Digital Factories 2020
Shaping the future of manufacturing

91% of industrial companies are investing in creating digital factories in the heart of Europe

98% expect to increase efficiency with digital technologies like integrated MES, predictive maintenance or augmented reality solutions

90% of respondents believe that digitisation offers their companies more opportunities than risks

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Introduction

Digitisation is radically changing the face of manufacturing companies. Digital factories are transforming manufacturing, as companies implement innovative technology and look for employees with fundamentally different types of qualifications. These new digital factories are being created in the heart of Europe to produce highly customised products and systems.

Leading manufacturing companies are deploying a number of key technologies to digitise production as well as their entire supply chain. These include big data analytics solutions, end-to-end, real time planning and connectivity, autonomous systems, digital twinning and worker augmentation, among many others. These technologies provide significant efficiency gains and allow companies to produce highly customised products, often at lot size one. But the full effect of digitisation is only realised when companies are connected in real time to their key suppliers and critical customers.

Our research shows that leading industrial companies have moved beyond pilot projects and are already investing in rolling out digital solutions. In this report, we provide an overview of how far industrial companies have come and what challenges they face.

We also portray eight digital leaders who have already excelled in implementing breakthrough Industry 4.0 solutions. Based on a solid digital strategy, these industrial pioneers have implemented innovative digital technologies, while embarking on a complete digital transformation. And they have brought their most valuable resource – their employees – along for the journey through digital trainings and a communication concept that motivates their employees to contribute to the digital success of their companies.

Please reach out to us for a discussion about the results of this study and the digitisation of your factories.

For more information, please see:
www.pwc.de/industrie40, http://www.next.pwc.de/digital-factories

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Executive summary

Digital factories are high on the top management agenda:
The results of our survey show that 91% of industrial companies are investing in digital factories. However, only 6% of all respondents describe their factories as being "fully digitised" yet.

Digitisation supports customer centricity and regional manufacturing:
Three quarters of the survey participants who are planning further investments in digital factories name regionalisation of manufacturing for better customer proximity and individualised, flexible production as main investment reasons.

Digital factories strengthen "Made in Germany/Europe":
A total of 93% of respondents planning further investments in digital factories intend to locate some or all of these in Germany over the next five years. 77% of all investments in the next five years will be for setting up new or expanding existing digital factories in Germany and Western Europe. Digitisation is strengthening the competitiveness of Europe's industrial center.

No quick payback – digital factory investments are strategic with an ROI of two to five years:
Nearly half of our respondents expect to see an ROI of their digital operations investments within five years, compared with just 3% who expect an ROI within one year.

Fig. 1 Digital Factories 2020: Key messages

Top management must lead digital transformation – start now

Implementing digital manufacturing means building a digital workforce

Companies make smarter decisions using predictive data analytics and machine learning

Technologies like cobots, digital twins or augmented reality drive leaner and more productive operations

Connecting factories internally and externally through an integrated MES is essential

Digital Factories 2020 Key messages

High on the management agenda – 91% of industrial companies are investing in digital factories

Digitisation supports customer centricity and regional manufacturing

Digital factories strengthen „Made in Germany/Europe"

No quick payback – digital factory investments are strategic with an ROI of two to five years

Companies expect efficiency gains of 12% over five years

Strategy   Benefits   Technology   People

Companies expect efficiency gains of a total of 12% over five years:
Efficiency gains are the main reason named by almost all (98%) respondents for investing in digital factories. Integrated planning, better asset utilisation, lower quality cost and benefits from automation contribute to efficiency gains.

Connecting factories internally and externally through an integrated MES is essential:
Connecting machines and other assets to communicate across a common infrastructure is the first step to digitisation. Manufacturing Execution Systems (MES) plan and control production in real time, enhancing efficiency, manufacturing flexibility and asset utilisation. To get the most benefit, these systems need to be integrated with the ERP infrastructure. That enables companies to digitise not just internal processes, but across the entire supply chain as well.

Technologies like cobots, digital twins or augmented reality drive leaner and more productive operations:
Digital technologies that help workers get more done, faster, and improve processes and product quality are gaining ground fast – the numbers of companies implementing them will double in the next five years. Collaboration between workers and machines is a key area of development, as is creating digital twins – virtual representations of factories. Augmented reality solutions help employees in building zero defect products.

Companies make smarter decisions using predictive data analytics and machine learning:
Artificial intelligence and data analytics are driving the digital factory; more than half of the companies we surveyed already use smart algorithms to make better operational decisions. Connecting the dots inside the factory and within the company ecosystem, as well as intelligent use of information, will be a "must-have" to stay competitive.

Implementing digital manufacturing means building a digital work-force:
Digital factories require a new way of working. The make-up of the workforce will need to change, and companies will need to recruit and retain employees accordingly. Data scientists need to find smart algorithms to improve operational performance and smart man-machine interaction requires new skill sets. Digital training programmes, as well as hiring external "Digital Natives" secure success in building a digital factory.

Top management must lead digital transformation – start now.
The digital transformation of a company requires top management leadership and guidance. Now is the time to act, as competitors around the globe are embarking on their digital journey.

Strategy

Digital factories are high on the top management agenda

Nine out of ten industrial companies that we interviewed for this year's survey are investing in digital factories. In our global study on Industry 4.0 last year[1], we noted that companies had moved from talk to action. This year's results and the responses from 200 companies in Germany document a continued strong focus on digitisation. Digitisation maturity levels vary widely, though. 6% of companies have already fully digitised their factories and are leading the way. The vast majority – 85% of the respondents – either say their factories use digital technologies widely, with some elements already connected (44%), or are using digital technologies for stand-alone solutions within their factories (41%). These figures demonstrate the strong commitment that industrial companies in Germany place on bringing technological advances to their factories. Over half of the respondents plan to expand their factories over the course of the next five years, which shows that there is still a long way to go before factories are fully digitised.

Getting there will mean investing and partnering with internal and external stakeholders and using open innovation. Philips, for example, is using this approach at its factory in Drachten (see *Philips: Innovation and collaboration*, page 10). It will also mean hiring and developing people, and managing significant amounts of change by working closely together with employees to build trust and secure their commitment. Nokia developed its vision of the "conscious factory" through this type of collaborative approach. Factory workers and management from all around the world came together to map out the company's path for the future (see *Nokia: The Conscious Factory – supply chain management of the future*, page 14).

Only a small portion of companies are not planning to make their factories digital at all (9%). As the rest of our study will show, these companies risk lagging behind and losing competitiveness. Of the companies that have already invested in digital factories, about a third believe they have already done enough and are not planning further investments. Given the wide range of clear benefits that the digital factory brings and that are outlined in this report, we believe these companies risk falling behind competitors who are taking a more proactive approach to digitisation and continuous improvement.

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[1] PwC (2016): Industry 4.0: Building the digital enterprise, http://www.pwc.com/industry40.

Fig. 2 Nine out of ten companies are investing in digital factories

91% total potential

Industry 4.0

Degree of digitisation

9%
Digital factory
not planned

41%
Use of digital
technologies for stand-
alone solutions

44%
Wide use of digital
technology, factory is
partially integrated
and connected

6%
Factory is completely
digitised
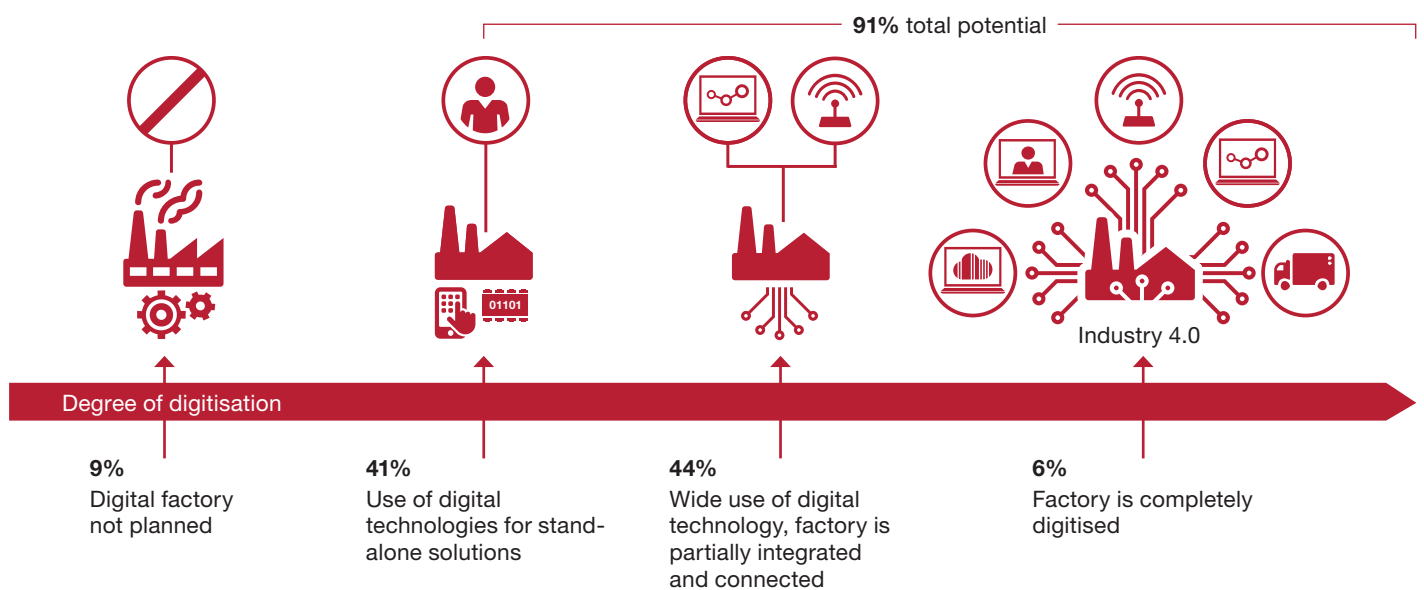
Q: Which of the following statements on the topic of digitisation and digital factory development best describes the situation in your company? Please take your most advanced factory with relevant production volumes as a basis for your reply.
Base: All respondents

Digital factories support customer centricity and regional manufacturing

Customer centricity is key for companies to survive in today's competitive markets. Companies are moving ever closer to their customers in order to react to changing and dynamic preferences more quickly. Customers themselves benefit from tailor-made products with little or no delivery costs. In some industries, entire value chains are becoming more regionalised, as 'just in time' and 'just in sequence' logistics strategies drive suppliers to be closer to their customers.

In fact, almost three quarters of our respondents who are planning further investments name regionalisation of manufacturing as a main reason for setting up or expanding digital factories (see Figure 3, page 11). Over half of them confirm that the individualisation and personalisation of their product offering was one of the main reasons for digitising their factories. Regionalisation efforts can also help reduce transportation and logistics costs, a significant motivation for expanding digital factories for nearly half of the respondents.

Three out of four respondents set up digital factories to react to customer preferences more quickly.

Philips: Innovation and collaboration

Philips develops high-quality, innovative products for a worldwide market in Drachten. These products aim to make life more healthy and comfortable for people and include Senseo coffee machines, Ladyshaves, hairstylers, hairdryers, vacuum cleaners, beard trimmers, hair clippers, and wake-up lights. Next to this, Philips Drachten has been the development and production center of the advanced electronic Philips shavers since 1950. More than 2,000 people of 35 different nationalities work on the site, making Philips Drachten one of Philips' biggest development and production centres in Europe, taking the lead in applying advanced industrial innovation.

In the factory production engineers and production workers manage product development and production side-by-side. Joint development and production are supported by key digital technologies, including automated assembly and digital twins, robots, 3D printing and big data analytics. These innovative digital technologies enable differentiation through "first time right designs", zero defect manufacturing and demand driven supply chains. In future, Philips seeks to continually improve its manufacturing towards further customisation and even more flexible research and development.

