Industry 4.0

How digital technology is changing companies' production processes

Results of a survey
in ten European countries

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Content

1 Introduction

Digitisation originated in the service sector. Technology such as digital platforms and chatbots was first used to interact with private customers. However, more steps were then taken to drive developments to digitise companies' production processes, especially in countries like Germany where industrial manufacturing is of great economic relevance.

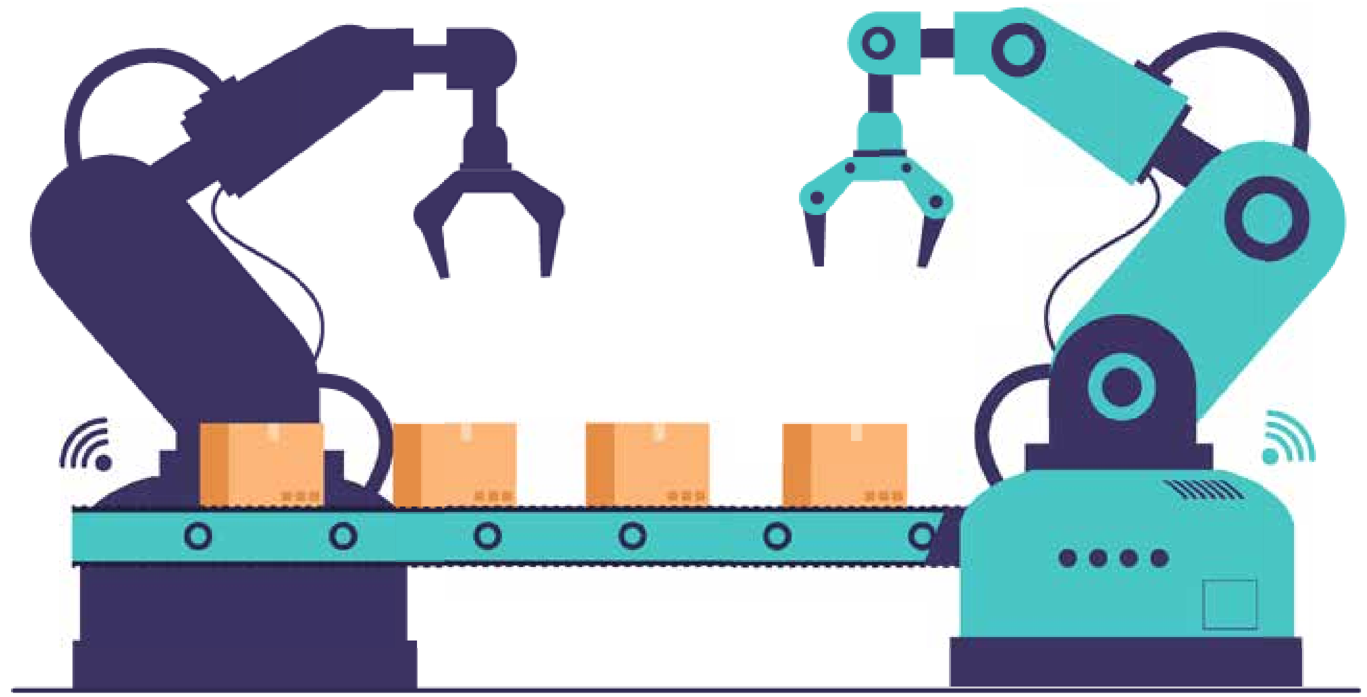
The digitisation of industry – and especially production – is often referred to as the 'Fourth Industrial Revolution'. The First Industrial Revolution through mechanisation in the late 18th century was followed in the early 20th century by the Second Industrial Revolution in the form of mass production through the use of electrical energy in particular. The Third Industrial Revolution in the 1970s brought with it fully automated production, something which was made possible by the use of computers on an increasingly large scale.

Digitisation is now the driving force behind the Fourth Industrial Revolution, which is why the term 'Industry 4.0' is used frequently in this context. Digitisation promises economic benefits such as cost reductions or potential yields for companies in the manufacturing sector, although it also entails a fundamental restructuring of internal processes and supply chains.

In this regard, Industry 4.0 is a key aspect of the digitisation of business. At the same time, the topic is closely related to Logistics 4.0 and Work 4.0 which the Handelsblatt Research Institute and TeamViewer have already examined in two previous reports. Production is not possible without internal logistics because the parts and products have to be moved between the individual production stations. Moreover, the use of technology to digitise production goes hand-in-hand with a restructuring of operational processes, causing employees' work processes there to change.

This report examines the topic due to this correlation as well as the central role of Industry 4.0 in business. The main basis of this investigation is a survey of companies in ten European countries. This offers a 'European' perspective of Industry 4.0 along with the opportunity to identify differences between individual countries; whether, for example, Spanish companies have already made great strides in digitising their production or are taking a different approach to companies in Poland.

Finally, the report includes concrete examples of practical applications to make the nature of the subject matter less abstract. These examples illustrate the approaches companies have already taken to the digitisation of their production. To begin, however, we should consider what Industry 4.0 can mean in theory.



2 The digitisation of production

The digitisation of production involves making changes to numerous corporate processes, even beyond the production facilities. For example, Industry 4.0 is changing the work processes of employees.

That being said, the implementation of new, digital technology remains the starting point of the transformation. Networking and automatic control are making production processes increasingly digital and autonomous. Traditional manufacturing methods are fusing with modern technology and real-time data analysis to create smart factories. The more data and information are shared and evaluated, the more intelligent systems can be. Machines and systems are increasingly capable of optimising their processes along the entire value chain independently.

Consequently, Industry 4.0 is bringing numerous advantages for companies in its wake. These include efficiency improvements, cost reductions and ways to save resources in particular. Processes are becoming more intelligent, more flexible and faster, resulting in more automation and in turn increased productivity, lower manufacturing and operating costs, better scalability and more sustainability in manufacturing. Companies will be able to manufacture and ship more products of higher quality at a lower cost and with less human interaction. This is because the production process will be characterised by self-optimisation and autonomous decisions made by the system. This goes hand-in-hand with optimised machine use. The use of resources can be reduced significantly in the process, as can the number of raw materials and spare parts in storage. Real-time quality controls mean less wastage. Industry 4.0 improves the way in which the production process can be tracked. This makes company processes easier to schedule while reducing machine idle time. The latter is the result of factors such as optimised maintenance.

