3D simulations/digital twin for product design and testing

E2E planning

- Advanced analytics to optimize the manufacturing and distribution footprint
- Analytics for dynamic warehouse resource planning and scheduling
- Closed-loop planning
- Digital integrated business planning
- Dynamic network optimization
- Dynamic production scheduling with digital twin
- Dynamic simulation for warehousing design
- E2E real-time supply chain visibility platform
- No-touch master planning (allocation to the plants)
- Predictive demand forecasting
- Predictive inventory replenishment
- Production planning optimized by advanced analytics
- Real-time inventory management (internal/extremal)
- Real-time sales and operations planning

E2E delivery

- Asset utilization and yard management for logistics
- Available to promise (ATP) based on real-time constraints
- Digital-enabled picking and transport
- Digital logistics control tower
- Digital track and trace
- Dynamic delivery optimization
- No-touch order management
- Predictive maintenance in fleet assets
- Robotics-enabled logistics execution
- Uberization of transport
- 3D printing

Customer connectivity

- Connected devices to track and measure consumer behaviours
- Connected devices to track and measure product performance
- Customer analytics enabled by radio frequency identification (RFID)
- Customer end-user interface to configure and order a product, and track delivery
- Delivery to customers wherever they are through new delivery solutions
- Digital twin of customer system
- GPS-based map and customer location
- Market insights generated by advanced analytics
- Mass customization and business-to-consumer online ordering
- Online communities for customer insights
- Smart/intelligent packaging

Source: World Economic Forum and McKinsey & Company.

FIGURE 5 | **New lighthouses: Next-generation use cases**

Site	Change story	Use case	Impact	
Bosch Suzhou, China	As a role model of manufacturing excellence within the group, Bosch Suzhou deployed a digital transformation strategy in manufacturing and logistics, reducing manufacturing costs by 15% while improving quality by 10%.	Digital shift performance management	▲ 8%	Direct productivity
		Digitally enabled automatic material call-off system	▼ 35%	Production stock
		Customer end-user interface to configure and order	▼ 10%	Logistics cost
		Smart quality management allocation	▼ 6%	Maintenance cost
		Cycle time and changeover optimization by machine vision	▲ 10%	Machine productivity
Ericsson Lewisville, USA	Faced with increasing demand for 5G radios, Ericsson built a US-based, 5G-enabled digital native factory to stay close to its customers. Leveraging agile ways of working and a robust IIoT architecture, the team was able to deploy 25 use cases in 12 months and, as a result, increased output per employee by 120%, and reduced lead time by 75% and inventory by 50%.	5G collaborative robotics and automation	▲ 120%	Output per employee
		5G robotics-enabled logistics execution	▼ 65%	Manual material handling
		5G sensor-based data collection for energy management	▼ 97%	CO_2 emissions
		Artificial-Intelligence-powered optical inspection	▲ 5%	Throughput
		Digital twin for remote production optimization	▲ 8%	Efficiency
Foxconn Chengdu, China	Confronted with fast-growing demand and labour skill scarcity, Foxconn Chengdu adopted mixed reality, artificial intelligence and IoT technologies to increase labour efficiency by 200% and improve overall equipment effectiveness by 17%.	Digitally enabled man-machine matching	▲ 200%	Labour productivity
		Artificial-intelligence-powered optical inspection	▼ 92%	Manual inspection
		Predictive maintenance aggregating historical and sensor data	▲ 17%	Overall equipment effectiveness
		IoT-enabled manufacturing quality management	▼ 99%	Quality alert time
		Production planning optimized by advanced analytics	▼ 25%	Inventory
Henkel Montornès, Spain	To drive further improvements in productivity and boost the company's sustainability, Henkel built on its digital backbone to scale Fourth Industrial Revolution technologies linking its cyber and physical systems across the Montornès plant, reducing its costs by 15% and accelerating its time to market by 30% while improving its carbon footprint by 10%.	Energy optimization by predictive analytics	▼ 10%	CO_2 emissions
		Digital tools to enhance a connected workforce	▼ 20%	Changeover time
		Artificial-intelligence-powered process control	▼ 20%	Unscheduled downtime
		Robotics-enabled logistics execution	▼ 16%	Inventory
		Digital track and trace	▲ 30%	Speed to market
HP Inc. Singapore	Facing an increase in product complexity and labour shortages leading to quality and cost challenges, along with a move at the country level to focus on higher-value manufacturing, HP Singapore embarked on its Fourth Industrial Revolution journey to transform its factory from being manual, labour-intensive and reactive to being highly digitized, automated and driven by artificial intelligence, improving its manufacturing costs by 20%, and its productivity and quality by 70%.	Automated in-line optical inspection	▲ 70%	Labour efficiency
		Collaborative robotics and automation	▼ 10%	Manufacturing cost
		Real-time asset performance monitoring and visualization	▼ 10%	Reduction in yield loss
		Analytics platform for remote production optimization	▲ 70%	Outgoing quality
		Additive manufacturing (3D printing)	▼ 40%	Lead time
Johnson & Johnson Consumer Health Helsingborg, Sweden	In a highly regulated healthcare and fast-moving consumer goods environment, J&J Consumer Health addressed customer needs through increased agility using digital twins, robotics and high-tech tracking and tracing to enable 7% product volume growth, with 25% accelerated time to market and 20% cost of goods sold reduction. It made further investments in connecting green tech through Fourth Industrial Revolution technologies to become Johnson & Johnson's first ever CO_2-neutral facility.	3D simulations/digital twin for product design and testing	▲ 25%	Speed to market
		Collaborative robotics and automation	▲ 16%	Gross profit improvement
		Sensor-based data collection for energy management	▼ 18%	CO_2 emissions
		Digital track and trace	▼ 15%	Cost of goods sold
		Digitally enabled batch release	▼ 90%	Labour cost
Midea Shunde, China	To expand its e-commerce presence and overseas market share, Midea invested in digital procurement, flexible automation, digital quality, smart logistics and digital sales to improve product cost by 6%, order lead times by 56% and CO_2 emissions by 9.6%.	Agile buying through price prediction	▼ 5%	Raw material cost
		Robotics-enabled logistics execution	▼ 53%	Lead time
		Artificial-intelligence-powered optical inspection	▼ 15%	Customer complaints
		Lights-off logistics	▲ 40%	Loading efficiency
		End-to-end real-time supply chain visibility platform	▼ 40%	Channel inventory
Procter & Gamble Amiens, France	P&G Amiens, a plant with a steady history of transforming operations to manufacture new products, embraced Fourth Industrial Revolution technologies to accommodate a consistent volume increase of 30% over three years through digital twin technology as well as digital operations management and warehouse optimization, leading to 6% lower inventory levels, 10% improvement in overall equipment effectiveness, and 40% scrap waste reduction.	Digital twin for remote production optimization	▼ 6%	Inventory
		Connecting machine-level data with enterprise software	▼ 30%	Customer complaints
		Analytics for dynamic warehouse resource planning	▲ 9.8%	On-time delivery
		Digital engineering	▲ 25%	Capacity
		Advanced analytics to optimize logistics	▼ 40%	Packaging materials