Philips' Drachten site forms part of Innovatiecluster Drachten, a group of 16 high-tech manufacturing companies unique in Northwestern Europe, attracting employees and other high-tech companies from all over the world. The network also includes close collaboration with the regional and local authorities as well as educational institutions. The initiative helps strengthen and secure the future of the Drachten area as an industrial location in the northern Netherlands.
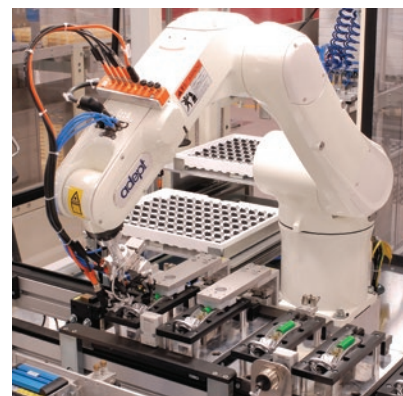
Many companies are using digitisation to make their factories more agile, so they can achieve far greater levels of flexibility and are better able to adapt to fluctuations in customer demand. To get the most out of these factories, companies are making investments to set up or expand factories in markets where they are generating revenues. 40% of our respondents reported plans to expand production capacity close to their customers (see Figure 4), and the numbers were even higher for larger companies with an annual turnover of over €3bn. This customer focus is driving production decisions more strongly than labour costs. Only about one fifth of all respondents plan to relocate manufacturing capacity to low-wage countries, although the number is somewhat higher for larger companies (30% for larger companies compared with 12% for smaller companies). Almost all respondents reject a potential reshoring of production from low-wage countries back to Germany (see Figure 4).

Fig. 3 Efficiency and customer centricity are top reasons for expanding digital factories
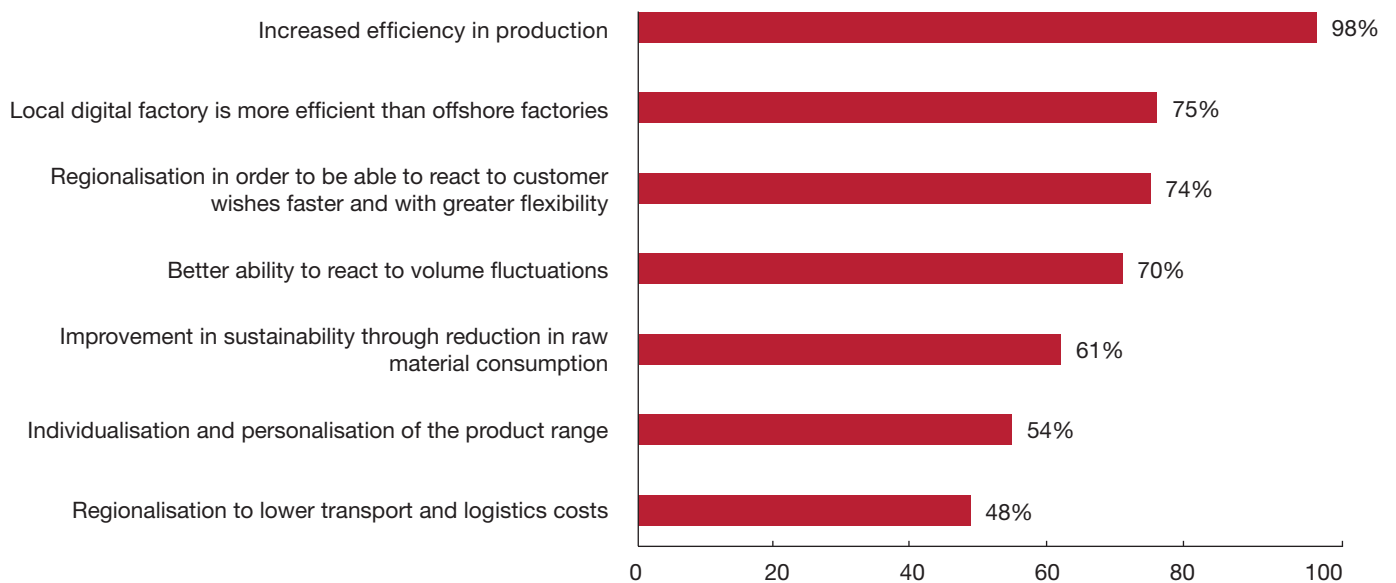
Q: What are your significant reasons for setting up or expanding digital factories?
Base: Respondents planning to set up or expand digital factories

Fig. 4 Manufacturing companies to serve customers close to their home market

Capacity expansion in home country

64%

Capacity expansion close to customers

40%

Reshoring to home country

3%

19%

43%

Offshoring of production to
low-wage countries

Outsourcing to strengthen core
competencies
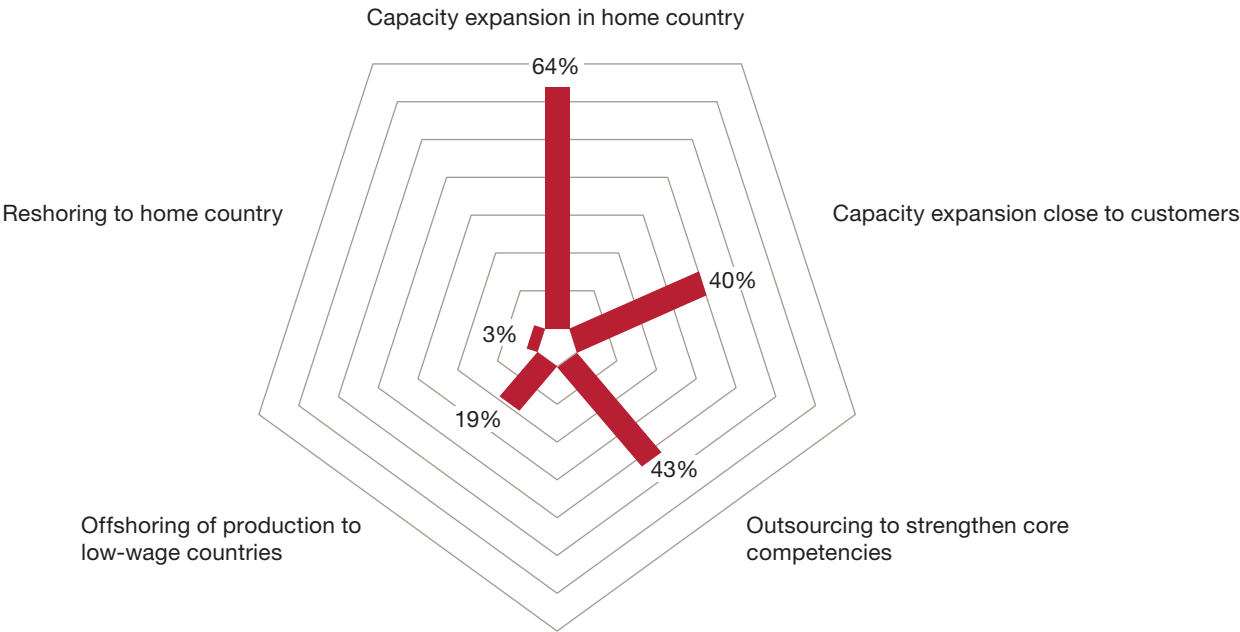
Q: Which strategies are you adopting with regard to your production locations?
Base: All respondents

Smaller companies with an annual turnover of less than €0.5bn are generally focusing much more strongly on their home market: 81% of their investment spend will focus on Germany, compared to 51% of larger companies' investments.

Digital factories strengthen production "Made in Germany/Europe"
The respondents to our survey who are planning further investments in digital factories show a strong commitment to Germany and Western Europe as an important investment destination.

A total of 93% of respondents planning further investments in digital factories intend to locate some or all of these in Germany over the next five years. This reflects a strong focus on Germany across the survey sample as a whole, and the high level of trust that companies place in the country as a strong location for setting up and developing digital factories. As Figure 4 above shows, 64% of respondents overall plan to expand their capacity in their home country. Mid-sized companies are the most enthusiastic: while 59% of smaller and 55% of larger companies plan to increase their capacity in their home country, almost three quarters of mid-sized companies (revenues between €0.5bn and €3bn) will do so.

In terms of the level of investments, respondents intend to allocate 77% of their investments to setting up digital factories in Germany and Western Europe over the next five years. That's particularly true of smaller companies (those with annual revenues of less than €0.5bn) – they plan to dedicate 87% of their total investments in digital factories over the next five years to plants located in Europe (see Figure 5). In contrast, larger companies (annual revenues over €3bn) are investing more broadly, with 61% of their investment volume in the same time period planned for Europe.

Other regions are much less in focus for setting up or expanding digital factories. For example, respondents overall only plan to allocate 7% of their investments to Asia, and 5% to Eastern Europe.

Fig. 5 European companies are focusing most strongly on digital factory investments in their home markets

Western Europe 77%
Smaller companies 87%
Larger companies 61%

Eastern Europe 5%
Smaller companies 3%
Larger companies 7%

North America 7%
Smaller companies 6%
Larger companies 16%

South America 2%
Smaller companies 0.1%
Larger companies 2%

Asia 7%
Smaller companies 6%
Larger companies 8%

Middle East/Africa 0.2%
Smaller companies 0.1%
Larger companies 0.4%
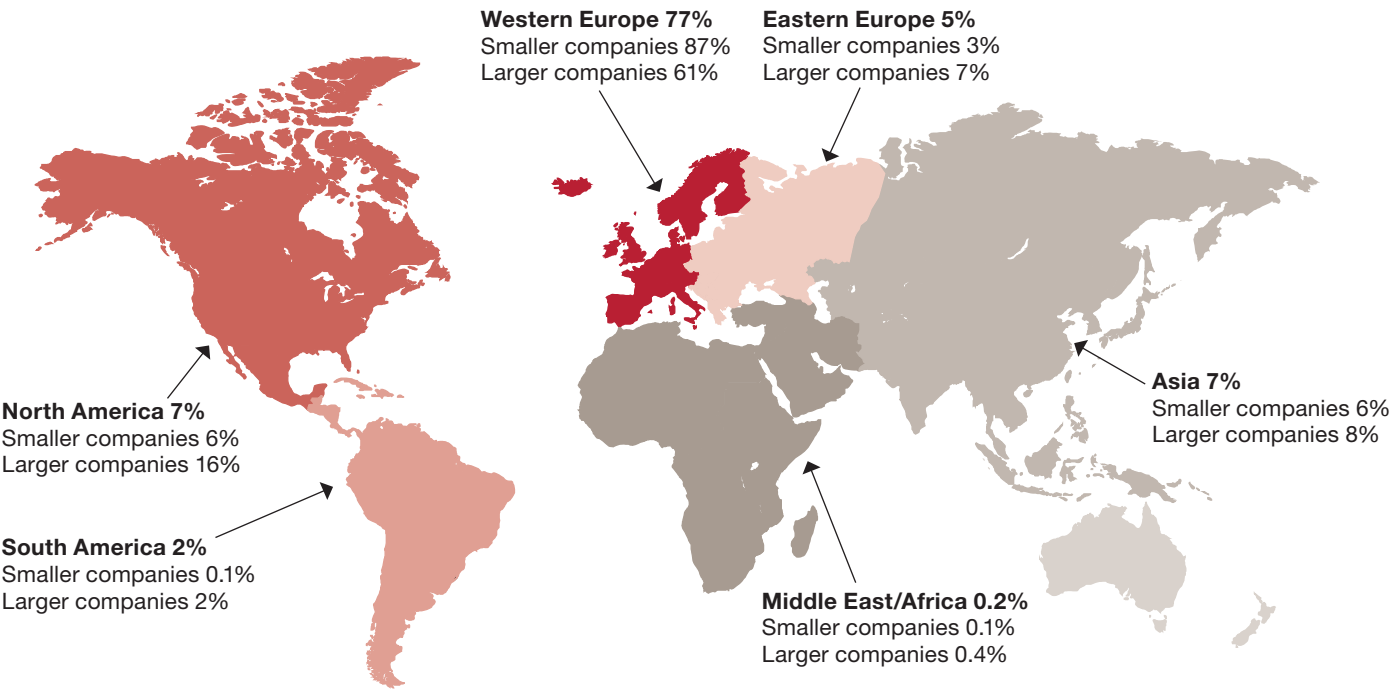
Q: How will you divide your investments in digital factories in these regions over the next five years?
Base: Respondents planning to set up or expand digital factories; figures are rounded and may not add up to 100%

Nokia: The Conscious Factory – supply chain management of the future

Building the future together: Nokia started its project in 2012 with a clear strategic objective: envision the factory and supply chain of the future. Both the leadership team and employees mirrored their current activities, observed important trends that are starting to impact manufacturing and imagined what the more distant future could look like. The result was "The Conscious Factory", a vision for the near future, 2022, and a roadmap on how to build it. This factory is "dark" – minimal electricity is consumed only on demand – and it is green, with zero emissions, zero waste and no stocks. It is highly lean and cost-effective, so productivity is far higher. And it can be built and located virtually everywhere: a factory in a box.