Additionally, employees' work is becoming safer and less of a burden because robots and machines are able to perform monotonous and dangerous tasks. In the production environment of the future, companies will even be able to customise their products more and more, enabling customers to choose from a variety of different options – this is an increasingly important requirement. The increased flexibility of production will range from highly varied mass production to single items in one-off designs.

Not only production methods will therefore change, but new products and business models might also arise. This potential is based on a series of underlying technologies, some of which are outlined below.

2.1 Additive manufacturing

Additive manufacturing, also known as 3D printing, is a manufacturing process in which material is added and welded together, layer by layer, in order to create a product. Material is only used where it is needed to manufacture the product; in other words, it will retain a near-net-shape. This way, any object can be 'printed' regardless of its shape. Complex moulds and tools are no longer necessary – only the digital dataset is required.

Various materials can be used in additive manufacturing. Metals such as aluminium and titanium as well as plastics and ceramics are currently in widespread use. Additive manufacturing even makes it possible to use composite alloys (such as nickel or titanium-based alloys).

Flexibility is one of the most significant advantages of additive manufacturing. Unlike most conventional manufacturing techniques which require specific tools and moulds for every new geometry, 3D printers can respond to product design changes immediately. Changes to a product can be made at almost any time, without drawn-out development periods to manufacture tools and working materials delaying the production process. This makes it cost-effective to manufacture products even in single quantities. This increased flexibility also gives more design freedom, resulting in more individual and more personalised product designs. Production is significantly more efficient due to low material consumption and the reduced need for storage.

Even complex parts can be created in a single work stage with additive manufacturing. Individual parts merely have to be produced first and then welded together to form the actual component. Companies can therefore save both time and money.

For a long time, only prototypes were created with 3D printers. Even now, this remains one of the main applications of additive manufacturing. Companies are continuously building and improving prototypes with a view to manufacturing better products and fixing defects. If they use 3D printing to do this on their own premises and use their own materials, the entire process is faster and, in particular, cheaper than it would be to work with an external supplier. Moreover, a 3D printer does not take up any space on production lines, which avoids idle time and high costs.

Additive manufacturing even plays an important role in small batch production. As it eliminates the need to manufacture expensive tools and moulds, it can contribute to lowering the costs of manufacturing products in small to medium quantities. 3D printing has even proven to be highly significant to on-demand production because parts can be printed there and then on site, cutting down on warehousing. This also goes for the production of spare parts. As such, it is no longer necessary to keep spare parts in storage or put up with long waiting times. Thanks to 3D printing, a defective machine can be put back into operation quickly and disruptions to the production process can be avoided. It even reduces dependence on external suppliers, which is of considerable advantage when delivery routes and times are long. These days, 3D printers create more than just prototypes, small batches and spare parts; 3D printing has even started making inroads into mass production. Compared to conventional production methods such as injection moulding, 3D printing is considered to be comprehensively slower and more cost intensive at mass-producing simple shapes. However, technological advancements in some fields of application are starting to make additive manufacturing a reasonable option even in mass production. By acquiring technical knowledge of 3D printing technology and techniques, more cost-effective hardware and improved scalability, even mass production can benefit from the advantages of 3D printing. This results in faster times to market, flexibility in terms of converting production and product customisation even in mass production. Ideally, 3D printing can be integrated into existing machines.

2.2 Augmented, mixed and virtual reality

Augmented reality (AR) means adding extra aspects to the real world or overlaying them over the real world with wearable devices such as smartphones, tablets or special data glasses, also known as smart glasses. AR can overlay text, graphics, images or videos over a view of the real world, enabling users to see and interact with real or virtual objects in their field of vision. Contextual or time-specific process information helps users perform manual tasks.

Augmented reality can be used in many different ways in industry. Firstly, AR is a way to provide advanced training quickly and easily with virtual work instructions which display the right steps and hand movements for the person performing the task. This makes it possible to train employees on machines or guide them through various work processes such as routine maintenance, repairs or assembly. As information is delivered in digestible amounts, it is absorbed easily and the error rate decreases tremendously. At the machine, information and work instructions are projected straight into the AR glasses, allowing the technician to use both hands to perform the work. Digital handbooks make it easier to perform regular maintenance on often complex systems. This eliminates the laborious process of referring back to written documentation. The documentation itself can even be incorporated directly into the process. For example, a worker can record spoken comments which are converted to a text-based note (i.e. a speech-to-text tool), or the camera built into the device records images. If integrated, these reports are then transferred back into the system automatically.

Augmented reality also encourages remote collaboration. If no expert is on site, a local technician can be given remote support. Expert opinions can be sought over video chats and problems can be solved through cooperation. In the process, the expert sees exactly what the local technician sees.

Mixed reality (MR) works in the same way as augmented reality in principle, although virtual 3D objects, information notices and instructions can be generated and positioned in an area permanently or for an extended period of time. This enables the technician to keep the machine and the instructions in their field of view. Other employees or external experts are also able to follow the markers. The objects always remain in their designated locations, even if the technician is no longer on site. This further accelerates repair work.

With virtual reality (VR), the user experiences a computer-generated simulation of reality. The VR system is an artificially created world with images and potentially even sounds, completely cut off from the outside world. This world can be experienced on large screens, in special rooms or with a VR headset.

VR systems are only of limited use in a production environment as they are cut off from the outside world. Simulation does have its applications in terms of training, creating virtual prototypes and configuring products.

AR, MR and VR systems can cut manufacturing times and reduce error rates. They make work easier, make tasks quicker to complete and reduce the rate of accidents. Additionally, personnel can be given basic or advanced training with ease and at any given time.

2.3 Big data analytics

Data is the lifeblood of a digital factory because it can be converted into knowledge and insights. The ever-increasing degree to which production systems are networked is resulting in vast quantities of structured and unstructured data which have to be processed at high speed. As the insights derived from this help optimise production, big data applications play a highly important role in Industry 4.0.