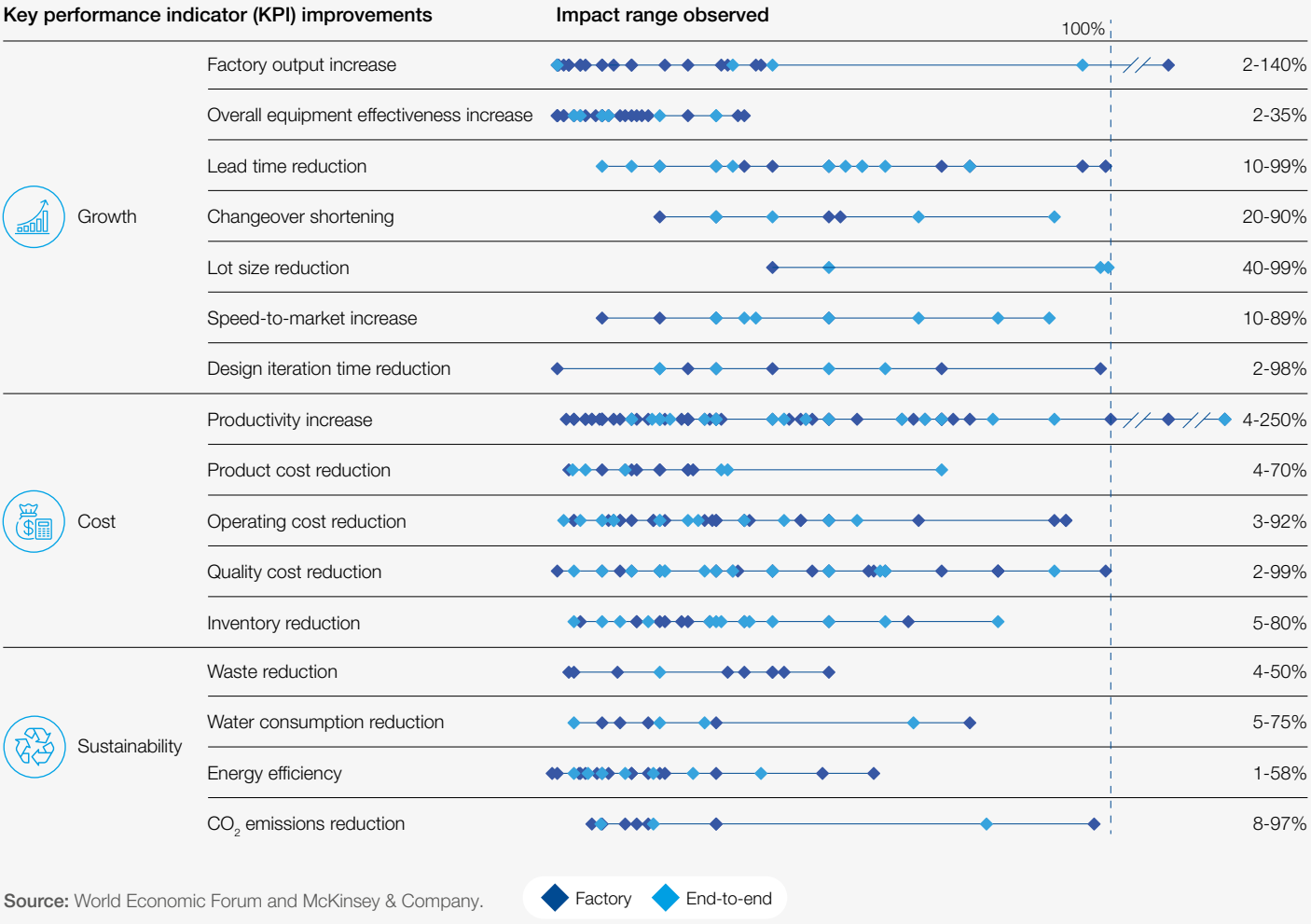
Site	Change story	Use case	Impact	
Procter & Gamble Lima, USA	A shift in consumer trends meant more complex packaging and an increased number of products that had to be outsourced. To reverse the tide, P&G Lima invested in supply chain flexibility, leveraging digital twins, advanced analytics and robotic automation, resulting in an acceleration of speed-to-market for new products by a factor 10, an increase in labour productivity by 5% year over year, and in plant performance that was two times better than competitors in avoiding stock outs during the year.	Digital twin for flexible production	▲ 900%	Speed to market
		3D simulations/digital twin for product design and testing	▼ 70%	Product development
		Robotics-enabled logistics execution	▲ 100%	Productivity
		Production planning optimized by advanced analytics	▲ 95%	Demand/supply sync
		Robotics-enabled logistics execution	▼ 50%	Plant-to-warehouse costs
ReNew Power Hubli, India	Facing exponential asset growth and rising competitiveness from new entrants, ReNew Power, India's largest renewables company, developed Fourth Industrial Revolution technologies, such as proprietary advanced analytics and machine learning solutions, to increase the yield of its wind and solar assets by 2.2%, reduce downtime by 31% without incurring any additional capital expenditure, and improve employee productivity by 31%.	Analytics platform for wind turbine optimization	▲ 1.35%	Yield
		Predictive maintenance for solar module	▼ 40%	Solar panel efficiency loss due to dust deposition
		Image analytics to detect defects	▼ 16%	Downtime
		Predictive maintenance for wind turbine	▼ 30%	Unplanned maintenance
		Analytics platform for solar plant optimization	▲ 0.10%	Yield
Siemens Amberg, Germany	To achieve its productivity goals, this site implemented a structured lean digital factory approach, deploying smart robotics, artificial-intelligence-powered process controls and predictive maintenance algorithms to achieve 140% factory output at double product complexity without an increase in electricity or a change in resources.	Robotics-enabled logistics execution	▲ 50%	Labour efficiency
		Digital engineering	▼ 30%	Engineering effort
		Artificial-intelligence-powered process control	▲ 20%	Work-in-progress
		Predictive maintenance aggregating historical and sensor data	▲ 13%	Overall equipment effectiveness
		Analytics platform for remote quality optimization	▲ 13%	Process quality improvement
STAR Refinery Izmir, Turkey	To maintain a competitive edge within the European refinery industry, Izmir STAR Refinery was designed and built to be "the technologically most advanced refinery in the world". Leveraging more than $70 million investments in advanced technologies (e.g. asset digital performance management, digital twin, machine learning) and organizational capabilities, STAR was able to increase diesel and jet yield by 10% while reducing maintenance costs by 20%.	Connecting machine-level data with enterprise software	▲ 67%	Workforce efficiency
		Real-time asset performance monitoring and visualization	▲ 2%	Overall equipment effectiveness
		Digital twin for production optimization	▲ 23%	Light catalytic gas oil yield
		Digital twin of sustainability	▼ 3%	Annual tons CO_2
		Analytics platform for remote production optimization	▲ 2%	Diesel yield
Tata Steel Jamshedpur, India	Facing operational KPI stagnation and an impending loss of captive raw material advantage, Tata Steel Jamshedpur's 110-year-old plant with deeply rooted cultural and technology legacies deployed multiple Fourth Industrial Revolution technologies, such as machine learning and advanced analytics in procurement to save 4% on raw material costs, and prescriptive analytics in production and logistics planning to reduce the cost of serving customers by 21%.	Agile buying through price prediction	▼ 4%	Procurement cost
		Digitally enabled negotiations	▲ 20%	Full-time equivalent productivity
		Production planning optimized by advanced analytics	▼ 21%	Cost to serve
		Artificial-intelligence-guided machine performance optimization	▼ 50%	Fugitive emissions
		IoT-enabled safety management	100%	Workforce safety coverage
Tsingtao Brewery Qingdao, China	Facing growing consumer expectations for personalized, differentiated and diverse beers, Tsingtao Brewery rethought its use of smart digital technologies across its value chain to enable its 118-year-old factory to meet consumer needs, reducing customized order and new product development lead times by 50%. As a result, it increased its share of customized beers to 33% and revenue by 14%.	Mass customization and business-to-consumer online ordering	▼ 99.5%	Minimum order size
		Digital-enabled flexible manufacturing	▼ 50%	Lead time
		Predictive demand forecasting	▲ 6%	Overall equipment effectiveness
		Big data/artificial-intelligence-enabled product design and testing	▼ 50%	R&D cycle time
		Digital tracking and tracing	▲ 29%	Material reuse
Wistron Kunshan, China	In response to high-mix and low-volume business challenges, Wistron leveraged artificial intelligence, IoT and flexible automation technologies to improve labour, asset and energy productivity, not only in production and logistics, but also in supplier management, as a result improving its manufacturing costs by 26%, while reducing its energy consumption by 49%.	Full robotics-enabled logistics integration	▼ 20%	Whole pipeline stock level
		Digital tools to enhance a connected workforce	▲ 15%	Line balance optimization
		Digital supplier performance management	▲ 63%	Material handling efficiency
		Digital dashboards to monitor overall equipment effectiveness performance	▲ 5%	Overall equipment effectiveness
		Energy optimization by predictive analytics	▼ 49%	Energy consumption

Source: World Economic Forum and McKinsey & Company.

1.3 Lighthouses are role models, driving impact beyond productivity

A detailed look at the successful lighthouse cases reveals that the organizations achieving growth from investments in technology are also realizing improvements in other areas (Figure 6). They report increases in factory output and overall equipment effectiveness (OEE), as well as decreases in product costs, operating costs and quality costs. Regarding their sustainability, the leaders realize reductions in CO_2 emissions, waste and water consumption, and improvements in energy efficiency. Their greater agility leads to inventory and lead time reductions and to changeover shortening; accordingly, both speed-to-market and design iteration accelerate. Finally, customization initiatives result in lot size reduction.

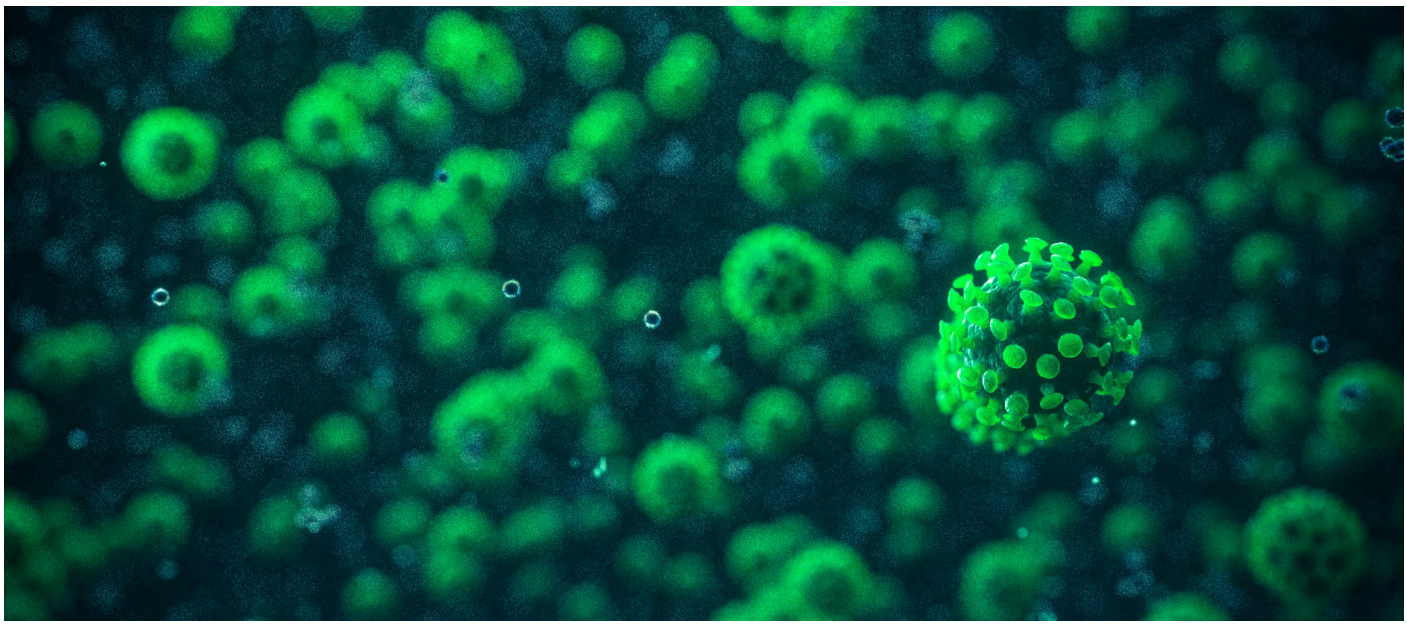
FIGURE 6 **Lighthouses: Going beyond productivity and building more agile and customer-focused organizations**



Source: World Economic Forum and McKinsey & Company.