By bringing employees into the process from the outset and developing a joint vision for the future, Nokia ensured that employees would be able to shape the future together with management. In this way, Nokia also built a stronger intrapreneurial mindset. Cultural changes included an increased emphasis on global collaboration. Sharing ideas based on available technologies and having regular innovation club meetings to introduce new thoughts was very essential. Instead of isolating knowledge in separate silos, employees with different talents began working more closely together worldwide – from Shanghai to Oulu, Finland.

The road to the conscious factory means making not just the factory smarter, but the company's people as well. Nokia achieved that by defining essential competencies, such as social networking, Six Sigma, analytics and programming skills, and finding ways to help employees build the needed skills. For example, staff trainings include "Pizza bots" to help workers familiarise themselves with programming and using practical examples.

In 2017, Nokia is well on track, having implemented changes across its global network. In addition to lean management, data analytics are now being used to improve manufacturing processes and increase stability, as well as to measure yield, quality and costs. Workplace technologies implemented include wearables for operators, robots and gesture-based controlling.

As a result of the changes implemented so far, Nokia's production now operates at world-class levels, securing global competitiveness. The company has also taken major steps towards its vision of the factory in a box.

On the road ahead lies the integration of the whole supply chain. There are challenges along the way, particularly due to different maturity levels. Yet the advantages of an integrated supply chain are clear: Nokia can make better use of the real-time information that is currently available internally worldwide, for example through predictive maintenance, and to collaborate seamlessly with external parties in areas like order tracking.
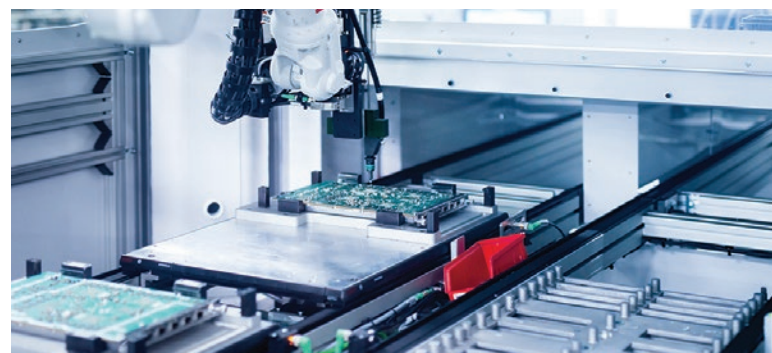
Benefits

No quick payback – digital factory investments are strategic with an ROI of two to five years

The respondents who are planning to expand their digital factories intend to invest on average 6% of their total annual revenues over the next five years, i.e. 1.2% p.a. There are some differences between industries, though. Companies in the consumer goods industry are at the high end of the scale, while companies in the metals and mining and electronics industries are lagging (see Figure 6).

Nearly half of our respondents expect to see an ROI over five years, compared with just 3% who expect an ROI within one year (see Figure 7). Around a quarter expect to see a return over three to four years. These results are consistent across companies of all sizes and reflect a significant change from our previous studies, where respondents anticipated much faster returns. We believe that companies are carefully planning their investments and business cases for digital factories. As companies gain experience with digital factory solutions, they are getting a clearer picture of implementation timelines and the level of effort required, leading to more conservative estimates on how long it will take to achieve a return on investment. While most do not anticipate immediate returns, our respondents clearly expect digital factories to pay off in the medium term.

Fig. 6 Investment levels vary across industries

Metals and mining	Electronics	Engineering/ industrial equipment	Process industry	Industrial manufacturing	Consumer goods
4%	4%	6%	6%	6%	8%

Ø 6%
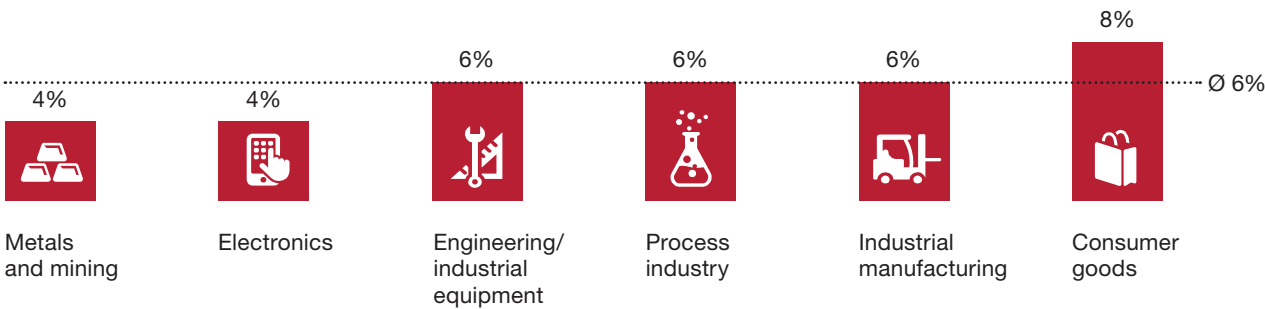
Q: Based on the total revenues of your company, how much will your company probably be investing in total in setting up and developing digital factories over the next five years?
Base: Respondents planning to set up or expand digital factories

Fig. 7 Companies expect payback for digital investments in two to five years

In 5 years

In 3–4 years

In 2 years

3% In 1 year

14%

Expected ROI on digital factory investment

26%
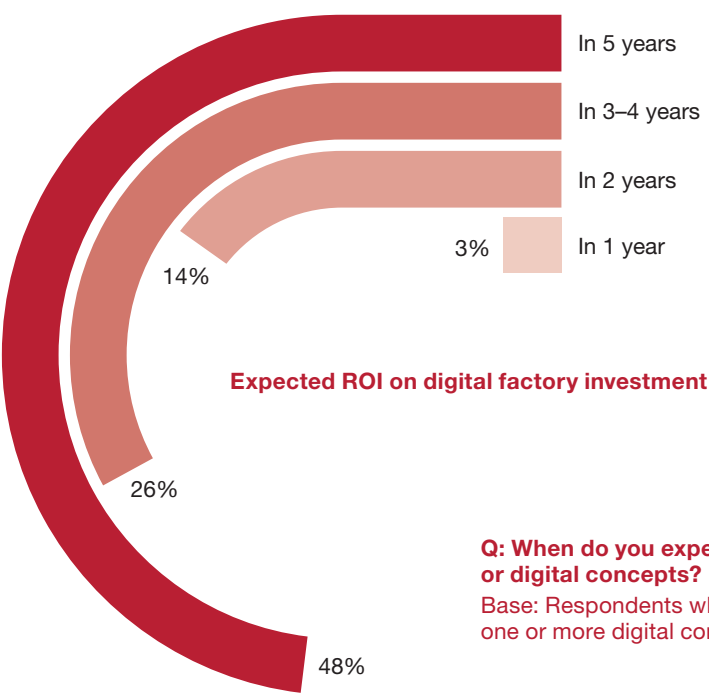
Q: When do you expect to get a return on your investments in digital factories or digital concepts?
Base: Respondents whose companies have or are planning a digital factory or the use of one or more digital concepts. 9% of respondents did not name the period.

48%

Companies expect efficiency gains of 12% in total over five years
Increasing efficiency is the reason that almost all respondents name as key for investing in digital factories. Respondents overall expect solid gains from their companies' efforts to digitise production. Over the next five years, they expect these initiatives to drive efficiency and revenue increases of 12% on average respectively (see Figure 8). While that is lower than the gains respondents to our broader Industry 4.0 survey last year expected, last year's estimates were based on looking at gains over the entire digital enterprise, whereas this year's research focuses on the production environment. We believe that these estimates also reflect an increased realism, as more companies are now moving from pilot projects to implementation.

The levels of efficiency expectations vary across industries. The engineering/industrial equipment industry is most optimistic, with an average expected efficiency increase of approximately 15%, while the industrial manufacturing industry anticipates average gains of around 10% (see Figure 9).

75% think that the local digital factory is more efficient than offshore factories.

Fig. 8 Respondents expect both efficiency and revenue gains of 12% on average over the next five years
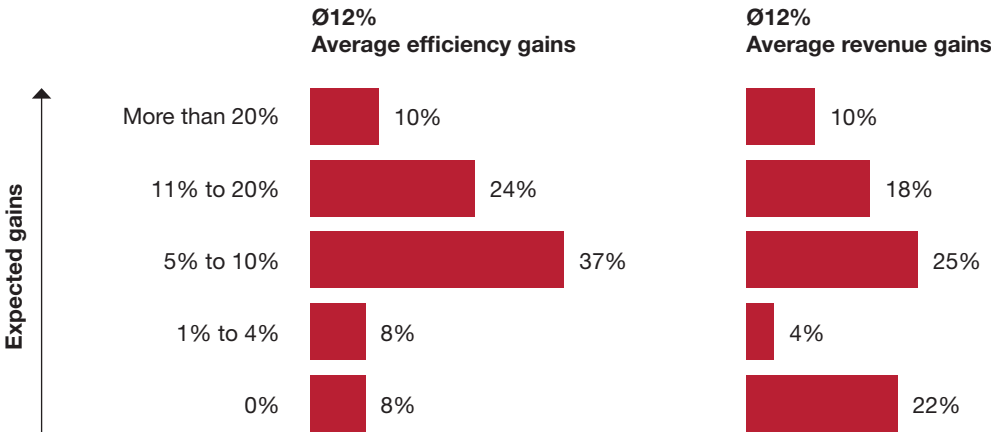
Ø12%
Average efficiency gains

Ø12%
Average revenue gains

Expected gains

	Average efficiency gains	Average revenue gains
More than 20%	10%	10%
11% to 20%	24%	18%
5% to 10%	37%	25%
1% to 4%	8%	4%
0%	8%	22%

Q: An efficiency gain by how many percent in comparison to now do you expect for your company over the next five years from digital factories? A revenues gain by how many percent in comparison to now do you expect for your company over the next five years from digital factories?
Base: Respondents whose companies have or are planning a digital factory or the use of at least one digital concept

Digital factory approaches can bring other benefits alongside increasing factory efficiency. In the aerospace and defence sector, for example, companies are using digital factory solutions to keep up with new types of aircraft and engine design that are challenging the limits of conventional manufacturing. MTU Aero Engine's greenfield plant, Halle 77, was specifically designed using digital factory solutions to produce a new type of aircraft engine component, the "blisk" (see *MTU Aero Engines: Building the future in Munich*, page 19).

Digital factories can also help companies achieve their sustainability goals, as the consumption of energy and raw materials can be reduced. More than four-fifths of our survey respondents say they are already using data to improve resource efficiency, or will do so in the future. Some of the savings are likely the result of more streamlined supply chains and less warehousing, as raw materials are ordered and supplied only in the required quantity.