The data obtained from networked devices originates from the entire value chain and covers the full life cycle of a product. It serves as the basis for big data analyses. However, the data only represents additional value for companies once it has been collected and evaluated. With big data analyses, a wide range of data from the production process can be combined, compared and processed. This includes sensor data from the production process, such as temperature, pressure, flow rates or vibrations, geodata such as device location and routes and general data relating to the systems, such as maintenance intervals or descriptions of critical moments. Only through innovative information processing can valuable correlations, patterns, trends and preferences be identified in the datasets, on the basis of which important decisions can be made about the production process.

2.4 Blockchain

Although blockchain technology initially focused on applications in the financial sector, it has since become clear that blockchain can deliver additional value in some fields of Industry 4.0 too. New business models, innovative organisational structures and work processes have been made possible. Far more production data can be used with blockchain as the standard of security is higher. As blockchain technology logs sensitive process data – such as specific measurements, product characteristics and material qualities – irreversibly and in a secure, transparent and verifiable manner for all participants, there can be mutual trust between various parties with different interests. Blockchain serves as decentralised data storage whose data is updated continuously for all participants and is impossible to modify retroactively. Data can therefore be documented for everyone, beginning with the preparation of the contract and encompassing production, packaging and supply data. This makes blockchain a 'network or platform of trust' and leads to more automation in production. For example, blockchains might contain information that can be used to identify products, modules or components. This allows for continuous quality controls within the production process and companies are able to ensure that only flawless parts and products leave the company, as defects can be discovered and remedied in good time with blockchain. Furthermore, blockchain in production can

make it possible to purchase raw materials and sell finished products through the production machines directly, largely without human interaction. Consequently, production processes can be automated further with blockchain and new business models can be created.

2.5 Cloud computing and edge computing

Cloud computing provides a virtual, scalable IT infrastructure for smart factories. With cloud platforms, companies can access data, processes, applications and storage from a virtual data centre – the cloud – without having to build their own complex and expensive physical IT infrastructure. The cloud is therefore a platform for operating industrial software applications. It even makes it possible to network systems and machines across different sites. Cloud-based platforms offer excellent flexibility and scalability as they can be adapted easily and modified quickly.

All of the data obtained in a smart factory can be stored and processed in the cloud and accessed from anywhere. Data from various production environments, each with their own components and data sources, can be stored centrally with cloud computing. Additionally, the various data can be pooled and evaluated in the cloud with data analysis tools. Production data can be processed in real time in the cloud, making it possible to factor the data straight into decision-making processes.

As very large quantities of data have to be processed in the production process, often in real time, cloud computing is not always the ideal solution. Cloud solutions are best suited to applications which require a low network bandwidth for transfers, as faster connections often mean higher costs. Large quantities of data which have to be processed at low latency – the time it takes to send data from a device to a server on the Internet and back – require a more effective solution. This concerns applications in a production facility in particular, as fast or even real-time responses are often needed. Edge computing has proven advantageous when it comes to avoiding data transfer times to the cloud and back. In edge computing, data is processed in a decentralised manner right where it was generated, resulting in a shorter transmission path and in turn very low processing times of less than one second. Instead of a remote data centre, the data is processed on special edge devices, such as a machine sensor or a smartphone. Edge computing prioritises a decentralised infrastructure over the cloud, making it possible to transmit data in real time.

2.6 Digital twin technology

Production processes can be reproduced digitally (and accurately) with a digital twin. The goal is to understand the real production process better and be able to simulate it. In a digital reproduction of the machine or system, actions are simulated in real time on the basis of sensor data. If the sensor data has to be examined in order to detect bottlenecks, problems or room for improvement, this does not affect the daily operations. A digital twin can map the full life cycle. This makes it possible to simulate, predict and improve the functions of a machine. Processes and the use of materials can therefore be optimised without the need for sizeable investments or any intervention in the actual process itself. Ideally, problems can be detected and prevented before operation even begins. This way, even highly complex production routes can be examined with little effort. This results in less unscheduled downtime and shorter lead times.

2.7 Internet of Things

The Internet of Things – more specifically, the Industrial Internet of Things (IIoT) in a production context – is a digital network of all physical and digital resources in the production process, which are connected to one another via sensors for the purposes of collecting and analysing operating data continuously, so that information can then be used to improve processes. This increases transparency within a company and makes it easier to track productivity and efficiency. As machines are better suited than humans to collecting, communicating and evaluating data precisely and consistently, there is enormous potential for the production process. The IIoT therefore makes data which has existed in the industrial environment for years usable. The data can be aggregated in a central database and provides a comprehensive overview of the site, even allowing for comparisons with other sites in the company's group. The ultimate goal is optimised, self-organised production all along the value chain.

Unlike the Internet of Things in other fields, the Industrial Internet of Things focuses not on consumers and users, but rather industrial processes and procedures, even if both are based on the same concepts and technologies, such as interconnectivity, automation, autonomy and real-time data. Tasks and production processes are controlled and monitored with the Industrial Internet of Things. This is done using technologies such as intelligent and precise sensor technology which, for example, is integrated into machines, devices, infrastructure, energy systems and pipes. Control does not necessarily have to be on site; it can also be remote. Physical and virtual objects are networked via IIoT platforms. These process and evaluate data generated by the production process, sometimes in real time. This increases the transparency of the production process and the entire supply chain, and makes it possible to automate, optimise, predict and rationalise processes. This way, errors, potential defects and need for maintenance can be detected and dealt with in good time.

Ultimately, data-driven decisions can be made, manual adjustments made or the production process controlled fully or partially autonomously on the basis of all the processed information. Likewise, problems and inefficiencies can be detected at an early stage. Furthermore, IIoT solutions pave the way for resource management optimisations, such as reducing energy consumption by identifying inefficient machines or integrating renewable energy. Water and other resources can also be used more efficiently. Continuously monitoring the status and performance of machines and systems can even prevent potential breakdowns, as maintenance can be carried out punctually. Analysing predefined indicators such as temperature, pressure, fill level or vibration can detect deviations that point to impending breakdowns or impaired performance. Problems can be avoided if the system raises the alarm at the right time. The supply chain can be optimised by seamlessly tracking the movements of raw materials, intermediate products and finished products in transit, and responding to any obstacles or delays in an appropriate manner. The system ensures that raw materials are replenished smoothly so as to prevent idle time in production.