2 Global disruptions trigger unique growth opportunities

The past year's shocks to global markets due to the health crisis have imposed massive disruption. While the challenges are many and struggles abound, it is nonetheless true that these changes to the status quo present tremendous opportunities to grow and gain market share. Companies across the industrial landscape willing to take decisive action can capitalize on this moment, and manufacturers are no exception. The time is now to achieve not only quantitative but also qualitative growth, such as raising the bar for customer experiences and increasing capabilities to react with agility to a dynamic market.



2.1 Aftershocks will continue to resonate

Market uncertainty will remain high. This variability will continue to be present in demand, supply and customer expectations. Remaining competitive demands speed and adaptability; companies must find pathways to extend value. To do this, they need scalable technology and flexible production systems.

Consumption spikes have led to unexpected demand. This in turn strains production lines as companies try to keep up. Managing these spikes requires nimbleness afforded by quality data analytics. Without the transparency provided by accurate, timely data and analysis, manufacturers will tend to be reactionary and lagging in their decisions while pressure is imposed on inventory management. Meanwhile, pre-pandemic supply chains struggle to provide raw materials, resulting in supply fluctuations that affect finished goods inventories. All of this stress exists in a marketplace where consumers have many options, gravitate towards customization and expect consistently high levels of service.

2.2 Lighthouses show the way ahead

Digital innovation is no longer optional. Companies that achieve 4IR innovation at scale – those with the capability and agility to adapt – are positioned to thrive under these changing, high-pressure conditions, while others fall further behind, widening the gap between frontrunners and the rest. Lighthouses have made the courageous decisions to engage the full power and potential of the 4IR. This enables them to act on the opportunity that disruption presents, and fuel the growth that sets them apart.

Thriving companies have engaged scalable technology that supports business goals, which is now a requirement to become an industry-leading digital organization. Their reimagination of operations is leading to a return on their investment in resilience as they find themselves capable of matching supply to demand amid continued system shocks. Some are stepping into the void left behind by other companies that disappoint customers or that bear the burden of immense inventory costs.

3 Lighthouses drive sustainable growth

“Lighthouses are demonstrating how digitally infused operations go beyond productivity improvements to create sustainable, profitable growth.

Lighthouses are demonstrating how digitally infused operations go beyond productivity improvements to create sustainable, profitable growth. To be sure, the productivity gains are there, resulting from digital machines and management applications driving output increases at the factory level. Looking past productivity, two ways to drive growth stand out: by adopting new business models and unlocking capacity in the people and production processes.

New business models

By deploying 4IR technologies at scale (Figure 7), lighthouses are creating new revenue streams through new business models. Their flexible production systems allow customizable product development informed by a better understanding of customer demands. Put simply, these companies are more in touch with what their customers want, even as these desires change – and they have built the capability to respond rapidly and gain market share in the void left by others that cannot.

Alibaba Xunxi’s sophisticated consumer intelligence system couples with an array of digital tools to deliver efficient, highly customizable design and production, reducing the minimum order quantity by 98% (compared to the industry average). Tsingtao Brewery has used digital tools to enable consumers to order small amounts of highly customized products, and to reduce new product development lead time by half while boosting revenues. Meanwhile, Johnson & Johnson Vision Care has created a hyper-personalized E2E user experience through mobile- and web-based platform applications that connects patients to professional, retailer and manufacturer and leverages advanced analytics to customize orders, resulting in a double-digit new customer conversion rate.

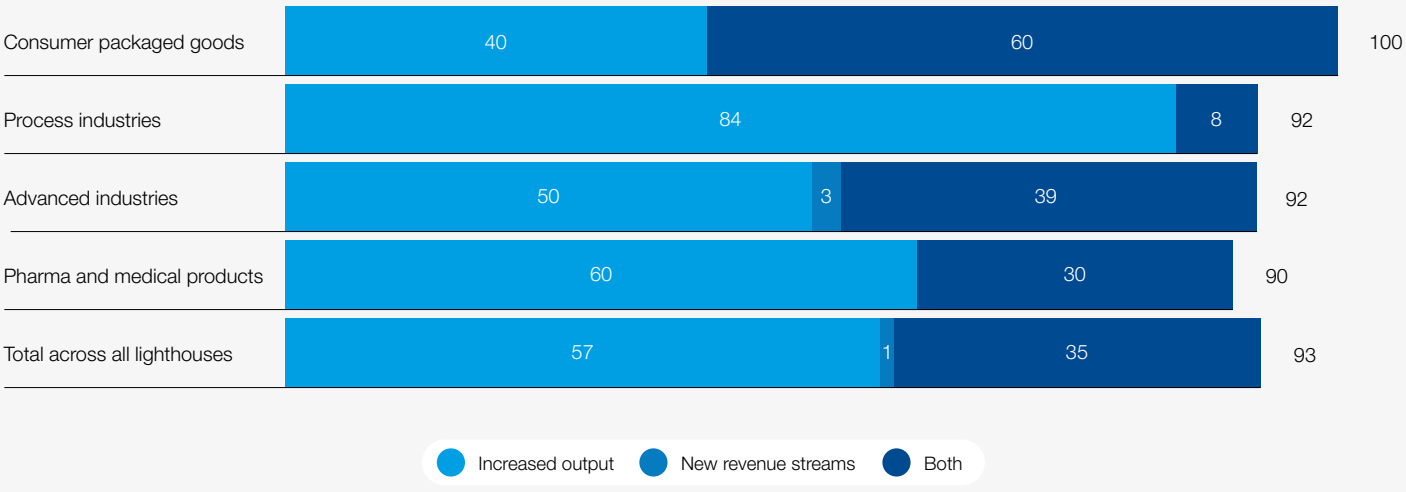
Unlocking capacity

Lighthouses are unlocking capacity to drive growth and profitability as every additional throughput accessed by 4IR technologies contributes to what can be produced and sold. These measures optimize resources and infrastructure while enabling workers to realize their potential equipped with powerful digital applications – all without massive capital investment or negative environmental impact.

Novo Nordisk has coupled digital scheduling and work-management apps with production line optimization, automated OEE monitoring and digital performance management to release capacity. At Bosch, digital shift performance management and a digitally enabled automatic material call-off system, along with cycle time and changeover optimization powered by machine vision, have improved worker and machine capacity while boosting quality and reducing costs. Procter & Gamble has used digital twins and advanced analytics at its Lima, USA site to increase speed to market tenfold.

FIGURE 7 **Lighthouses: Boosting growth with little or no capital**

Lighthouses using Fourth Industrial Revolution technologies to enable growth
% of lighthouses citing growth-related KPIs



Source: World Economic Forum and McKinsey & Company.

3.1 Innovating business models

Leading organizations have realized that they cannot continue to do things in the same old ways. They recognize the imperative to respond to changing customer demands for customized products, even in the face of market disruptions. To achieve this, they have prioritized the innovation of business models that leverage the power of the 4IR. Among the greatest advantages this affords them is heightened transparency into buying behaviours and customer choice. By keeping up-to-date insights on dynamic and individual customer preferences, they know what they need to do to remain – or become – the company of choice. They realize the importance of having mass-customization capability, and they are innovating business models that make best use of resources to deliver tailored products to market at unprecedented speeds.

Tsingtao Brewery leverages 4IR technology to innovate new business models to drive growth

Tsingtao Brewery is China's second-largest brewery and the sixth largest in the world. Facing consumer demand for diverse, personalized types of beer, Tsingtao has engaged new business models and smart digital technology across the value chain to optimize customer engagement, product development, production and distribution (Figure 8).

By capturing customer preferences accurately, Tsingtao enables personalized marketing. The company has presented the first online customization platform in the industry, enabling customized packaging for business-to-business or business-to-consumer sales channels. It achieves tailored product development that targets the main drivers of product popularity, generating a detailed "fingerprint" for each product to inform product development based on demand.

The flexible production model, coupled with automatic quality management, allows immediate and small-batch production with rapid, flexible response capabilities. Optimized supply chain planning and best-in-class supply chain analytics engines reduce distribution inefficiencies and shorten lead times. Artificial-intelligence-powered E2E planning allows Tsingtao to meet customer demands quickly and efficiently.

Through digital-enabled flexible manufacturing, the company cuts lead time and production scheduling time. More accurate demand forecasting reduces product change and increases OEE. Mass customization and business-to-consumer online ordering has cut the minimum order size by 99.5%. By improving its ability to know and respond to customer preferences, Tsingtao has experienced genuine growth and improved brand preference.