But the vision goes further still. Some companies are planning "lights-out" factories, where electricity is only consumed on demand. Our survey supports the idea that digital factories can help protect the environment: 61% of respondents planning further expansion of digital factory initiatives say increased sustainability is one of their motivations. As the latest data shows, energy consumption by the industrial sector has been declining since 1990[2]. In our view, industrial companies in Germany and Europe still have the potential to further increase their energy savings with the support of digital factories.

Fig. 9 Average five year efficiency gains expected from digital factories vary across industries

Industrial manufacturing	Metals and mining	Electronics	Consumer goods	Process industry	Engineering/ industrial equipment
10%	10%	12%	12%	12%	15%

Ø 12%

Q: An efficiency gain by how many percent in comparison to now do you expect for your company over the next five years from digital factories?
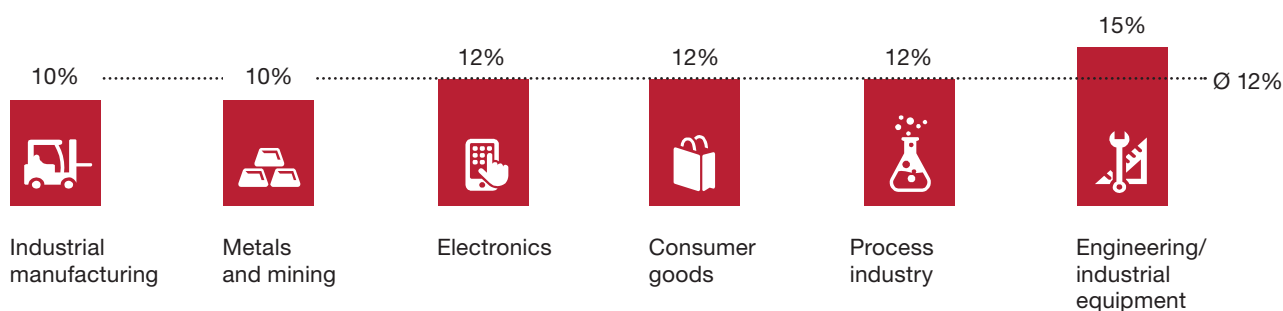Base: Respondents whose companies have or are planning a digital factory or the use of at least one digital concept

Digital factories can help companies achieve their sustainability goals by reducing use of energy and raw materials.

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[2] Cf. Umweltbundesamt (2017), Energieverbrauch nach Energieträgern, Sektoren und Anwendungen, https://www.umweltbundesamt.de/daten/energiebereitstellung-verbrauch/energieverbrauch-nach-energietraegernsektoren.

MTU Aero Engines: Building the future in Munich

MTU Aero Engines is one of the world's leading producers of a new type of component for aerospace engines, the "blisk" – blade integrated disk. These are high-tech components where the disk and the blades form one single part; they find increasing use in modern engine compressors. To fill the demand for these innovative components, MTU built a greenfield plant called "Halle 77", its Centre of Excellence for blisks in Munich, which was inaugurated in 2013. The investment into the innovative shop building, including its machinery, is worth over €70 million. The facility's target is to increase blisk production from 600 in 2012 to 4,000 by 2020.

The blisk production facility was designed from the outset as a digital factory capable of using advanced technology to produce sophisticated components at a low cost. The plant links the company's growth strategy closely to its digitisation and innovation efforts.

The production concept is based on optimised, automated process workflows and the latest in machinery and equipment. The core of the concept is a 96-meter-long main distribution system connected to a host computer capable of automatically controlling all processes at any time by using a Manufacturing Execution System (MES). Each component is provided with a routing card and unique order number, plus an integral RFID chip. Using this order number combined with data on the availability of fixtures, tools and computer-aided programmes, the MES calculates the workloads of all the workstations in the production hall. The components are then supplied to the available machines through the main distribution system. Up-to-date machining programmes run automatically, and workers have access to the appropriate processing screens that are made available on monitors.

The MES integrates real-time planning and production management. By using optimisation and business parameters, the system ensures that production is as efficient as possible. It also monitors progress and reports any disruptions.

MTU Aero Engines' top priorities for the new building were energy efficiency and cost effectiveness, and this holds true of both the production concept and of the construction of the building, which incorporates many energy-saving features.

The blisk Centre of Excellence is far from the company's only foray into digital factory technologies. Also notable is MTU Aero Engines' use of additive manufacturing (3D printing) for series production. The company is already using Selective Laser Melting (SLM) to produce parts for the A320neo engine, the "PurePower® PW1100G-JM" from Pratt & Whitney. Thanks to its flexibility, the process is particularly suitable for producing small product runs – or even individually tailored products.
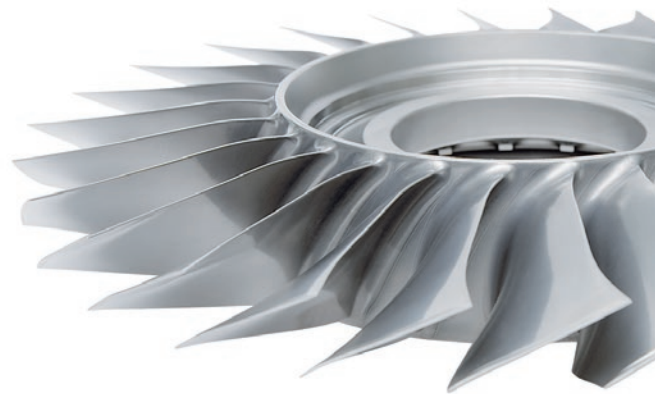
Technology

Connecting factories internally and externally through an integrated MES is essential

Connectivity within the factory is accelerating at a rapid pace. Simply put, it is required to enable machines and other assets to communicate based on a communication infrastructure and establish a central instance to process information, like a Manufacturing Execution System (MES).

While today 29% of respondents say their companies have implemented networking technologies that connect components, machines, production management, transportation vehicles, workers, and even products, more than twice as many (60%) expect to do so by 2022 (see Figure 12, page 26). Connectivity usually includes sensors reading data from RFID chips and sending it to data platforms, and a similar number of respondents (64%) say they have already implemented such sensor networks and connected data platforms, or plan to do so (see Figure 11, page 24).

Bosch Rexroth, for example, has already implemented an RFID tracking technology at its Homburg plant. This plant serves as a global pilot plant for the Bosch group (see *Bosch Rexroth: Lot size one through connectivity,* page 25). Nearly half of respondents also say their companies use track and trace systems (or plan to do so) to track the location and progress of components within the production process.

By using an MES, it is possible to use this information to plan and control production in real time, for example by sensing or predicting unplanned events and generating automatic response or optimisation actions based on analysed data. Some companies are also developing system-based shelf-life monitoring to prevent inventory stockouts and optimise inventory levels. Fujitsu's server production plant in Augsburg uses digital factory solutions to streamline inventory processes. The companies uses an interim storage facility (the plant's "supermarket") and self-driving electric vehicles that are integrated into its MES in order to ensure "just in sequence" delivery of components (see *Fujitsu: Smart factory on a digital campus*, page 27).

Fig. 10 Key technology features of a digital factory

Parameter A = …
Parameter C = …

Parameter A = …
Parameter B = …

Alert/
order

1	**Digital twin of the factory**	The digital twin of the factory helps to plan, design and construct the factory building and infrastructure. It can be used to support testing, simulating and commissioning the building
2	**Digital twin of the production asset**	A digital twin of one or more production assets is used for design, virtual startup and ongoing operation. The focus is on simulating an asset's operations, to set and optimise its key parameters and enable concepts such as predictive maintenance or augmented reality
3	**Digital twin of the product**	A digital twin of the product is a digital representation of the product and links Engineering und Product Lifecycle Management (PLM) with factory operations. It is engineered as part of the R&D process and helps driving frontloading in product development by making it possible to simulate and test the product at an early process stage
4	**Connected factory**	Connected factory refers to the concept of connecting relevant factory objects such as resources, machines, transportation vehicles or products through a connectivity layer for control and optimisation purposes. Often leverages Manufacturing Execution Systems (MES) integrated with an ERP system (see integrated planning)
5	**Modular production assets**	Use of flexible, modular production assets instead of traditional production lines. Modular production assets like robots, storage vehicles, fixtures etc. are flexibly integrated in the production flow as required by the current production process
6	**Flexible production methods**	Use of flexible production processes such as additive manufacturing (e.g. 3D printing). These production processes can support a high variant variety and can increase flexibility drastically
7	**Process visualisation/ automation**	Visualisation and automation of factory processes, for example with mobile applications (apps) combined with virtual and augmented reality solutions like tablets or digital glasses. This includes improved cooperation between people and machines and innovative user interfaces
8	**Integrated planning**	Integrated planning and scheduling systems within the factory from machine level over Manufacturing Execution System (MES) to Enterprise Resource Planning (ERP) systems including extended partners like suppliers and customers. Integrated planning allows an immediate reaction to changes in resource availability or demand
9	**Autonomous intraplant logistics**	Factory systems capable of operating and performing logistics activities without human intervention. These systems sense and process real-time information about digital or physical surroundings to navigate safely through in- and outdoor environments, while simultaneously performing all necessary tasks. Solutions include automated guided vehicles (AGV) as well as aerial drones for special tasks
10	**Predictive maintenance**	Remote monitoring of dynamic condition of machines with help of sensor data and big data analytics to predict maintenance and repair situations. This helps to increase resource availability and optimise maintenance efforts
11	**Big data driven process/quality optimisation**	Big data analyses can help to detect patterns in production or quality data and provide insights to optimise processes or product quality. Models range from pure statistical "black box" models to expert and knowledge based "white box" approaches
12	**Data-enabled resource optimisation**	Optimisation of energy and resource consumption through intelligent data analyses and controls e.g. energy or pressurised air management in facilities based on actual demand and/or supply
13	**Transfer of production parameters**	Fully automatic transfer of production parameters to other factories, e.g. to implement a lead plant concept where optimisations can be reproduced in other plants
14	**Fully autonomous digital factory**	Plant which operates independently, based on self-learning algorithms, where people are only required for initial design and setup as well as ongoing monitoring and exception handling. While this can reduce operating cost, main applications include use in hazardous or remote production facilities
15	**Track and trace**	Location of products and raw material within the factory is tracked via sensors and integrated into a data platform connected to internal systems such as MES or ERP systems. This provides full transparency about the production progress and inventory levels as well as allowing the tracking of individual parts/ products

Fig. 11 The adoption of key digital technologies is increasing in the next five years