2.8 Artificial intelligence

Industrial automation in the manufacturing sector can be raised to a new level with artificial intelligence (AI). In machine production and in the production environment, AI can be used in a wide range of fields ranging from product and process development to resource planning and procurement to maintenance and logistics. AI-controlled machines open up new ways to structure the production process by obtaining findings independently and controlling processes intuitively, thus reducing the need for human intervention. AI enables them to learn, optimise themselves and respond to changes independently. Combining structured machine data with unstructured data such as images, videos and sounds makes it possible to detect patterns and correlations. The more cognitive the AI, the less human intervention is needed in the processes.

The almost boundless quantities of sensor-based data obtained in an Industry 4.0 production process can only be evaluated in real time and used for optimisation with AI. This makes it possible to obtain unprecedented information about the production process. Within manufacturing, AI has found numerous applications in industrial automation. For instance, AI can coordinate production processes independently or assist humans and robots with difficult assembly work. The use of AI results in faster, higher-quality manufacturing which uses fewer materials and less energy.

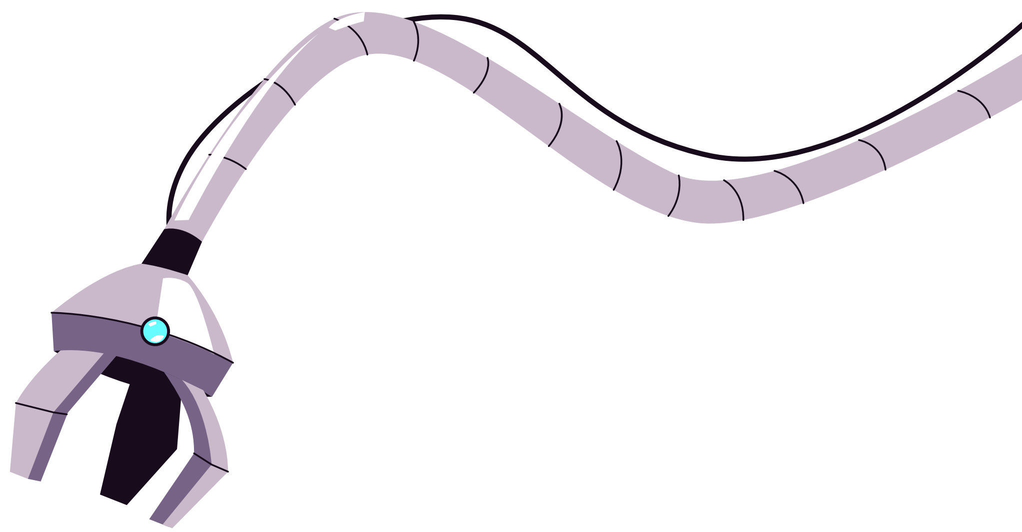
In keeping with the criteria of efficiency and cost minimisation, AI can be used to monitor, optimise and control individual process stages or even complex entire processes within defined system boundaries, autonomously and with minimal human interaction. Machines can learn complex relationships independently and act independently within their preset parameters, either in an anticipatory manner or intervening in ongoing operations.

Previously undetected aspects can be uncovered and emerging problems or anomalies in the manufacturing process can be identified and fixed, because AI has the capability to respond in real time to unforeseen and changing circumstances. There are numerous advantages to real-time monitoring, including overcoming production bottlenecks, tracking rejection rates and meeting customer delivery deadlines.

Predictive maintenance is another application of AI in the production process. Sensors on the networked machines capture lots of status information. Algorithms are now able to detect certain patterns in the machine data, making it possible to predict future status conditions. Whereas the need for maintenance used to be derived from the data using rules-based methods (e.g. a set value being exceeded), AI can analyse the data faster and predict any need for maintenance more accurately. Unscheduled machine downtime is normally synonymous with considerable costs. To avoid these, predictive maintenance can be used to monitor machines and production systems and perform maintenance before it becomes necessary. Repairs can then be carried out proactively before the damage occurs, maximising operating times. Predictive maintenance even allows for individual maintenance sessions for individual machines and components. Predicting when maintenance or repairs should be performed greatly extends the service lives of systems, machines and tools.

Moreover, increasingly complex manufacturing processes in the field of machine production can result in faulty machine configurations and greater susceptibility to errors, and in turn extra work and increased resource consumption. Fast, precise and therefore cost-effective quality controls by AI are of considerable advantage for this reason. With the intelligent image recognition of self-learning systems, operating data can be analysed to compare the current status of products against the target status automatically. Quality defects can therefore be identified and corrected in good time. This requires all production-related systems such as status monitoring, production planning and process quality to be networked. Ideally, the results can be processed in real time so that the production process can react immediately. This could significantly reduce or avoid defective end products.

Moreover, AI can perform lots of monotonous tasks as part of routine manufacturing and assembly processes and process simple orders with voice control. Smart AI-controlled automated transport systems also improve the production process enormously.



2.9 Robotics

Robots have traditionally been tasked with performing repetitive routine tasks. This required complex programming for the production system and had poor adaptability to changing situations. Thanks to technological advancements and the use of AI, autonomous mobile robots (AMRs) require significantly less programming work. AMRs are used in production in order to minimise the amount of manual work. They can vary in terms of size, functions, mobility, manoeuvrability and intelligence. Consequently, they are used in applications ranging from robotic process automation to drones. They move autonomously and perform tasks without human intervention. Machine vision enables an AMR to process visual information from the factory, such as obstacles, workers or traversable space. With this information, the AMR is able to travel autonomously on the site and perform tasks independently or with minimal human intervention. This makes it possible to automate numerous tasks without having to invest in transport infrastructure such as rails. As AMRs allow for dynamic route planning, they have the flexibility to choose the best route within set parameters and avoid obstacles. They can communicate with workers and even parts of the production facility.

AMRs can learn from their environment and make independent decisions. Unlike human beings, they do not need breaks and can perform tasks that humans are unable or unwilling to do at a consistent level of quality. They are particularly well suited to monotonous tasks, leaving workers free to handle more creative assignments. Additionally, using them to carry out dangerous work protects employees and improves safety within the company. AMRs can perform all sorts of tasks, such as picking, packing, sorting, building and transporting, largely regardless of weight and size.