FIGURE 8 | **Tsingtao Brewery: Leveraging Fourth Industrial Revolution technology to innovate business models and drive growth**

In an age of new normal in the industry and in view of upgraded consumer needs for personalized, differentiated and diverse beer, Tsingtao Brewery has rethought how to use smart digital technologies across the value chain to empower the 117-year-old company to meet consumer needs.

Customer engagement
Accurate capture of customer preferences allowing for personalized marketing and customization

Package tailoring
First online customization platform in the industry, providing customized packaging for B2B or B2C sales channels

Product development
Tailored development of products targeting main drivers of product popularity

Granular product profiling
Exact fingerprint for each product to identify taste elements that drive demand to guide the development of new products

Production
Immediate and small-batch production with rapid and flexible response capabilities

Flexible production model
Highly flexible production lines allowing the production of multiple products in one line

Automatic quality management
End-to-end automatized quality monitoring, from the sourcing of raw materials to the distribution of the finished product

Distribution
End-to-end planning using AI technologies to meet customer demands quickly and efficiently

Optimized supply chain planning
Reduced distribution inefficiencies and shortened lead times that leverage best-in-class supply chain analytics engines

Case study: Tsingtao Brewery

Impact

56% decrease in lead time

50% decrease in production scheduling time

20% increase in demand forecasting accuracy

70% reduction in product change

37% increase in brand preference

Source: World Economic Forum and McKinsey & Company.

3.2 Unlocking capacity

Lighthouses are achieving growth and higher productivity by unlocking capacity through 4IR technologies and, notably, are doing so with little to no capital expenditure. In years past, achieving measurable growth required substantial investment in physical facility expansion and infrastructure. There is an alternative route: coupling state-of-the-art digital tools with flexible production systems. Leading companies are discovering new ways to achieve growth without a larger footprint.

Novo Nordisk's deployment of 4IR technologies unlocked capacity through overall equipment effectiveness improvements

Novo Nordisk has unlocked capacity through OEE improvements afforded by the deployment of 4IR technology (Figure 9). The Hillerød site has set an example for the rest of the company's internal and external production network. Advanced analytics, best-in-class data engineering and applications to address daily shop-floor operations power this optimization.

Digital systems help optimize performance management. An OEE data collection system records and categorizes every type of performance loss with minimal human intervention. Meanwhile, equipment connectivity and digital performance boards provide workers with real-time data. Downtime is reduced by automated testing of settings, while machine-learning-powered systems predict the most efficient settings, track changes and provide analysis.

Granular planning made possible through real-time tracking enhances scheduling, and the interpolation of machines, operators and technicians generates an optimized production schedule. This affords the optimal allocation and scheduling of assets and resources, avoiding buffers in planned asset uptime. It also provides real-time tracking of production progress, and offers alerts in case of deviations. With front-line employees directly involved in the development of digital applications, the true power of 4IR technology to enhance the work experience becomes apparent.

The 4IR transformation has had a wide reach, linking three data platforms across 10 information technology (IT) systems. Impacts include line OEE improvement, reduced unplanned downtime and increased people efficiency. It has also led to new digital jobs.

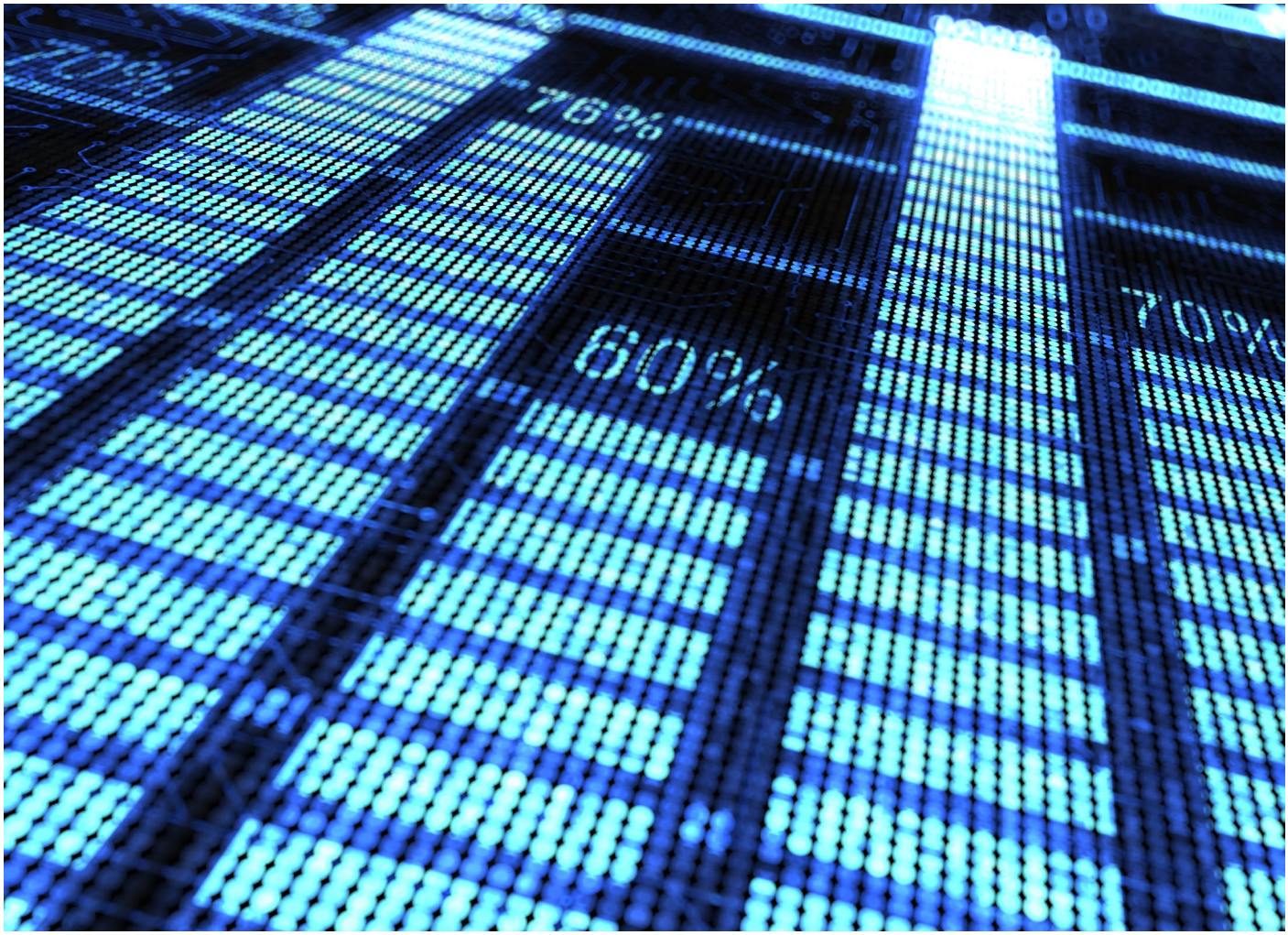


FIGURE 9 | **Novo Nordisk: Deploying Fourth Industrial Revolution technologies that unlocked capacity through overall equipment effectiveness improvements**

Novo Nordisk's Hillerød site set an example for its production network by unlocking capacity through Fourth Industrial Revolution technologies. Production-line optimization leveraging advanced analytics, best-in-class data engineering and specialized shop-floor apps – all coupled with a digital performance management system – enabled real-time decision-making across the production network.

Creation of a digital hourly production schedule based on the fastest repeatable cycle time:

- Spans machines, operators, technicians
- Allows for dynamic updates and optimization
- Used for live tracking and next event visualization

Optimal allocation and scheduling avoids unnecessary buffers in planned asset uptime.

Real-time tracking of production progress notifies deviations to plan.

Advanced algorithms drove downtime reduction by testing out the effects of hundreds of adjustable settings on a manufacturing line

- Applying machine learning to create a statistical twin of each station and predict efficient combinations of settings for the stations
- Using an application to track changes to the machine settings, visualize the optimal set-points and analyse the root causes for changes to settings

- Implementation of an overall equipment effectiveness data collection system recording and categorizing every type of performance loss with as little human intervention as possible

- Set-up of digital performance boards and trend-based notification systems for supervisors and maintenance personnel, leveraging real-time line data through equipment connectivity

- Development by front-line employees of digital applications on mobile devices targeting daily management tasks, to record and effectively spot and address shop-floor issues

- High impact applications: shift handover, escalation, process confirmation, problem-solving, weekly pit stop, optimal machine settings

Case study: Novo Nordisk

Impact

10 p.p. improvement in overall line equipment effectiveness

40-85% decrease in unplanned downtime

10-20% increased people efficiency

>10 new roles mastering new digital and analytics capabilities

10+ IT systems, 3 data platforms linked across 10 different IT systems

Source: World Economic Forum and McKinsey & Company.