64%

39%

Today   In use in future

Connected sensors

37%

18%

Today   In use in future

3D printing

33%

13%

Today   In use in future

Virtual/ augmented reality

22%

12%

Today   In use in future

Humanoid robots

20%

9%

Today   In use in future

Artificial intelligence

4%

2%

Today   In use in future

Drones
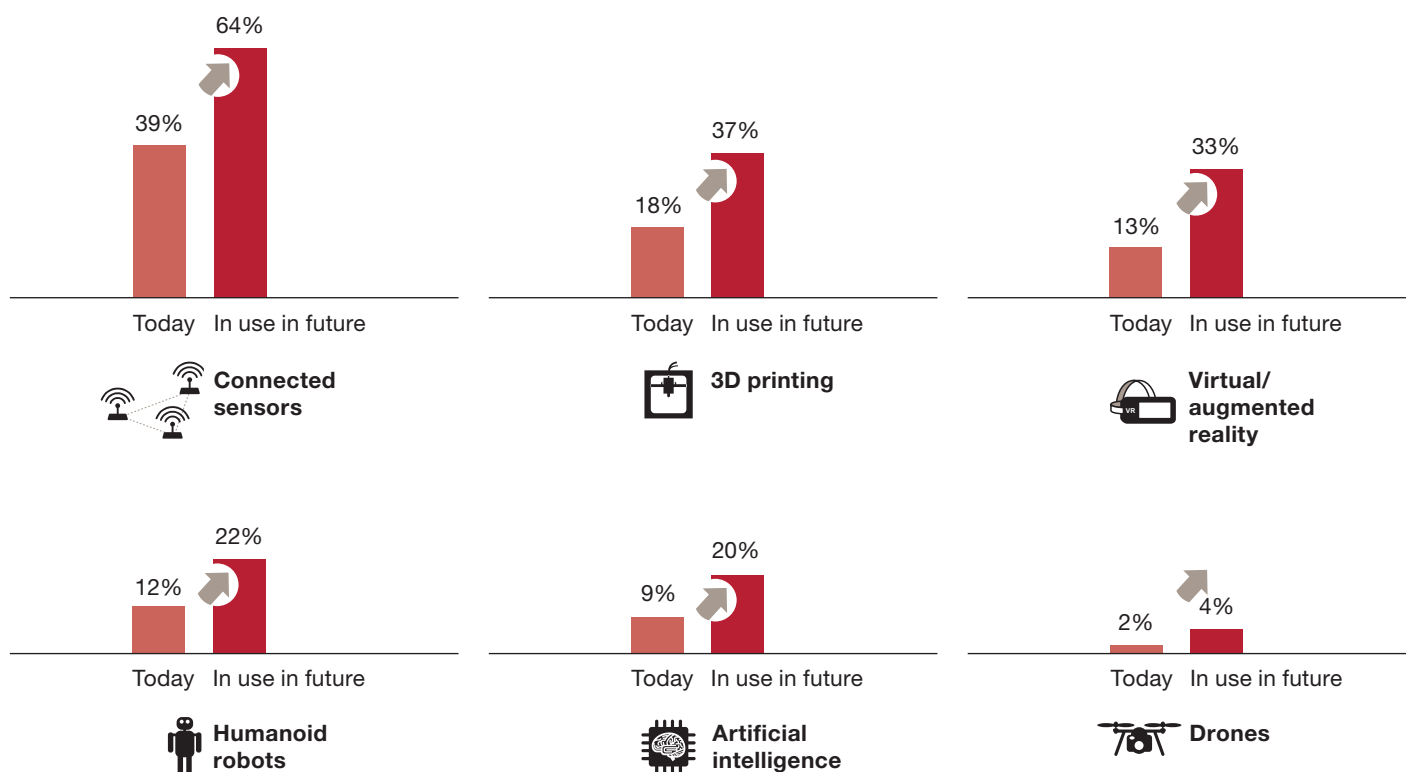
Q: Which technologies in detail are in use or planned in your digital factories?
Base: All respondents

Connecting the integrated MES to ERP systems and beyond the organisation can bring even more benefits

The connected factory is vertically integrated within an organisation, but many companies are also looking beyond the boundaries of the digital factory itself and are targeting horizontal integration of the entire value chain, including suppliers, the production network and customers. Enhanced track and trace capabilities and dynamic connections with Enterprise Resource Planning (ERP) systems create transparency and make it possible to apply data analytics to optimise supply chain planning from end-to-end. Like networking within the factory, these processes may use sensors and RFID chips to generate and communicate data to an integrated planning platform (including interfaces with key value chain partners). That can even extend all the way to the end customer; more than a third of companies (36%) have plans to implement product tracking; others will likely rely on information within ERP systems such as customer orders to achieve an integrated value chain.

To get there, simply connecting systems is not enough. For true synchronisation, both within production and with external factors like customer demand and possible constraints on supply, organisations will have to develop tightly integrated systems (MES, ERP, sensor) and overcome the silo culture still found in many companies.

Bosch Rexroth: Lot size one through connectivity

In Homburg (Saar), Bosch Rexroth has established a leading plant for Industry 4.0 solutions. The site with 50 years of history and app. 700 employees reflects the company's position as one of the first movers in Industry 4.0 in Germany.

A focus on people and a strong innovation mindset lie at the heart of the Homburg plant's success as it moves forward to develop new solutions and pilots. Jobs in the plant are changing to be more interdisciplinary, and so are the qualifications and skills needed by employees. Alongside traditional manufacturing jobs, the plant is likely to need more software developers and other IT-related positions.

The Homburg plant is both a user and an internal provider of Industry 4.0 solutions: It is a producer of industrial and mobile controls as well as hydraulic motion equipment, and it is the global pilot plant for small series within the Bosch group. Built around top management's core strategy, the Homburg plant has laid the foundation for how to successfully implement and leverage digitisation and connectivity. Together with other pilot plants in the network, the Homburg plant collaborates closely with the Bosch Rexroth product area assembly technology and the "Bosch Connected Industry" project house, which consolidates and coordinates solution sets, ensuring efficiency and avoiding redundancy. These lead plants develop solutions and have global responsibility for establishing standards that can be rolled out to other factories. Every plant also takes advantage of the global services in the Bosch network like the Bosch cloud or corporate IT structures, leveraging economies of scale.

Bosch Rexroth uses a wide range of innovative technologies. These include paperless active cockpits, self-guiding products, independent working cells, automatic employee and product recognition and inline quality testing. By implementing new technologies alongside maturing technologies including RFID E-Kanban and pick to light, the Homburg plant is able to improve efficiency and output while increasing the number of variants produced at their assembly lines.

By using these technologies and leveraging the increased flexibility at the line, the goal is to make lot size one affordable. Customers like industrial OEMs are currently doing late stage customization of the Bosch hydraulic motion control units at their own lines to ensure in sequence production. By joining Bosch Rexroth's product area assembly technology more closely with mobile controls, the company has laid the foundation to move from a parts supplier to an agile module supplier. This not only allows Bosch Rexroth to vertically integrate their supply chain, but also offers opportunities to develop value added services in the future like remote diagnostics, predictive maintenance or pay per use.
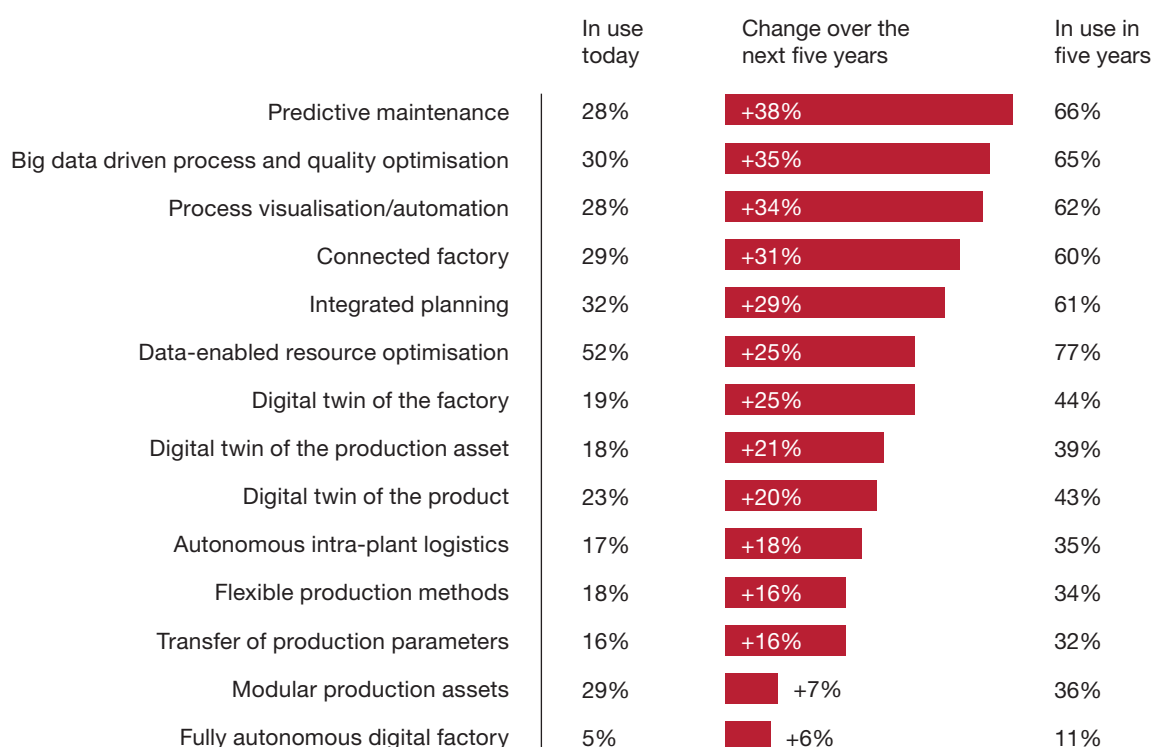
Technologies like cobots, digital twins or augmented reality drive leaner and more productive operations

Helping workers get more done

Many companies are also planning to implement a variety of digital technologies that help workers get more done, faster, and improve processes. While 28% of companies report that they are already using strategies for process visualisation and automation like mobile apps and virtual or augmented reality, 62% expect to do so in just five years – a dramatic increase (see Figure 12).

There is little doubt that the work environment in the digital factory will change radically and the process has already begun. Companies are implementing tools to give workers access to the information they need when they need it, often using mobile apps that are independent of a particular workstation. In-line quality checks are also becoming more common, where employees are notified of errors and can correct them, and where the accuracy of the production process is cross-checked automatically. In addition some companies are using mobile apps to help employees collaborate better remotely, e.g. around scheduling and approval of maintenance tasks. Robots and other digital technologies will also make workers' lives in the factory easier, safer and more efficient. Cobots – "collaborative robots" – go far beyond just performing pre-programmed tasks. Workers can "train" these robots through interactions, without the need for time-intensive programming, simply by repeating activities.

Fig. 12 Use of connectivity technologies and big data analytics is set to increase dramatically

	In use today	Change over the next five years	In use in five years
Predictive maintenance	28%	+38%	66%
Big data driven process and quality optimisation	30%	+35%	65%
Process visualisation/automation	28%	+34%	62%
Connected factory	29%	+31%	60%
Integrated planning	32%	+29%	61%
Data-enabled resource optimisation	52%	+25%	77%
Digital twin of the factory	19%	+25%	44%
Digital twin of the production asset	18%	+21%	39%
Digital twin of the product	23%	+20%	43%
Autonomous intra-plant logistics	17%	+18%	35%
Flexible production methods	18%	+16%	34%
Transfer of production parameters	16%	+16%	32%
Modular production assets	29%	+7%	36%
Fully autonomous digital factory	5%	+6%	11%

Q: How relevant are the following concepts for your company?
Base: all respondents

Fujitsu: Smart factory on a digital campus

In its digital factory in Augsburg, Fujitsu has brought together the entire value chain on a single campus, from development through to interactions with the end customer, including service and training. At the heart of the factory is sophisticated information technology (IT) driving production and logistics. For example, in the innovative interim storage facility, the "supermarket", components are prepared for assembly and stored in special transport cartons for individual orders. These include integrated dynamic displays that show workers which components belong to each order. The displays are a significant part of the strategic method that prioritises an extremely high level of flexibility and paperless production processes. A self-driving electric vehicle, the "logistics train" ensures that the production units get the components they need "just-in-sequence".

With its Augsburg showcase factory, Fujitsu is developing and producing computer hardware in Germany at competitive costs. On the campus of the "breathing factory", that responds flexibly to the level of orders, the Japanese concern is using cloud-based services, digital applications and rapid prototyping to develop a plant that showcases the digital factory as an integrated part of a comprehensive, customer-focused Industry 4.0 approach.

Following the example of the Toyota Production System, in 2011 Fujitsu converted the production floor from the straight line that had been used for many years to production cells organised in a U-shape. As a result, manufacturing teams can see the entire development of "their product" from the beginning of the process to finished device. Up-to-date testing techniques, modern concepts for making materials available and the highest level of flexibility for all batch sizes are part of the lean production philosophy.