Generally speaking, companies have been using industrial robots for decades already. Most were surrounded by cages to keep them separate from employees and avoid accidents, as these robots were unable to react to their environment and could not detect obstacles. Thanks to improved sensors and AI, robots can now work 'hand-in-hand' and cooperate with employees to carry out tasks.

3 Industry 4.0 – Results of a survey in ten European countries

3.1 Methods of investigation

From 29 October to 14 November 2021, the market research Institute YouGov carried out an online survey of 4,531 corporate decision-makers on behalf of the Handelsblatt Research Institute and TeamViewer. The empirical section of the report is based on this survey. It was rolled out in ten European countries: Denmark, Germany, France, Italy, the Netherlands, Norway, Poland, Sweden, Spain and the United Kingdom.

The survey sheds light on the digitisation of production in a 'pan-European' context as well as deviations from this 'pan-European' average in individual countries.

The following examination of results focuses on the overall 'European' situation, which is why the individual results from the ten countries are presented as an aggregate. Differences between the individual countries are also addressed, however.

The topic of the survey is Industry 4.0. The questions look at the following aspects:

- Relevant aspects of Industry 4.0
- The state of digitisation in corporate production
- Challenges in the digitisation of production
- Main responsibility for the digitisation of production
- Advantages of Industry 4.0
- Individual future technologies: how they are expected to shape the production of the future and their current and planned use by companies
- Potential applications of the Internet of Things
- Potential applications of augmented reality
- Potential applications of artificial intelligence
- Changing production processes on factory floors

Given the focus of this survey, it is only of relevance to companies in which production processes are at least somewhat important. The following results are therefore based on the responses given by a random sample of 1,452 companies in the chosen ten European countries that meet these criteria.

3.2 The digitisation of production

3.2.1 Dimensions of Industry 4.0

The concept of Industry 4.0 was first introduced to the general public at the Hannover Messe trade fair in 2011. The term was coined by Henning Kagermann and Wolfgang Wahlster from the German National Academy of Science and Engineering as well as Wolf-Dieter Lukas from the German Federal Ministry of Education and Research. Originally, it referred specifically to the digitisation of production as a 'Fourth Industrial Revolution'.

The term then became internationally widespread and has since become synonymous with the general digitisation of companies – even outside of the context of production. As such, Industry 4.0 and the underlying idea can encompass more than the use of new types of technology in production.

The majority of companies in Europe therefore take the term 'Industry 4.0' to mean a multidimensional approach. It is absolutely not the case that the term merely refers to networking, the use of technology, data use or the digitisation of production process.

For around 70 per cent of the companies, Industry 4.0 involves the use of augmented reality (AR) and artificial intelligence (AI) alongside the aforementioned aspects (see image 1). Overall, it refers to a comprehensive transformation which, for most of the surveyed corporate decision-makers, brings in its wake changes to work processes where humans and machines cooperate and workers are assisted with manual processes by technology.

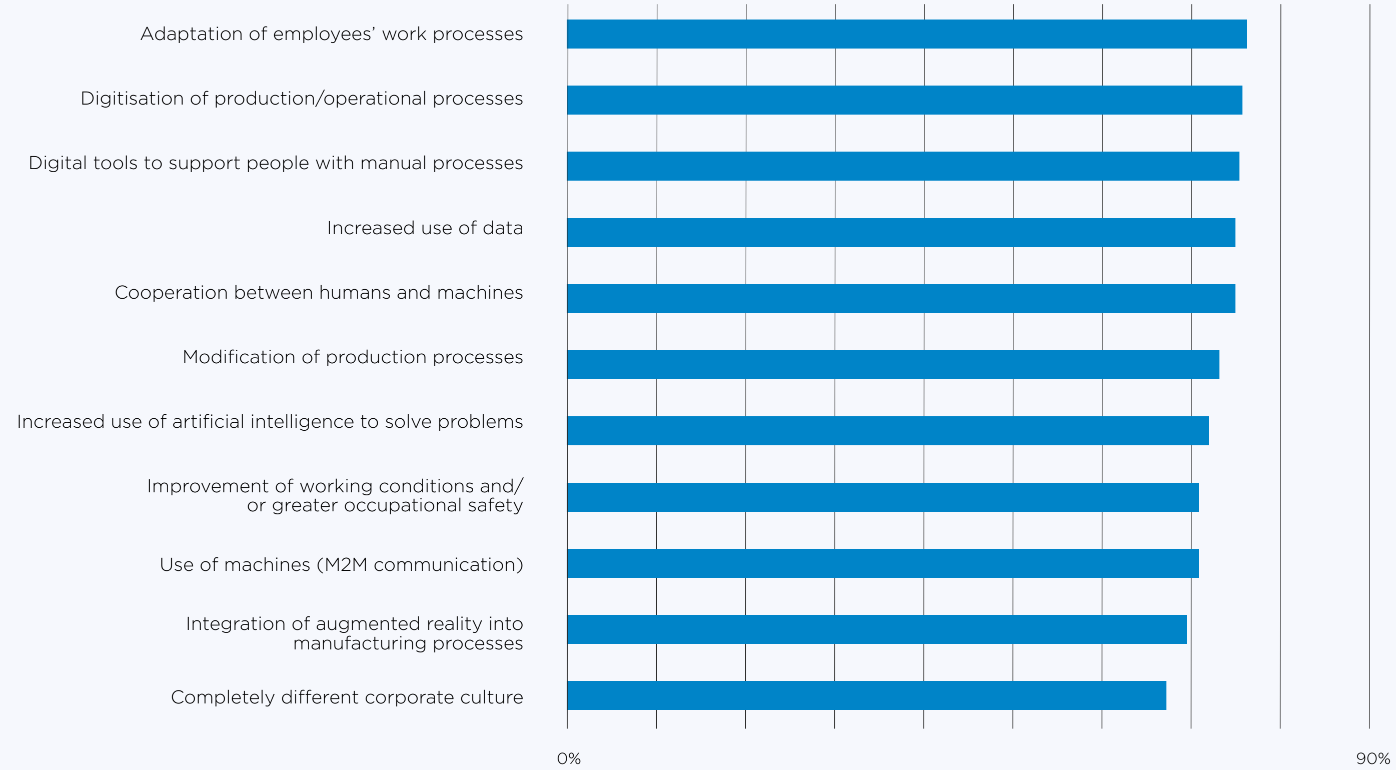
More than 70 per cent of the European corporate decision-makers are of the opinion that this transformation will lead to improved working conditions, better occupational health and safety and a completely different corporate culture.