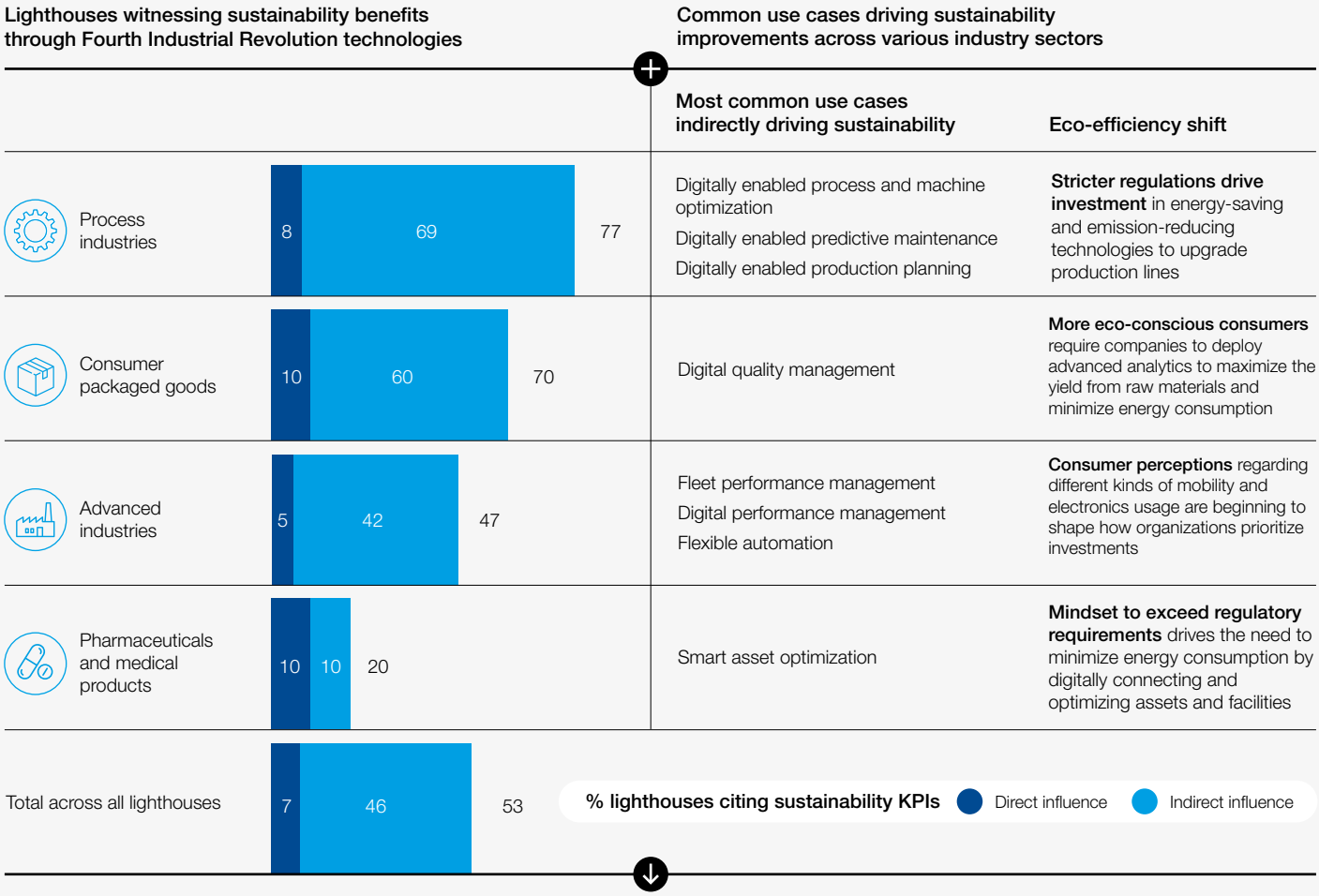
3.3 Realizing sustainable growth

Defying conventional wisdom that suggests environmental responsibility detracts from productivity and, by extension, profitability, leading companies are discovering that growth (including higher productivity) and eco-efficiency are compatible. In fact, measures yielding productivity improvements are actually driving resource efficiency gains tied to environmentally conscious impact. Companies discovering this compatibility and making the most of it are realizing dual benefits simultaneously: cost reduction and increased sustainability.

The majority of lighthouses drive sustainability through 4IR technologies (Figure 10). While much of the positive sustainability impact to date has resulted indirectly from 4IR transformations aimed at different goals, companies are increasingly focused on measures that aim for it explicitly, such as carbon and water usage reduction. This combination of indirect and direct impact points industry in a positive direction. Use cases such as digitally enabled process and machine optimization, predictive maintenance and production planning wil continue to improve eco-efficiency through resource optimization (eco-efficiency is one of the four durable shifts presented in the September 2020 White Paper entitled "Global Lighthouse Network: Four Durable Shifts for a Great Reset in Manufacturing"); meanwhile, emissions reduction efforts and other green-specific measures will lead to cleaner production.

FIGURE 10 **Productivity, growth and sustainability: Reducing resource utilization through Fourth Industrial Revolution efficiency gains**

53% of lighthouses are driving sustainability through Fourth Industrial Revolution technologies



Implications towards increased sustainability

Certain industry sectors, like process industries, have already done much to increase their operations' overall sustainability. This is due to the fact that many of their Fourth Industrial Revolution implementations focus on process improvements normally aimed at enhancing yield, energy and throughput.

Improving quality management in consumer packaged goods companies helps to reduce waste and therefore the overall environmental footprint.

Various fleet-performance- and direct-production-related measures have been shown to reduce resource usage by generally increasing efficiency.

Source: World Economic Forum and McKinsey & Company.

Henkel is scaling sustainability through its production network

Pursuing its commitment to achieve a 65% carbon footprint reduction by 2025 at its production sites and drive this goal within the industry, Henkel leveraged 4IR technology across peer networks (Figure 11). Its digital twin connects and benchmarks more than 30 factories worldwide, using hundreds of online efficiency systems and thousands of sensors to yield more than 1 million data points per day. This real-time data monitoring provides new benchmarking.

These programmes have direct sustainability effects. They digitized a high-energy laundry process (spray drying) by incorporating it into the digital twin and scaling it across the peer network. Likewise, a machine-learning-powered expert system extends benefits across the peer network by prescribing optimizing actions to operators.

Indirect impacts include "cradle-to-pantry" traceability to eliminate labels and support short innovation cycles, which has eliminated product obsolescence. Meanwhile, the digital twin tracks product data and prescribes sustainability and safety actions. Finally, shop-floor connectivity powers apps that reduce paper while supporting planning and monitoring from a distance.

Henkel built on its digital backbone to scale 4IR technologies linking cyber and physical systems across its Montornès plant, reducing its costs, accelerating its time to market and improving its carbon footprint. These efforts have also resulted in measurable impacts across operations, including reductions of waste production, total energy consumption, CO_2 usage and water usage.

FIGURE 11 | **Henkel: Using Fourth Industrial Revolution technology to drive sustainability impacts and reset internal benchmarks**

Following through on a commitment to reduce its carbon footprint by 65% by 2025 at its production sites and actively drive this within the industry, Henkel has leveraged Fourth Industrial Revolution technologies across peer networks and has re-baselined internal global benchmarks with real-time data access and feedback.

Digital twin

Connect and benchmark

>30 factories (all sites connected worldwide)

– 250 online efficiency systems
– 3,500 sensors deployed
– >1 million data points per day

Feedback + real-time data monitoring provide new **benchmarking across sites**

A cloud-based replica of the facility recreates operations and **prescribes sustainability and safety actions**

Energy optimization by predictive analytics

Digitizing high-energy process

High-energy laundry process (spray drying - the biggest single internal energy consumer) incorporated into a digital twin and scaled across the peer network

Machine learning leverages the peer network to prescribe actions to operators to emulate optimal actions/methods

Expert system identifies deviations from optimal operating point

Other use cases improving sustainability

Cradle-to-pantry traceability

2D matrix code eliminated labels and supported short innovation cycles to reduce product obsolescence to ZERO

Data link to digital twin tracks product data and prescribes sustainability and safety actions

Shop-floor connectivity

No-instruction-needed apps connected to digital twin, replacing paper and supporting planning and monitoring at a distance

Case study: Henkel

Impact

70% reduction of paper in shop-floor processes

35% reduction in total waste

16% reduction in total energy consumption

10% reduction in CO_2 usage

4% reduction in total water usage

Source: World Economic Forum and McKinsey & Company; Henkel Climate Protection Strategy and Targets.

Johnson & Johnson used 4IR technologies to close the last mile of carbon emissions reduction with a CO_2-neutral plant

Johnson & Johnson Consumer Health in Helsingborg, Sweden coupled advanced controls with green installations to cut energy consumption and become the company's first CO_2-neutral plant (Figure 12), earning government recognition.

Traditional green technology initiatives included updated hardware installations; likewise, the plant engaged in a shift to renewables through biogas sourcing, while prioritizing both municipal and supplier collaboration to support sustainability. To reach full decarbonization, 4IR initiatives beyond traditional green measures were essential. These had a direct as well as an indirect influence on the sustainability effort, showing how both innovative 4IR technology and 4IR-driven agile working modes can function in concert to achieve results.

Smart energy management integrated with automated systems and sensors, while production efficiency measures achieved higher productivity, improved speed to market, reduced labour cost and lowered resource consumption. Robotic applications improved OEE, and digital twin product development simplified the supply chain to reduce the cost of goods.

This approach reduced energy consumption, and nearly one-fifth of this reduction emerged directly from 4IR technologies. The plant achieved CO_2 neutrality, totally eliminating CO_2 emissions. This is down from 5,000 tons in 2010 to 0 in 2017, and it has sustained this figure since.

FIGURE 12 **Johnson & Johnson: Closing the last mile of its carbon reduction effort with Fourth Industrial Revolution technologies, leading to the plant being CO_2 neutral**

In an effort to reduce the environmental footprint of one of its largest self-care plants, Johnson & Johnson Consumer Health in Sweden leveraged Fourth Industrial Revolution technologies by pairing advanced controls with green installations in order to develop environmental sustainability and as a result achieve its first ever CO_2-neutral facility.