Extremely fast production to exact customer specification is possible thanks to digital shopfloor data management. "Smart factory" solutions increase transparency and quality, ensure that data is always current and reduce costs. These range from supporting the supermarket concept through the permanent optimisation of the transportation and warehousing structures all the way to customer-specific digital labels and sensors such as RFID tags. Modular software-based building blocks – the "connected applications" that make up Fujitsu's Manufacturing Execution System round out the digitised production process. These allow for precise/specific changes within an individual module and significantly faster reaction times.

Production processes can be virtually tested and optimised with digital twins.

Continental Automotive has already begun implementing many of these technologies. The result: increased efficiency, better ergonomics and more flexibility (*Continental Automotive: The interconnected factory*).

We see collaboration between workers and machines as a key area of development, and one where many companies may still need to take a closer look. While many companies are focusing on improving process visualisation and automation, far fewer are planning to implement some of the technologies that can help increase acceptance; as one example, "humanoid" robots are being developed that can produce and read facial expressions, but just 22% have any plans to implement them (see Figure 11, page 24). We look at the importance of how people interact with technology in more detail later in this report.

A number of the companies we interviewed in more detail told us about systems they use to manage logistics processes, but doing so is still fairly rare – fewer than one out of five respondents say their organisations are already using autonomous intra-plant logistics. That number is set to double over the next five years though, as companies look to increase efficiency and reduce errors by taking advantage of the decreasing prices and maturing autonomous technologies available in the market. Today's systems go beyond automated milk runs of pre-programmed routes, which have been available for more than two decades. Instead, logistics is becoming not just truly autonomous, but also responsive in real-time through the use of connected systems that identify logistics requirements and communicate these to self-guided transport systems. These systems communicate with each other, as well as with networked work stations and warehouse locations and respond dynamically to changes in demand and supply.

Extended use of artificial intelligence (AI) and drones is still far off
In the future, robots will even be able to learn on their own. In fact, one-fifth of respondents have plans to implement artificial intelligence or self-learning machines. Only a small percentage of our survey respondents say they will use drones, although that number is also on the increase.

Digital "twins" – virtual products, productions assets, and factories – streamline development and enhance operation
It is now possible to create a digital representation, or "digital twin", of products, equipment and even entire production lines and plant infrastructure. Four out of ten companies plan to create and use digital twins within the next five years. Digital twins are often used during the development of a product or when planning production. They make the development process more efficient, improve quality and help to share information between stakeholders. By combining digital twins of a product and the production line, new production processes can be virtually tested and optimised before any physical work has been started. And when digital twins are shared with partners, they are better able to optimise their processes to align. Digital twins are an enabler for many other applications like virtual or augmented reality and remote maintenance.

Continental Automotive: The interconnected factory

Facing shorter development cycles while maintaining quality and efficiency requirements: Continental Automotive is confronting the constant challenge of how to adapt their electronics production lines to ensure the delivery of the highest quality products to their customers while evolving towards a truly smart factory. The company is already well on its way and has taken important steps towards the interconnected and highly efficient factory of the future. In today's electronics production plants, huge amounts of raw production data are already being generated by production equipment and stored in cloud based data lakes. Smart products also recognise where they are in the production process at all times.

One example of Continental Automotive's progress is the ideal SMD (surface mounted device) Line, one of several Industry 4.0 initiatives developed with top management support. The SMD Line not only reduces failure rates and increases quality, but intelligent process control systems based on data analytical methods also reduce cost. The SMD Line offers high levels of flexibility. Because it is scalable and modularly expandable, it can respond dynamically if product volumes or variances change.

The SMD Line is comprehensively networked and automated. It knows the material demands for current and upcoming production cycles and autonomously orders the required components from the connected warehousing system. Automated Guided Vehicles (AGVs) pick up the ordered components and deliver them to buffers at the assigned lines. The AGVs also simultaneously manage the removal of empties and trash. During the manufacturing process, big

data analytics tools are constantly monitoring production. Machine to machine communication allows certain elements of the production to autonomously correct errors or optimise the production process. For example, if a machine's output deviates from expected norms, an automated notification to the system manager requests an inspection.

Production employees are becoming improvement managers and are taking responsibility for all autonomous workflows. Implementation of state of the art collaborative robots technology in the production setting allows operators to work hand in hand with robots that use sensors and cameras to recognise their environment. This technology has led to efficiency gains, improved ergonomics and greater levels of flexibility, since today's light weight robots can be programmed for new processes within minutes. Still, the overarching vision is that digital tools will only support – not replace – employees.

On the way to the envisioned smart factory, Continental Automotive will also implement further Industry 4.0 initiatives. Partners such as the Robotics Research Unit of OTH Regensburg will support them along the way.

Re-thinking production: mid-sized companies are furthest ahead
It is notable that the most popular technologies being implemented in the digital factory today, and even those most likely to be planned for the next five years, will drive increases to efficiency that still rely on the traditional model of the assembly line, as pioneered by Henry Ford back in 1913.

But what might happen if companies re-think that process entirely? Only around a third of companies are planning to make use of modular production facilities (36%) or flexible production processes (34%, see Figure 12, page 26) over the next five years; more concretely, just 37% plant to implement 3D printing or have it in use already (see Figure 11, page 24). That may reflect the fact that these technologies often imply the need to completely re-think the manufacturing strategy or even the company business model – a risk many companies aren't willing to take. In our view, it's absolutely critical for companies to have a holistic digital strategy that's informed by both their overall business strategy and technology development.

Mid-sized companies with €500m to €3bn in annual revenues are generally more open to new manufacturing technologies such as modular production facilities or additive manufacturing (3D printing). These companies have sufficient scale to make investments in new technology – something smaller firms often lack – but are often more flexible and able to implement new technologies more quickly than their larger counterparts.

Companies make smarter decisions using predictive data analytics and machine learning
Data is driving the digital factory; more than half of the companies we surveyed already use it to optimise their resource use. Around three out of ten companies have also started using big data to optimise quality and processes, and to institute predictive maintenance – and respondents tell us those numbers will more than double within the next five years (see Figure 12, page 26). The largest companies – those with over €3bn in annual revenues – are most likely to be adopting big data solutions. That is not surprising as some of these solutions require significant investments and the capacity to structure and analyse large data sets, which means developing expertise in data analytics and system integration.

The digital factory of the future will generate significantly more data through the use of sensors. And because capabilities in data integration and memory continue to increase, it will also be possible to integrate digital factories into future supply chain ecosystems in real-time. As we've already noted, companies will be able to connect their machine data vertically into their MRS and ERPs and then connect to their suppliers and customers. Key data on supply and demand will be available in real-time, throughout the entire supply chain. Tomorrow's digital factories will be able to plan maintenance activities and needed downtime during periods of low-customer demand, optimising margins – something a few companies have already started doing today.

Connecting the dots inside the factory and within the company ecosystem, as well as intelligent use of information, will be a "must-have" to stay competitive. As our study last year showed, companies are recognising this and significantly developing their big data capabilities.

Data is driving the digital factory.

People

Implementing digital manufacturing means building a digital workforce
Digital factories require a new way of working, so your company will need to build a digital workforce. That has a whole host of implications. The make-up of the workforce will need to change, and companies will need to recruit and retain employees accordingly. Just as important will be working closely together with your people before and during implementation of new technologies. We are entering a new era of man-machine interaction and it is critical not to underestimate the importance of people in the digital factory.

Fig. 13 More than half of the respondents expect the size of their factory workforce to increase or stay the same as a result of digitisation

Will increase	16%
Stay constant	40%
Will decrease	42%

56%
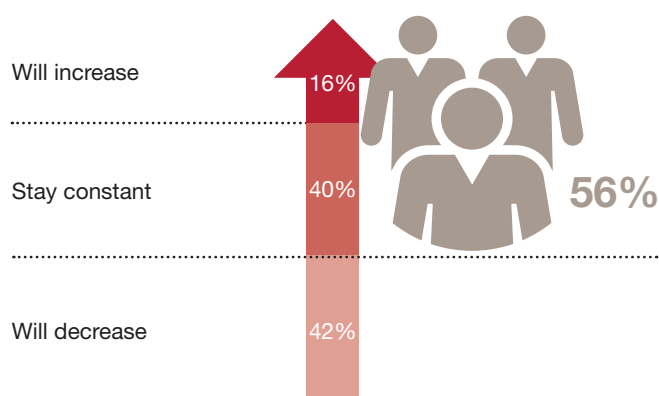
Q: What changes do you expect to the number of employees in your factories in total in 10 years as a result of digitisation?
Base: all respondents

Digital factories can help companies meet demographic challenges
Germany currently has an ageing society. In our 2016 study of German workforce trends, we discussed the impact of this demographic shift. By 2030, there will be 3.5 million fewer German workers available compared to today[3]. For most sectors that is likely to lead to significant shortages of qualified employees as large numbers of workers enter retirement. Digitisation can help level off these shortages and reduce them to two million, as another PwC study in 2016 has shown[4].

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[3] PwC (2016): Demografischer Wandel: In Deutschland werden Arbeitskräfte rar.
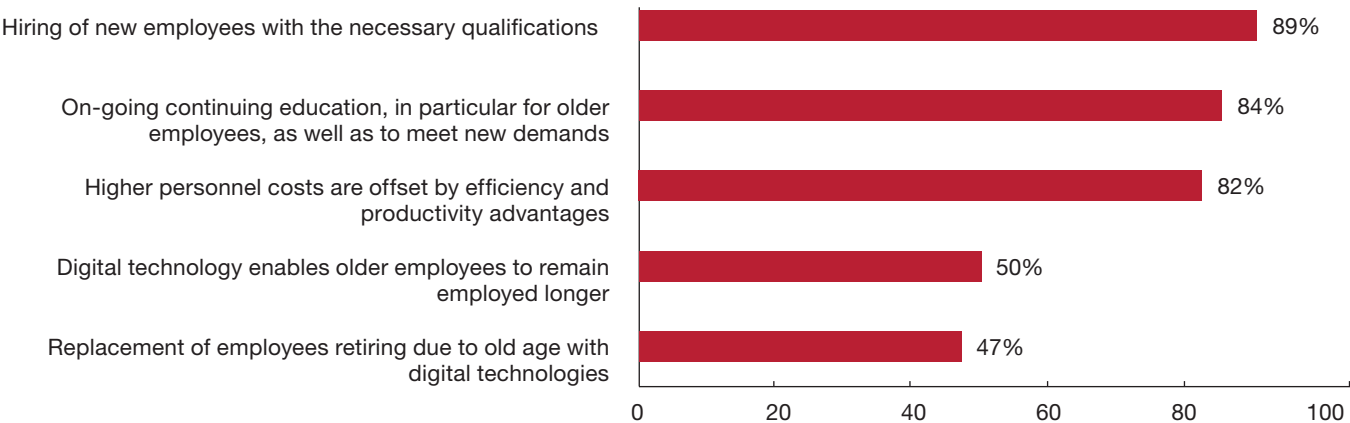[4] PwC (2016): Der Einfluss der Digitalisierung auf die Arbeitskräftesituation in Deutschland.

89% say digitisation will drive the hiring of new employees with the necessary qualifications.

While 42% of respondents expect the number of employees in digital factories to fall, even more – 56% – say it will stay the same, or even increase over the next ten years (see Figure 13). There is strong evidence to suggest that digital factories will help German companies meet the challenges posed by an upcoming shortage of trained workers. Nearly half of companies (47%) say they intend to replace some of the expected attrition due to age by using digital technologies (see Figure 14). And half of our respondents tell us that they believe digital technologies will help older workers continue working longer (see Figure 14). Of those companies that do expect to decrease their headcount, most anticipate reductions that are largely in line with expected productivity increases, rather than extensive lay-offs.

There will be abundant opportunities for job-seekers with the right skills; 89% of all of our survey respondents expect to hire new employees who have the qualifications needed to make the most of digitisation (see Figure 14). However, our respondents see finding employees with sufficient qualifications as the biggest people challenge they face – 81% expect to have difficulties in this area (see Figure 16, page 34).