This multidimensional understanding of Industry 4.0 is evident in all ten of the surveyed countries. Across all its dimensions, this view is particularly widespread among companies in Germany, Italy, Spain and Poland.

Furthermore, the results show that larger companies and companies which have already made great strides with digitisation tend to attribute all of the aspects covered by the survey to the term 'Industry 4.0'.

Image 1: Aspects belonging to the concept of Industry 4.0

Proportion of surveyed corporate decision-makers who (tend to) agree that the aspect belongs to the concept, in %



3.2.2 Progress of digitisation

The majority of the surveyed companies are still on the starting line in terms of the digitisation of production. Fewer than one quarter of the respondents said that their company has already started to digitise (see image 2). More than half of the companies admit that they do not even have a strategy to digitise their production. For them, digitisation might consist of individual measures with no guiding principle to unite them all. In this regard, it is not surprising that only one tenth of the surveyed companies say that they have already made good progress with digitisation.

Larger companies have already made strong progress with the digitisation of their production. Consequently, the proportion of companies that have begun to digitise increases along with company size, albeit not at a constant rate. That being said, Industry 4.0 is about more than just the use of new technology (see section 3.2.1), although it is an important aspect. And the implementation of these technologies requires financial and human resources which larger companies tend to have at their disposal.

Image 2: Status quo among companies with regard to the digitisation of production

Proportion of surveyed corporate decision-makers, in %

Remaining percentage: do not know / N/A.

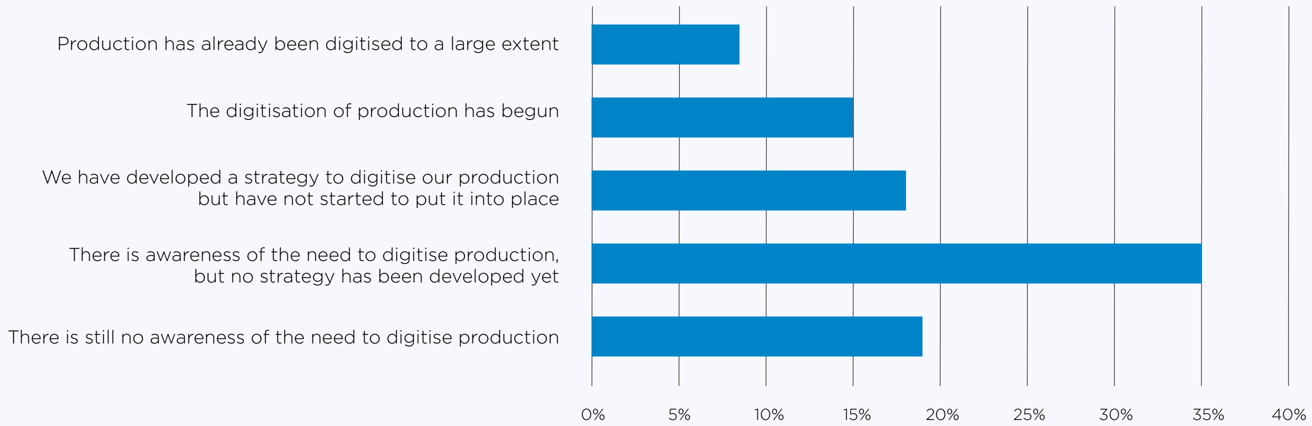
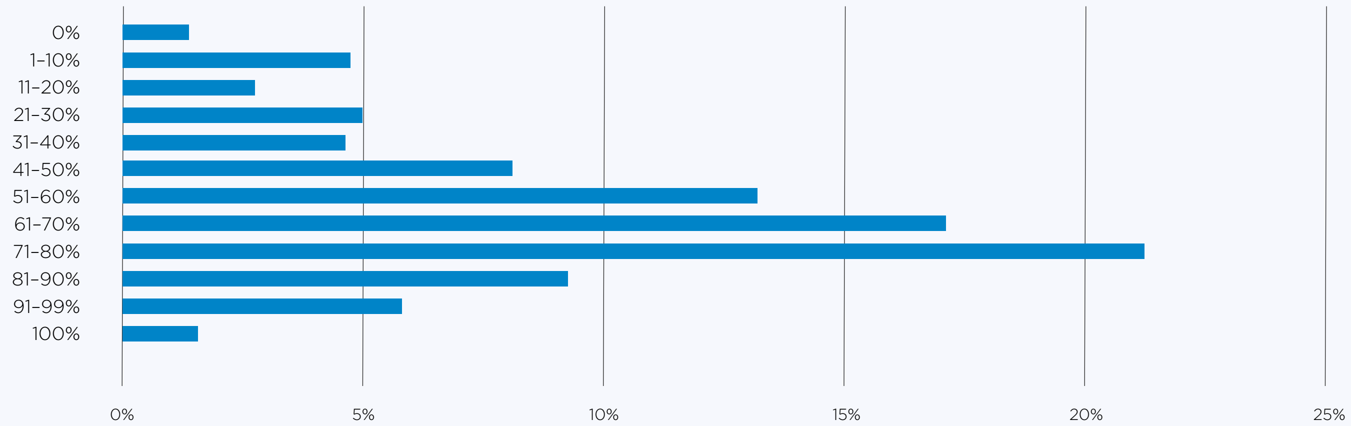


Image 3: The progress of the digitisation of production in companies

Proportion of surveyed corporate decision-makers, in %

Remaining percentage: do not know / N/A.
Scale from 0% (= no digitisation) to 100% (= advanced where technologically possible)



Comparing countries, we see that companies in Spain, Sweden, the Netherlands, Italy and Germany have already made progress with digitising their production. For example, 29 per cent (Spain), 27 per cent (Sweden and the Netherlands) and 26 per cent (Italy and Germany) have already begun to digitise. French (19 per cent) and British (16 per cent) companies are somewhat further behind, on the other hand.