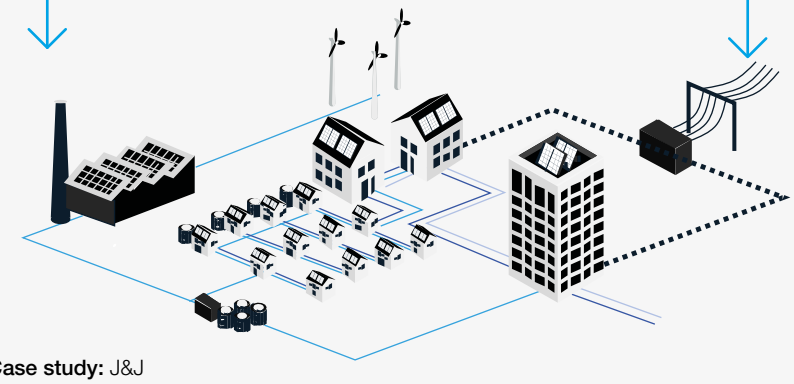
Traditional green tech initiatives

Updated hardware installations

- Ammonia-based and free cooling systems
- Heat recovery and efficiency systems
- LED lighting

Shift to renewables through biogas sourcing

Collaboration with municipality and suppliers to support sustainability efforts



Fourth Industrial Revolution tech enabling carbon neutrality

Direct influence: tackling carbon neutrality

- Smart energy management integrated with facility's automated system and sensors

Indirect influence: increased efficiency of production processes to produce more with less resources

- Robotic applications led to a 14% increase in overall equipment effectiveness
- Digital twin product development led to a 20% reduction in the cost of goods by simplifying the supply chain

Case study: J&J

Impact

25% reduced energy consumption

18% energy reduction directly from Fourth Industrial Revolution technologies

5,000 tons annual CO_2

reduced to **0** from 2010 to 2017

Source: World Economic Forum and McKinsey & Company.

4

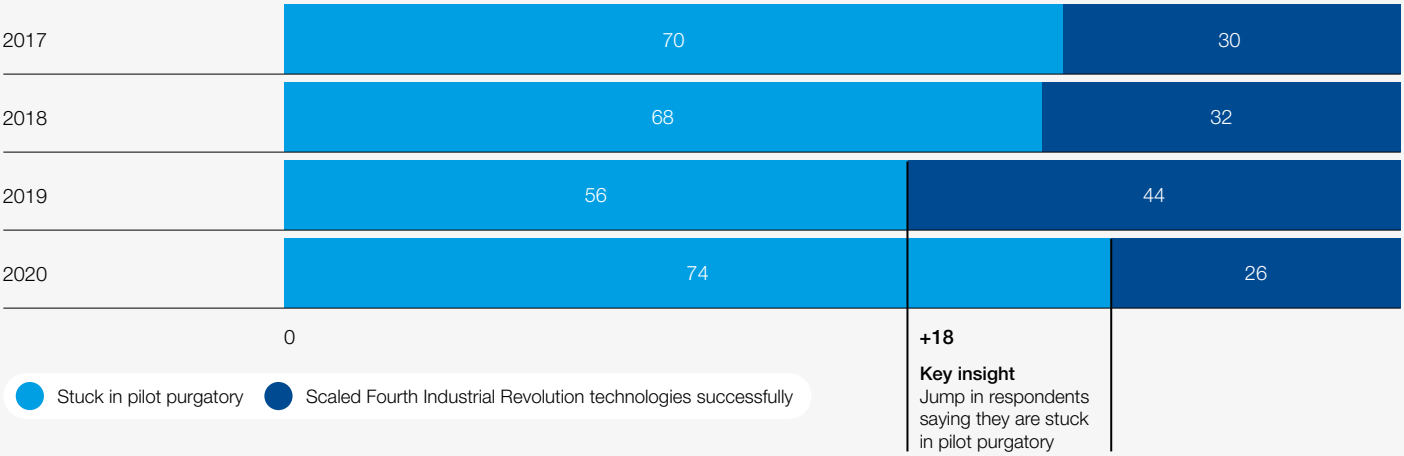
Taking Fourth Industrial Revolution innovations to scale

The growth lighthouses have achieved – both pre-pandemic and throughout a year of turbulence – makes clear that integrating 4IR innovations at scale is central to long-term growth. Among companies succeeding at this kind of growth, scaling is happening across the production network and value chains. The majority of organizations have yet to achieve this and, in fact, in the 2020 McKinsey & Company survey of global manufacturers, the percentage of companies that report a situation of "pilot purgatory" has risen sharply to 74% in 2020 (Figure 13).

The truth is, what it means to scale has "re-baselined", and it has proven to be more difficult than initially thought. Market disruptions and upheavals have precipitated difficult reckonings as industrials have had their investments pressure-tested, and a new understanding of scale has emerged from the realization that they did not scale as much as they thought. So how have the leaders in that successful 26% escaped this stasis and scaled successfully, even amid new levels of disruption? The secret lies with two key elements: agility and workforce development.

FIGURE 13 **Scaling Fourth Industrial Revolution technologies (2017-2020): Now tougher than initially thought**

Survey Question
% of respondents saying they had successfully deployed multiple Fourth Industrial Revolution use cases across multiple locations (n = 402)



Being stuck in pilot purgatory is a more common feeling in 2020

The 3-year trend showing Fourth Industrial Revolution technology is scaling reversed in 2020.

Industrials have had their investments pressure-tested and as a result have realized they did not scale as much as they thought.

Source: McKinsey & Company, Annual Industry 4.0 survey of global manufacturing.

Agile ways of working are at the heart of successful scaling. In order for 4IR advances to reach their potential across the production network and value chains, companies must build on agile principles to innovate and transform in an iterative manner. This means they can collaborate and manage change continuously – enabling them to anticipate technical limitations and move quickly to surpass them. Lighthouses are able to iterate quickly, fail fast and learn continuously. This plays out in the creation of minimum viable products (MVPs) in two-week sprints. Likewise, it allows for bundled use cases that facilitate rapid transformations in several waves of a few months each. This agile mode is a radical departure from older models involving year-long pilots aspiring for perfection, wherein continued technological innovation can render the completed pilots irrelevant by the time they are finished.

Of course, agile ways of working reach their full potential only with a skilled, 4IR-ready workforce. The adoption of 4IR technologies has introduced many changes to the tasks workers undertake, and companies do well when they understand the importance of keeping human workers at the centre of their transformation. Strategies like tiered pathways for upskilling ensure workers remain connected, integrated and directly involved in transformations – moreover, they equip workers with the expertise needed to contribute to future innovation.

4.1 Embracing agility to scale

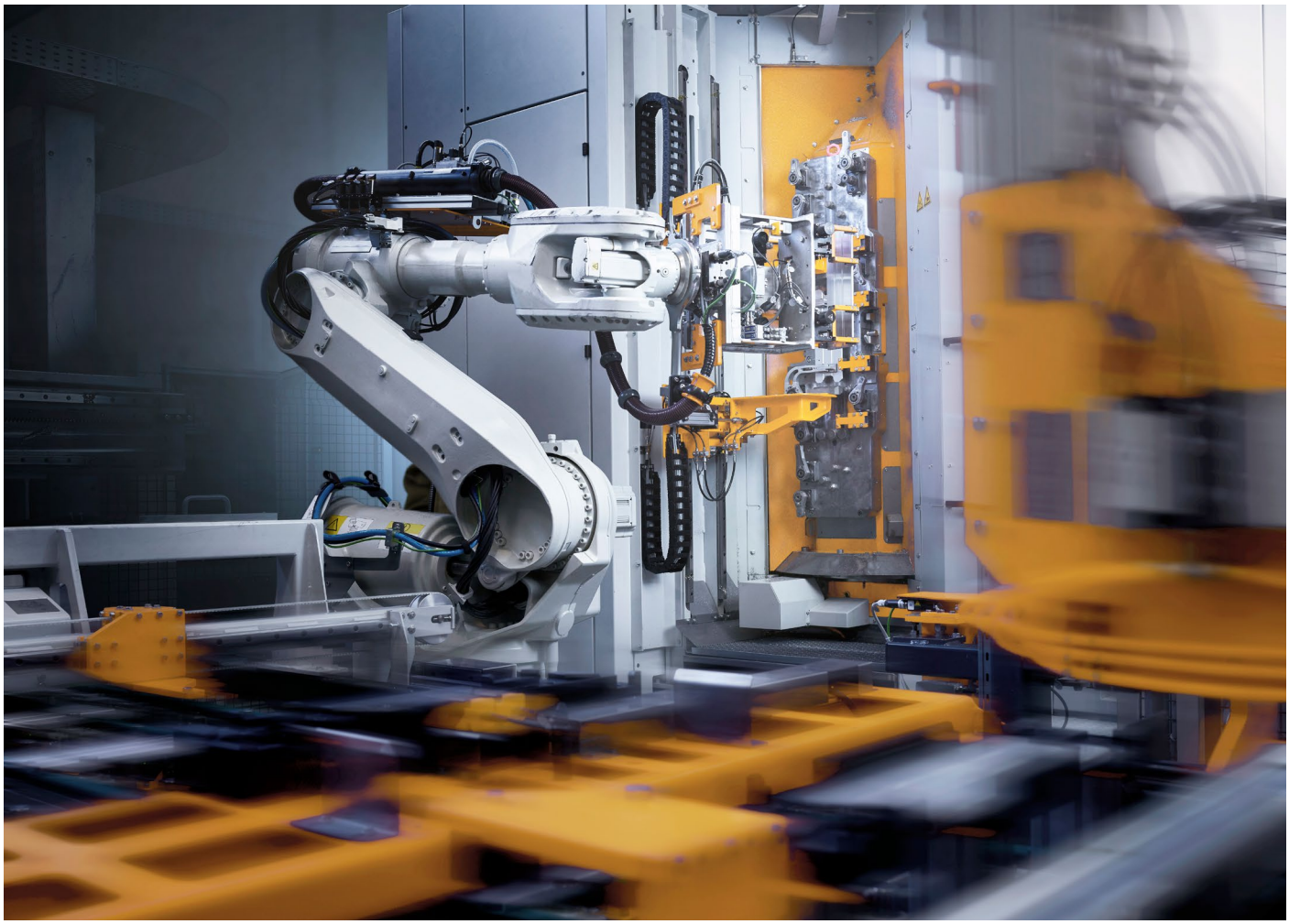
By fully embracing agile working modes, leading companies have been able to unlock new levels of growth and sustainability as they scale 4IR solutions quickly across their production networks and value chains (Figure 14). Lighthouses have made room for innovative thinking and dynamic approaches by prioritizing flexibility and adaptability in their operations. As a result, they are able to remain closely attuned to shifts in supply, demand and customer expectations.