Fig. 14 Digitisation will have a strong impact on hiring, training and factor cost of employees

Hiring of new employees with the necessary qualifications	89%
On-going continuing education, in particular for older employees, as well as to meet new demands	84%
Higher personnel costs are offset by efficiency and productivity advantages	82%
Digital technology enables older employees to remain employed longer	50%
Replacement of employees retiring due to old age with digital technologies	47%

Q: What effects do you expect for your company as a result of digitisation?
Base: all respondents

Working together to reshape vocational training ("Ausbildung") and higher education

Making sure that enough workers have the right skills to support digital factories will not be easy. The vast majority of our survey respondents are convinced that it will take pro-active collaboration between business, government and academia to turn digitisation's promise into reality.

The German vocational training system, known as "Ausbildung", has long been based on giving apprentices exposure to theoretical concepts in a classroom setting alongside real work experience. The newer "duales Studium", or dual course of study, model takes a similar approach, where college or university students gain initial experience in real business environments while simultaneously earning a degree. Both models represent a clear opportunity for academia and industry to work together to develop new training programmes that meet the evolving needs of the digital factory. That is already happening in some areas; for example, a major German automaker now offers a programme where students can earn a degree in business studies and Industry 4.0 through the dual course of study model.[5] These kinds of programmes can help companies face the challenge of finding sufficient numbers of qualified employees.

Fig. 15 The level of employee qualification is expected to increase over the next five years

Qualification	Status quo		In five years
Higher education	19%	↗	24%
Vocational training ("Ausbildung")	59%	→	59%
Unskilled	21%	↘	17%

Q: What is the structure of the workforce of your company in Germany with regard to qualifications? And what structure do you expect for your new hires in five years?
Base: all respondents; figures are rounded and may not add up to 100%

Overall, companies expect to use somewhat more graduates and fewer untrained employees, but the main focus will continue to be employees trained through the German "Ausbildung" system (see Figure 15). The types of jobs they need to be trained for, however, are likely to change dramatically. Digital factories will need fewer line workers, but more data scientists and programmers, for example.
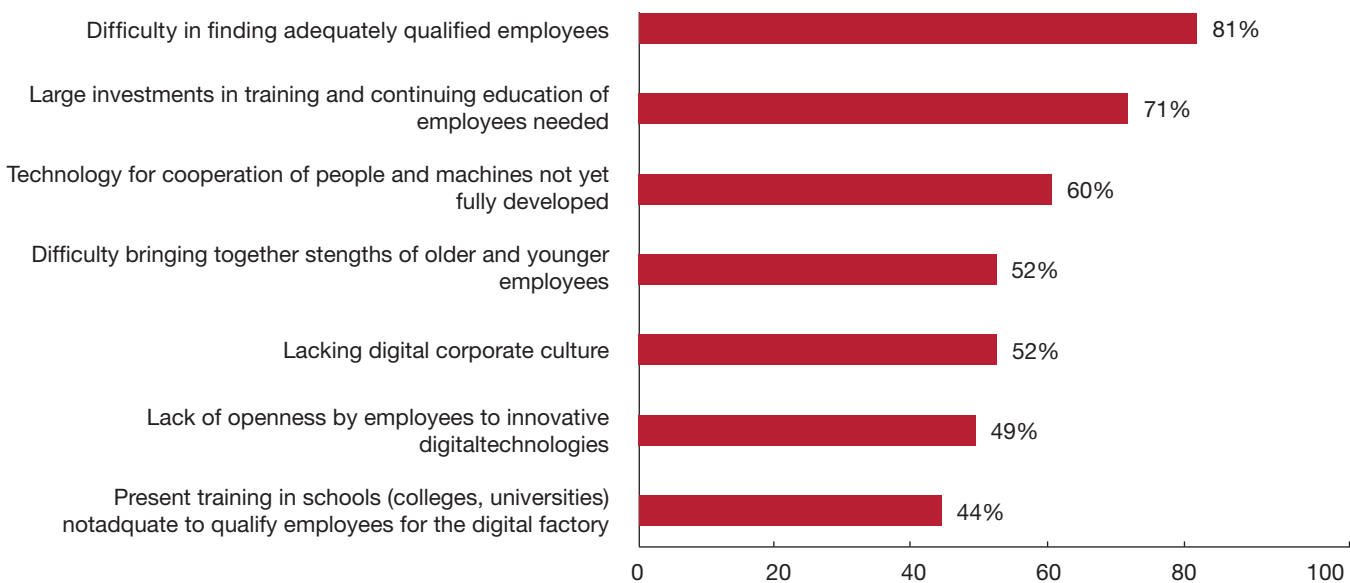
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[5] Bundesministerium für Wirtschaft und Energie (BMWi) „Die digitale Transformation im Betrieb gestalten – Beispiele und Handlungsempfehlungen für Aus- und Weiterbildung" November 2016, p. 44.

98% will continue to need graduates with traditional degrees but 83% believe they will need apprentices in fields for which there is currently no standardised training.

Our survey respondents see developing new types of vocational training as a priority – 83% told us they believe they will need apprentices in fields for which there is currently no standardised training. And while 98% expect to continue to need graduates in traditional fields like business, natural sciences and engineering, around three-fifths also believe that education at all levels will need to change fundamentally to keep pace with digitisation. For example, classical engineering studies should be re-designed in a multidisciplinary way so that the "Digital Engineer" also acquires skills in data analytics, product management, (multi-)project management as well as IT architecture and security[6].

Aside from these technical skills, we believe training should emphasise some important soft skills that cannot be replicated by machines, like creativity and innovation as well as leadership.

Fig. 16 Finding and training qualified staff is a major people challenge

Difficulty in finding adequately qualified employees	81%
Large investments in training and continuing education of employees needed	71%
Technology for cooperation of people and machines not yet fully developed	60%
Difficulty bringing together stengths of older and younger employees	52%
Lacking digital corporate culture	52%
Lack of openness by employees to innovative digitaltechnologies	49%
Present training in schools (colleges, universities) notadquate to qualify employees for the digital factory	44%

Q: Where do you see challenges for the digital factory with regard to your employees?
Base: all respondents

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[6] PwC (2017): Forschung und Entwicklung 4.0, p. 19.

Magna Steyr: Drones, data and a digital twin

It is not a scene from a Hollywood production. The action is taking place live, at Magna Steyr's automotive production plant in Graz. Silent drones swoop through a logistics hall, independently capture and scan material labels in the warehouse area and compare these with the available stocks. The Austrian-Canadian automotive supplier calls the research project "autonomous inventory". Drones are indoor-controlled, fly independently when necessary during regular processes, but can also be used for ad-hoc research.

The factory of the future is already well advanced in Graz: self-learning robots, driverless transportation systems and many big (smart) data solutions allow for pilots of more individually tailored production methods. People, resources and products communicate with each other in real-time. Transparency is critical. It is only possible to intervene and support value-added processes in real-time if you are able to identify what is happening within the process chain in real-time. For example, machines can direct a request for maintenance directly to the responsible department or supplier.

The ability of man and machine to work seamlessly together makes this factory "smart". Machines must adapt to people, not vice versa. New technologies are used where they have been proven to make sense. While robots help with tasks that are monotonous and difficult to perform ergonomically, the digital twin, the virtual representation of the real factory, provides necessary information on the work that needs to be performed. People in turn contribute their core skills, such as skilled reactions, creativity, flexibility and years of experience. Magna Steyr also uses collaborative robots. Workers can train them for special processes without the need for complex programming. Robots support workers in different ways, such as cooperatively providing a "third hand". Starting in 2017, the first robots will be available for workers to use during the assembly process.

The implementation of new projects happens in three steps: evaluation of the technology, prototype testing in a learning line and, finally, a roll-out in serial production. It has proven to be especially important to get employees involved as early as possible. Working together to prepare and implement use cases can allay any lingering skepticism.

In this way, Magna Steyr ensures efficient, cost-effective production and fills the increasing demand for the production of highly individualised products.

60% believe that technologies which enable people and machines to collaborate are not yet fully developed.

Are your people ready for new technologies? Getting the man/machine interface right

It is not enough simply to hire more staff, or train existing staff, though. Companies also need to make sure that employees feel comfortable working with new technologies. A total of 60% of our respondents feel that technologies which enable people and machines to cooperate are not yet fully developed (see Figure 16, page 34). In our view, understanding the impact on the people in your company is at least as important as calculating the financial benefit of a potential technology.

Companies need to reach out and work together with employees to shape their digital transformation. And this is where some of our respondents see hurdles: around half believe employees are not open to digital change (49%) and that their company lacks a truly digital culture (52% see Figure 16, page 34). Therefore, it is all the more important to actively build your people's trust in the technologies you want to implement and to make sure that developing a digital culture is a priority – from top management on downwards. The executives we interviewed in detail often came back to this core idea: people will continue to be at the heart of the production process and it is vital to get buy-in and commitment from your staff as you start and continue your digital journey.

Our experience shows that it is absolutely vital to include employees at all stages of developing and introducing new technologies. Magna Steyr is taking this approach at its digital factory in Graz. For new projects, such as introducing collaborative robots that workers can train for special processes without the need for programming, the company takes a three step approach of evaluating the technology, prototype testing in a learning line, and finally rolling out in series production. Workers typically get involved in all three stages (see *Magna Steyr: Drones, data and a digital twin*, page 35).

When selecting use cases for development, it is helpful to choose those that can generate a high level of employee acceptance. Build trust by showing employees the benefits that new technologies will mean for them. They may be relieved of work that is highly repetitive and physically difficult, or will be able to improve their accuracy, for example through better instructions that reduce mistakes. Wittenstein is already doing just that. Its systems provide workers with tailored information at the right time to increase their productivity and flexibility; the company also developed its MES in-house with its users in mind. (see *WITTENSTEIN: Future Urban Production*, page 37).

49% say employees are not open to digital change, while 52% believe that their company lacks a truly digital culture.

WITTENSTEIN: Future Urban Production

WITTENSTEIN SE has built the "Future Urban Production", an urban production plant on-site in Fellbach near Stuttgart. This production facility for innovative gear technology in the center of town places the primary emphasis on developing a smooth working relationship between human operators and machines.

The production plant's "milk run 4.0" at WITTENSTEIN bastian GmbH in Fellbach evokes long-past days when milk was delivered by tractor: every hour a logistics operator drives through the gear technology factory. He uses a scanner to read barcodes at the delivery and pick-up areas, deposits needed materials and takes processed components with him. Each delivery is displayed centrally on a digital planning board. By combining this information with data from production planning, the system generates an exact online replica of the flow of materials. A traditional order folder in paper form also accompanies the vehicle, as this is a trusted source of information for operators. WITTENSTEIN takes care to get its people on board with digitisation efforts. The company sees its employees – and their combined creativity – as the core of all of its production processes.

Staff are provided with tailored information at exactly the right time to increase their productivity and flexibility. Timely escalation management takes place via WhatsApp. In case of a problem, the person who detected it scans in the machine with their tablet and sends a photo or video to the shift supervisor or foreman. And although people, machines and products now communicate via intelligent cyber-physical systems, the company has developed its own Manufacturing Execution System (MES) for the shop floor that ensures maximum user friendliness.

The factory building itself was also designed with people in mind; the architectural style helps to foster internal and external communication and transparency through the use of large glazed surfaces. The aim was to provide the people who work for the company with a comfortable setting that allows them to interact closely alongside highly digitised processes, from development through production to sales. The unusual location for an industrial facility offers a high quality of life and work with short distances: the low-noise and low-emissions Future Urban Production plant is located directly next to an energy-efficient residential neighborhood. The nearest commuter train station is only four minutes away by foot.

66% of respondents say that IT skills should be taught in primary schools.