Overall, these results suggest that the digitisation of production has not generally taken off yet. Progress in this area is currently lower than with logistics. As there is no overall strategy in many cases, it will not be possible to potentially catch up on digitisation immediately as a transformation that will be successful in the long term requires a strategy.

The status quo with regard to Industry 4.0 is far more positive when companies rate the current status of the digitisation of production on a scale from 1 to 100 (see image 3). The national average is around 60 per cent. Progress is only below 50 per cent for around one quarter of the surveyed companies. These findings might indicate that ambitions are only moderate when it comes to the more advanced digitisation of production processes.

Whereas companies with fewer than 5,000 employees tend to see a positive correlation between company size and their perception of digitisation, this correlation is not as distinct among larger companies.

Comparing the ten examined countries, we see that companies in Spain, Italy, Poland and Germany believe that they are more advanced, although the country-specific averages are only slightly above the overall average at 65 per cent (Spain), 64 per cent (Italy) and 63 per cent (Poland and Germany). The perceived state of the digitisation of production is lower among companies in the United Kingdom (46 per cent) and Denmark (46 per cent).

The results in image 2 and image 3 show two differing assessments of the state of digitisation in corporate production. Based on the percentage scale, most companies see themselves as ‘relatively advanced’ already, although this is not reflected by certain milestones such as a strategy having been accomplished. In some situations, companies score themselves more positively on the scale even though they have not done much at all in general because they are either unable or unwilling to do much in their individual situations. As such, the bar is set at a different level for every company.

And even if companies are already far advanced along the scale in their own estimation, they still have some work to do. From an economic standpoint, it seems plausible that the more progress has already been made, the higher the cost of additional digitisation.

3.2.3 Challenges in the digitisation of production

As they digitise their production, companies are confronted with challenges that can slow their progress. For example, these challenges relate to employees or even the general conditions.

According to the surveyed corporate decision-makers in Europe, the digitisation of production is a matter of resources first and foremost. In any case, around one third of the respondents say that the cost, in terms of both time and money, is the greatest challenge of digitising production (see image 4). This opinion is not dependent on company size. Even large companies which most likely have more resources at their disposal see this cost as the greatest challenge.

IT security is another challenge. Data and increasingly large networks are playing an increasingly important role in production with regard to aspects such as big data analysis and the Internet of Things. This causes the risk of cyberattacks to increase, making preventive security measures essential. And for around 30 per cent of the surveyed decision-makers, IT security concerns are of grave concern to them in terms of digitisation.

Image 4: The great challenges of the digitisation of production in companies

Proportion of surveyed corporate decision-makers, in %

Multiple answers can be given

Interestingly, this topic becomes more significant when progress has already been made with digitisation. Companies that admit they are only now waking up to the relevance of Industry 4.0 or developing a strategy see the time and costs as the greatest challenge. Among companies that have already begun to digitise or have made good progress, a larger proportion of the decision-makers say that IT security concerns are a significant challenge.

Furthermore, a digitised production process is not being built from the ground up in most cases; existing systems are instead being augmented – or digitised. For example, software is used to network machines that were already there. In some situations, this can result in compatibility problems between old and new technology. According to the companies in Europe, this is another challenge posed by the digitisation of production.

On the other hand, fewer companies believe that a lack of personnel, a lack of acceptance by employees and low prioritisation by management are the main obstacles to the digitisation of production.

The question of value is another interesting aspect. Only around one fifth of corporate decision-makers in Europe see the unclear benefits of digitised production as a key problem of digitisation. Only around one tenth of companies that have made some progress in this area are of this opinion. In this respect, uncertainty about the specific benefits should not prevent any company from digitising its production because this question usually answers itself over the course of the process.

The ranked order of the challenges is relatively similar from country to country, even if not every single position is identical. However, the group of aspects considered significant by most corporate decision-makers is the same in most countries. Nevertheless, companies have different focuses when it comes to the most significant challenge. Corporate decision-makers in Denmark, France, Italy, Poland and Spain most often answer with time and costs. In contrast, IT security concerns are the most common answer in Germany, the Netherlands and Sweden. One third of respondents in the United Kingdom say that the greatest challenge is incompatibility between old and new technology, whereas it is a lack of internal know-how in Norway.

When we consider what companies see as the most significant challenges, it becomes evident that they primarily lie within the control of the companies and can, in principle, be dealt with by larger investments. There is not a lack of conviction or willingness.

3.2.4 Main responsibility for the digitisation of production

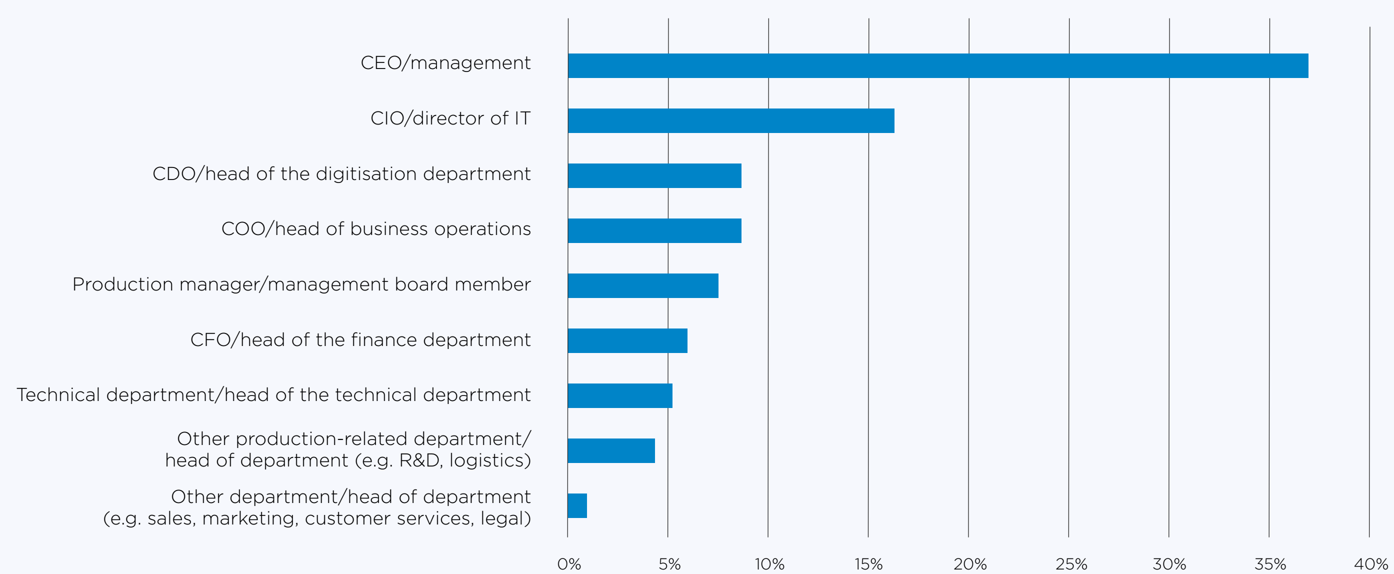
The digitisation of production is a large, drawn-out corporate project. Implementing new technology goes hand-in-hand with sizeable investments. In light of these costs and the great significant of digitisation, it is understandable that the topic of Industry 4.0 is often a top priority for companies.