This growth is extending beyond individual sites across the production network and value chains. There is evidence of this in the more than fourfold increase in lighthouse sites from companies that boast multiple lighthouse sites, from just nine in 2018 to 36 in 2021.These firms are reimagining themselves – and by extension their industries – across production networks and supply chains.

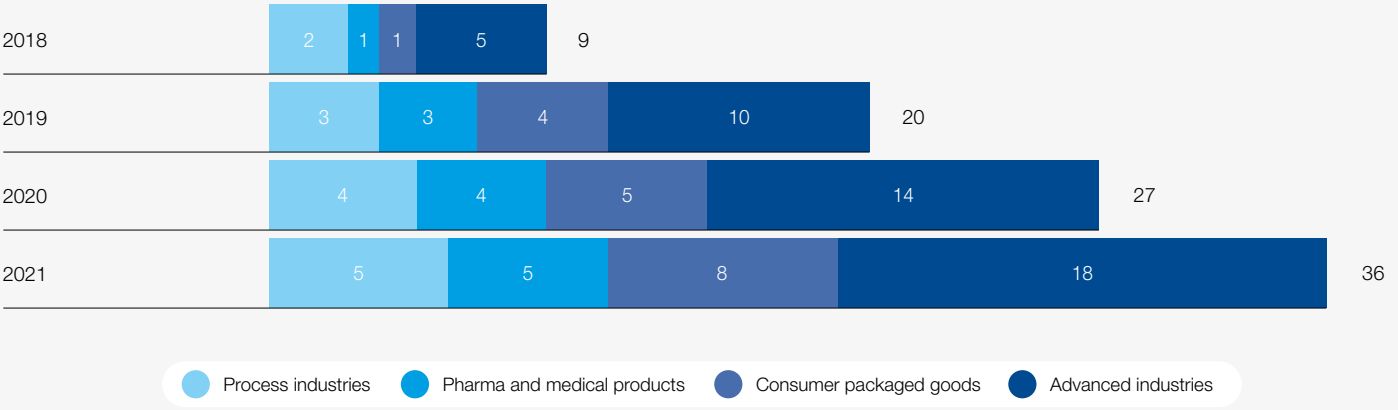
By developing transparency of capabilities and capacity across the network, along with dynamic network scenario planning, leading organizations are able to prepare for shifts in demand driven by rapidly changing customer preferences. They can introduce new product categories and achieve high levels of customization. Likewise, this equips them to respond to unexpected disruptions related to supply issues, distribution channels or facility closures. Agility is a hallmark across the organization – it permits speed and flexibility without loss of quality.

Lighthouses are also prioritizing better transparency and traceability across the network. By leveraging common data models across the value chain, they are able to manage production and supply chains to meet their sustainability commitments while giving consumers insights into product origins, composition and CO_2 footprint. These enable customers to make conscious buying decisions.

Finally, by scaling digital solutions and capabilities rapidly across their sites, companies that rely generally on dispersed manufacturing networks are able to implement technologies that would not have a positive return on investment at any single site. This also permits unlocking production bottlenecks across the network faster, and increasing productivity at individual sites. These companies empower themselves through the smart and coordinated dissemination of 4IR technology and working modes – thus each site's strength and agility is effectively enhanced by the strength and agility of the others.



Lighthouses associated with a company that boasts more than two sites in the Global Lighthouse Network
2018-2021



Source: World Economic Forum and McKinsey & Company.

Main ways companies are reimagining themselves across production networks and supply chains	Key benefits derived
The transparency of capabilities, capacity across the network and dynamic network scenario planning improve companies' ability to…	…prepare for demand and mix shifts driven by rapidly changing customer preferences (e.g. new product categories, far-reaching customization) …respond to supply chain disruptions and unplanned events (e.g. plant closures, distribution channel disruption, supply issues)
Better transparency and traceability across the network (e.g. by leveraging common data models across the value chain) allow companies to…	…manage production and supply chains to achieve sustainability commitments …give consumers visibility on product origin, composition, CO_2 footprint, etc., to help them make conscious buying decisions
Scaling digital solutions and capabilities rapidly across the sites enables companies that usually have dispersed manufacturing networks to implement technologies that would not have a positive return on investment on one site level and…	…unlock production bottlenecks across the network faster (e.g. to address shifts in demand) …capture further productivity gains at individual sites

Ericsson used an agile working approach to deliver fast value: Three use cases in 16 weeks

Aiming to serve local 5G radio customers sustainably with production close to its consumers (Figure 15), Ericsson built a greenfield 5G-enabled digital native factory in the United States in record time. With agile working methods and a robust industrial internet of things (IIoT) architecture and data foundations, the team succeeded in deploying 25 use cases within 12 months, including three use cases in 16 weeks. The company identified more than 80 digital use cases to transform E2E operations, then built the strategy to develop or procure them. They made quick design iterations with a use-case-bundling roadmap, instituted a pattern of rapid feedback with the IIoT vendor, and paced the work into six sprints.

Ericsson rolled out seven use cases at the MVP stage. They defined early on what would need to be built or acquired to manage the roll-out, and worked with the IIoT vendor on upskilling development combined with problem-solving and design workshops. The company enhanced the architecture to support new waves of use cases, which they continually deployed with smaller pools of team members. These measures improved output per employee and reduced manual material handling, while integrated environmental systems reduced energy consumption, water usage and CO_2 emissions.

FIGURE 15 **Ericsson: Using an agile working approach to deliver fast value – 3 use cases in 16 weeks**

To serve local 5G radio customers sustainably, Ericsson built a greenfield 5G-enabled digital native factory in the US in record time. With agile working methods and a robust IIoT architecture and data foundations, the team deployed 25 use cases at scale in 12 months.

Bundling of use cases

Identified 80 digital use cases to transform end-to-end operations

Built the strategy to develop or procure all the use cases

Quick design iterations

Prepared a roadmap detailing 25 use cases to develop in the first 12 months

Instituted a rapid feedback mechanism with the IIoT vendor

Divided the work into six sprints based on dependencies and interim deliverables

Minimum viable product implementation

Rolled out 7 use cases at the minimum viable product stage

Defined early what was to be built or bought to manage the roll-out

Upskilled development with the vendor, combined with problem-solving and design workshops

Scale-up

Enhanced the architecture to support new waves of use cases

Continually deployed use cases with a smaller pool of team members

Case study: Ericsson

Impact

Delivered 3 use cases in 16 weeks

25 use cases in 1 year

120% increase in output per full-time equivalent

75% reduction in lead time

50% reduction in inventory

Source: World Economic Forum and McKinsey & Company.

Schneider Electric scaled up 4IR use cases across five sites spanning the globe

Schneider Electric began deploying its 4IR strategy across five sites in 2017 and is currently scaling to more than 80 interconnected sites (Figure 16). Three current lighthouse sites and two scale-up sites collectively exhibit a number of functional-level digital use cases. A digital transformation office engages both internal and external talent with an agile working mode to deliver a transformation roadmap for the entire organization, facilitating the prioritization and development of use cases across the operating network. This offers the company a key enabler: a top-down 4IR global digital strategy.

The rapid horizontal deployment of the 4IR strategy is empowered by standard IT/operational technology (OT) platforms, which help avoid delays and bottlenecks in the dispersal of the digital strategy, while providing the transformation roadmap. Workforce development is a key element of nearly all 4IR innovations; thus, Schneider has formed a Digital Academy focused on capability building. By deploying this organization-wide transformation at every level, from infrastructure and technology to operating modes and upskilling, Schneider has engaged everyone in the company in the 4IR journey. The company has also improved labour productivity and customer on-time in-full delivery while reducing scrap cost, CO_2 emissions and total energy consumption.

FIGURE 16 **Schneider Electric: Deploying Fourth Industrial Revolution technologies across 80+ interconnected sites (from 5 sites in 2017)**

Schneider has scaled Fourth Industrial Revolution technologies by applying an approach that initially established digital lighthouse sites to fuel the transformation across its wider network.