Top management must lead digital transformation

Top management should lead digital transformation and encourage life-long learning

Digitisation is now fundamental to business success. We believe it is vital for senior executives to provide "tone at the top" and demonstrate their commitment. Our respondents believe that learning how to navigate a digital world should start early. Two-thirds of our respondents said that pupils should be taught IT skills in primary school. They do not expect the process to stop when apprentices or graduates are done with their training. Our respondents recognise that they will need to actively build their employees' skills and knowledge. More than four-fifths (84%) expect they will need on-going further education to bring employees (especially older employees) up-to-speed (see Figure 14, page 32).

Not all of these efforts will come cheap. Most companies see the high investments needed in training and education as one of the major challenges they face in getting their workforce ready for the digital future. But most also agree that the investments are worth making – more than 80% expect that increased costs will be offset by efficiency and productivity gains (see Figure 14, page 32).

Overall, the large majority of our respondents see digitisation as a positive; 90% told us they believe it offers more opportunities than risks for their companies.

Rising levels of prosperity through digitisation

That is not just true for corporations; there is good news for workers, too. Around half of companies expect salaries to increase, while 86% expect that the number of hours worked will stay the same. Ultimately, this suggests that some of the increases in efficiency and revenue companies generate will be shared directly with their workforce, leading to new levels of prosperity in Germany. In addition, around half of companies expect salaries to increase, while 86% expect that the number of hours worked will stay the same. Ultimately, this suggests that some of the increases in efficiency and revenue companies generate will be shared directly with their workforce, leading to new levels of prosperity in Germany.

90% believe digitisation offers more opportunities than risks for their companies.

51% believe that the average salary in a digital factory will increase.
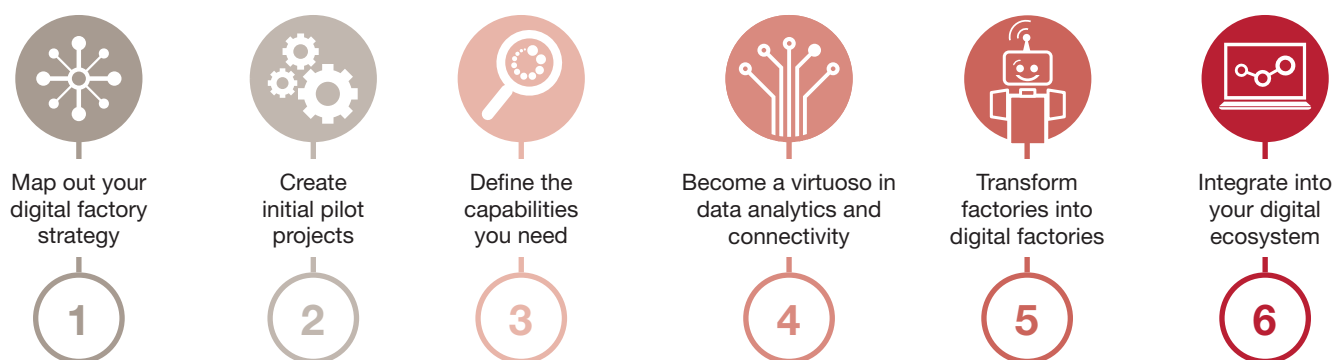
Blueprint for digital factory success

Leading industrial companies have made a clear commitment to building and enabling digital factories. They increase production efficiency and make it possible to produce more customised, high quality products to serve markets quickly and reliably.

We asked respondents whose companies are not planning digital factories what is holding them back. Their top challenge: a lack of digital vision and culture. In our view, that is also a "must-have" for companies that have already established digital factories, or are planning to set up or expand them. It is critical to have clear vision that takes into account not only individual technologies, but also how they work together throughout the entire life cycle of your products and within the network and your company's wider ecosystem.

Other major concerns holding companies back from taking advantage of the potential of digital factories include uncertainty about opportunities and unclear economic benefits, as well as worries about the level of investment needed. These factors point to the need to establish not just a clear vision, but also a realistic roadmap to digitisation.

To help you in developing or refining yours, we have adapted the six-step blueprint for digital success published in our Industry 4.0 report last year to the specific challenges companies face when building or expanding digital factories and integrating them into a digital ecosystem[7]:

Fig. 17 Blueprint for digital success

| Map out your digital factory strategy | Create initial pilot projects | Define the capabilities you need | Become a virtuoso in data analytics and connectivity | Transform factories into digital factories | Integrate into your digital ecosystem |
| 1 | 2 | 3 | 4 | 5 | 6 |

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[7] PwC (2016) Industry 4.0: building the digital enterprise.

Map out your digital factory strategy

Defining a coherent, consistent strategy is absolutely critical. Digital factories make use of a wide range of different technologies; it can be tempting to integrate these on an ad-hoc basis. Digital factory initiatives need to be more than the sum of their parts, though. You are likely to get more value if you have a clear idea of how each technology fits into your overall strategy and operational goals and how it works together with other technologies already available at your company. Your vision should span your entire organisation. To develop your digital factory strategy, start by understanding your current level of maturity. Make sure that people are as important as technologies and that you focus on projects that will bring the most value. Finally make sure you have a strong network of champions that includes top leadership, management, and workers or team leaders on the factory floor.

Create initial pilot projects

It can be difficult to secure funding and stakeholder buy-in, as the economic benefit case of digitisation is not always easy to calculate. And initially teams will only be able to provide very limited proof of concept and demonstration of technologies.

Pilots can help address these issues. They will help you learn the approach that works for your company. With evidence from early successes, you can also gain buy-in from the organisation, and secure funding for a larger roll-out. Because the digital factory is likely to bring profound changes for your workforce, it will also be important to make sure that workers and their representatives are integrated into any pilot project.

Possible options for pilots include vertical integration within one or two manufacturing sites including digital engineering and real-time data integrated manufacturing planning. Installing sensors and actuators on critical manufacturing equipment and using data analytics to explore predictive maintenance solutions can also provide some quick wins. Another good approach can be to digitise specific production lines within a particular plant, which can serve as potential starting points for you to learn and optimise.

You may want to consider collaborating with digital leaders outside your organisation, by working with start-ups, universities, or industry organisations to accelerate your digital innovation.

Define the capabilities you need

What is most important to your production process? Better, more automated logistics? Just-in-time, customised information for workers? Integration of sensor networks? We think it can be valuable to think in terms of capabilities, which can evolve, rather than technologies. Most, but not all, of these are IT-related. The real goal is not to implement the coolest new gadget, it is to achieve a particular outcome that increases efficiency, improves quality, or in some other way enhances your business. The capabilities you focus on in digital factory initiatives need to be closely linked to your company's production strategy and to overall business goals.

Building on the lessons learned in your pilots, map out in detail your (factory) system architecture and what capabilities you need. Here you will need to consider four strategic dimensions: organisation, people, process and technology.

Pilots serve as proof of concept.

Become a virtuoso in data analytics and connectivity

Data is driving the digital factory as companies accelerate their use of data-driven technology for process and quality improvement, resource management and predictive maintenance. In the digital factory, these solutions are almost always intimately linked to connectivity. Sensors help gather data, which is analysed by an information layer, and then communicated back to connected logistics facilities and production assets to fine-tune production in real-time. Every company will need to master both the connectivity tools and systems, which produce and communicate data, and the analytical tools that put it to work to improve efficiency and quality.
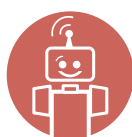
Transform factories into digital factories

The digital factory journey is a transformative one. And as with any kind of transformation, managing the change – particularly how it impacts your company's people – will be vital. Difficulty finding adequately qualified employees tops the list of workforce challenges identified by survey respondents. Other challenges include an insufficiently digital company culture, or reluctance on the part of workers to embrace digital change.

Ways to address this can be through early partnering with your workforce, and it is encouraging that companies both recognise the need to invest in training and continuing education, and believe its cost will be offset by the efficiency gains digital factory initiatives bring.

Cultivating a digital environment can only happen with committed leadership. Top management must place the digital factory strategy squarely at the centre of the C-suite agenda and make it a top priority. They can help free up their digital teams to drive quicker progress by avoiding classical project approval processes, which tend to be quite conservative. More streamlined reporting channels can ensure that digital teams focus on adding value rather than getting bogged down in administrative activities.

Integrate digital factories into your digital ecosystem

Many companies are focusing most strongly on vertical integration within individual plants as the main driver of their digital factory initiatives. Connecting MES with ERP systems enables significant improvements within the four walls of the factory. But digital factories should be one part of a broader digital ecosystem that potentially offers much more. When companies integrate supplier and customer information into the digital factory – horizontal integration across the supply chain – the potential for efficiency improvement accelerates. Imagine fine-tuning your planning and your production using real-time short-term customer demand and being able to flexibly adjust to your customers' requirements at minimal cost and with maximum customer satisfaction. This strategy of vertical and horizontal integration using track and trace will not only allow companies to optimise planning processes and production execution. It will also make it possible to deepen the bonds between a company and its strategic suppliers and customers.

However, in our view, that is just the beginning. If companies integrate digital features into products, they can potentially offer a whole range of services that take data and turn it into concrete value, for example by selling enhanced maintenance packages alongside equipment. There may also be ways to monetise the data generated by the manufacturing process itself. The implications are profound. Companies may be able to expand current business models or even rethink them completely. Instead of focusing solely or primarily on production, some companies may have opportunities to improve their margins by increasing market share in the lucrative after-sales market and to develop wholly new business areas.
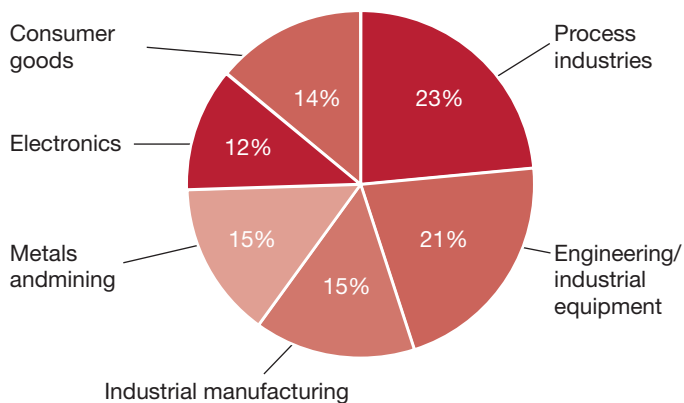
About the survey

This report "Digital Factories 2020 – Shaping the future of manufacturing" is based on quantitative research conducted by market research firm Kantar Emnid in January and February 2017 with 200 executives from industrial companies in Germany, supplemented by our editorial team's in-depth interviews with executives from leading companies.
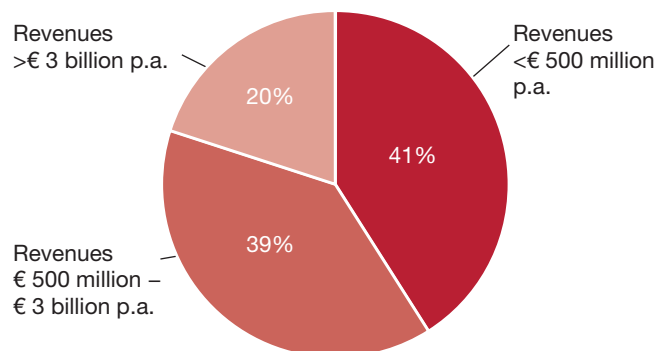
Quantitative survey participants were decision-makers with responsibility for at least one of the following areas: product development, production or technology. Companies of all sizes and in a diverse range of industries were surveyed (see Figure 18).

Fig. 18 Key facts about the respondents

Industry split of surveyed companies

Revenue split of surveyed companies

Consumer goods — 14%
Process industries 23%
Electronics — 12%
Engineering/ industrial equipment 21%
Metals and mining — 15%
Industrial manufacturing 15%

Revenues >€ 3 billion p.a. — 20%
Revenues <€ 500 million p.a. 41%
Revenues € 500 million – € 3 billion p.a. 39%

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