Key enablers for scaling

– Digital transformation office with co-located internal and external talent, paired with an agile way of working to deliver:
  - The prioritization and development of use cases across the network operating model
  - A transformation roadmap
– Top-down global digital strategy (tailored, sustainable, connected)
– Digital Academy for capability building and development
– Standard IT/operational technology (OT) platforms for faster horizontal deployment
– Compelling change story to engage shop floor to top floor

	Lighthouse			Scale-up sites	
Functional-level use cases	Batam, Indonesia	Le Vaudreuil, France	Lexington, USA	Wuhan, China	Monterrey, Mexico
End-to-end planning and scheduling		✓	✓	✓	
Digital performance management	✓	✓	✓	✓	✓
Digital/analytics energy management		✓	✓	✓	✓
Digital maintenance and scrap reduction	✓	✓	✓		
Automation and augmented operator		✓		✓	✓

Case study: Schneider Electric

Impact

40% reduction in scrap cost

25-40% increase in customer on-time in-full delivery

10-26% reduction in total energy consumption

40-78% reduction in CO_2 usage

75% increase in labour productivity

Source: World Economic Forum and McKinsey & Company.

4.2 Investing in workforce development

Lighthouse organizations place a high premium on workforce development because they know it is vital to engaging agile working modes and maximizing the power of digital transformation.

Lighthouse organizations place a high premium on workforce development because they know it is vital to engaging agile working modes and maximizing the power of digital transformation. Training, reskilling and upskilling keeps their workforces prepared and optimized in a 4IR environment. By keeping people at the centre of their 4IR transformation with a focus on inclusive growth, they enable people at every level of the company to take part in building the innovative, creative future at the heart of the 4IR's reimagined industry. Scaling is a team effort, and people are the team.

Siemens developed a 4IR skill roadmap matched to job profiles

To reach productivity goals, Siemens in Amberg, Germany initiated a lean digital factory approach; factory output increased 140% despite product complexity that doubled. It did so without an increase in electricity usage or a change in resources. Amid these productivity gains, Siemens applied an upskilling programme based on development tailored to individual workers.

Robotics-enabled logistics execution improved labour efficiency, while digital engineering rationalized efforts and artificial-intelligence-powered process controls boosted work in progress. A predictive maintenance system improved OEE, and an analytics platform for remote quality optimization raised process quality. Aware that new capabilities are essential to maximize the potential of the 4IR, Siemens matches individual job profiles to a 4IR skill roadmap that lays out a tailored upskilling path for each (Figure 17). Like HP Inc. (described below), Siemens engages in university partnerships, internal learning and targeted training to achieve its upskilling goals.

HP Inc. used 4IR optimization to create worker upskilling opportunities and shift tasks

HP Inc. Singapore's 4IR journey focused on workforce upskilling. As increasing product complexity met labour shortages, it faced quality and cost challenges. Moreover, it wished to embrace a national movement towards higher-value work. As a response, HP Inc. shifted from labour-intensive, reactive, manual work to highly digitized, automated work. This reduced its manufacturing costs while boosting both productivity and quality.

Because 4IR optimization has freed up considerable task responsibilities, it has offered new space and opportunity for upskilling (Figure 17). For example, operators become techno-operators, able to take on more complex tasks that were formerly delegated to technical specialists, and the chain of task-shifting continues. Like Siemens, HP Inc. has achieved this transformation through a combination of university partnerships, internal learning and targeted training.

As a consequence of a new way of working introduced by the Fourth Industrial Revolution, new capabilities and a workforce prepared for the changes ahead are needed. For simplification, two approaches are highlighted through Siemen's individual and HP Inc.'s team-based framing.

Matching the Fourth Industrial Revolution skill roadmap to job profiles

Siemens, Amberg

The upskilling path is laid out according to job profile, taking into consideration the key technologies and level of competence required

Profile (example)
Assembler

Skill segments	Fourth Industrial Revolution skill examples (competency requirement)
All	Resilience in the digital environment (understanding)
Basic Knowledge	Cybersecurity (understanding)
Expert	Cloud computing (knowledge only)

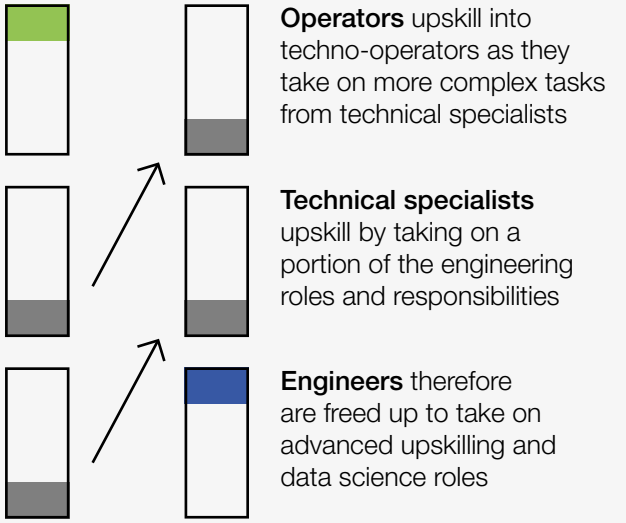
Shifting tasks to upskill the workforce

HP Inc., Singapore

Fourth Industrial Revolution optimization has freed up task responsibility, offering space for upskilling

Task time allocation across roles

Task optimized · Task shifted · New task



Key commonalities

University partnerships for advanced learning programmes, degree assistance

Internal learning, with in-house trainings, facilitated discussion platforms

Targeted trainings to lead a digitally enabled workforce

Source: World Economic Forum and McKinsey & Company.

5 Call to action: Extend the light further

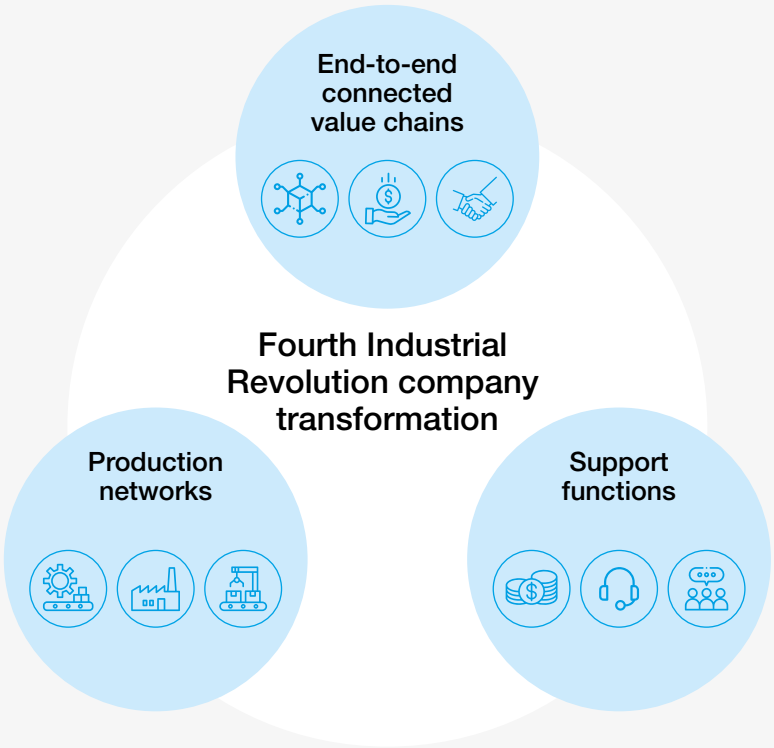
5.1 Extending the light's reach

Since its beginnings, the Global Lighthouse Network initiative has observed iterations in 4IR implementation. Leading organizations began their 4IR journeys with use cases first deployed at scale in manufacturing. In time, this deployment extended across E2E connected value chains. This deployment journey has greater horizons even beyond this, however. Today, leaders are scaling 4IR technologies more broadly still, aiming to extend the transformations modelled by lighthouses across entire organizations. This is the natural iteration at the core of the 4IR – that is, the logical progression of 4IR transformation as it continues to reach across the expansive industrial landscape.

Extending 4IR scaling this broadly is an aspiration – a vision for organizations that have succeeded in deploying 4IR technology at scale, integrating three categories: the production network, E2E connected value chains and support functions (Figure 18). In terms of the production network, this would mean successful scaling across all of the company's manufacturing sites. E2E connected value chains span product development, planning, delivery, the supply network and customer connectivity. This scaling extends to support functions, including human resources, finance and IT.

FIGURE 18 **Scaling Fourth Industrial Revolution applications across the entire company**

Use case evolution is coming to a logical conclusion as Fourth Industrial Revolution technology scales across production networks, end-to-end connected value chains and support functions, thereby transforming entire companies.



Category	Definition
Production network	All factories of the company
End-to-end connected value chains	End-to-end product development, planning, delivery, supply network and customer connectivity
Support functions	Functional departments such as Human Resources, Finance, Information Technology

Source: World Economic Forum and McKinsey & Company.

5.2 Inspiring other companies striving to deploy Fourth Industrial Revolution technologies

Organizations aiming for this level of successful 4IR deployment at scale are aspiring to transform themselves completely at the broad company level and, as such, to be the true leaders in a reimagined future of advanced industry. These lighthouses will be the brightest beacons of all, showing the way for others in a redefined manufacturing landscape in which people and processes realize their full potential through the power of 4IR engagement.

5.3 A call for applications

The Global Lighthouse Network continues to grow and encourages leading organizations to consider applying to join. Excited forward-thinking companies are invited to learn more by emailing LighthouseNetwork@weforum.org.

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