This is also evident from the surveyed companies in Europe: In almost two fifths of these companies, the CEO or management makes the final decision to invest in Industry 4.0 applications (see image 5). In particular, this is the case for companies in Denmark, Sweden and the United Kingdom.

That being said, CEOs play the most important role in Germany, Spain and the Netherlands too. However, the CIO makes the final decision in many companies in these countries.

For a little more than three quarters of the surveyed companies, the decision to invest in the digitisation of production is made on the C-level. This shows that Industry 4.0 is not seen as a 'minor project' there, but rather as something which will shape the company's future image and be of strategic importance. Whether and to what extent a company will press on with the digitisation of its production therefore depends on this upper corporate level and its position on digitisation.

Image 5: Who makes the final decision to invest in the digitisation of production?
Proportion of surveyed corporate decision-makers in %

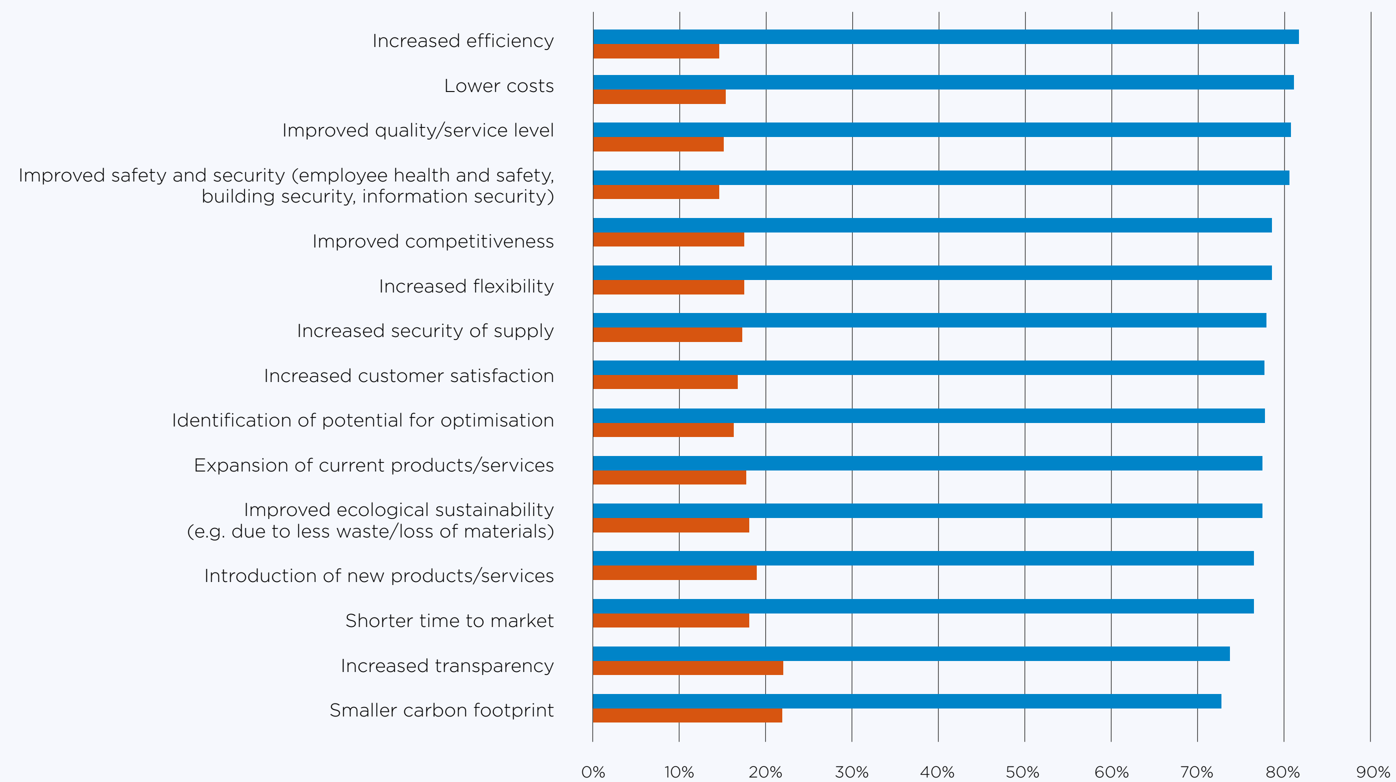


3.2.5 The estimated benefits of Industry 4.0

Companies are not digitising their production purely out of interest in new technology; the digitisation process is associated with real advantages and expected benefits. The most important goals being pursued by embracing Industry 4.0 – in the opinions of the surveyed companies in Europe – have economic links (see image 6). At almost 82 per cent, most companies see improved efficiency as a significant advantage resulting from the use of innovative technologies in production processes. Cost reductions are another important advantage. Besides these economic factors, improved quality or service level and security are cited as important aspects of Industry 4.0. The latter relates to the health and safety of employees, building security and information security.

On the other hand, somewhat fewer companies see reducing their carbon footprint and increasing transparency as key potential advantages. The expectations motivating companies to use digital technology are therefore primarily economic in nature.

Image 6: The benefits of using digital technology in production
Proportion of surveyed corporate decision-makers, in %



3.3 Future technology

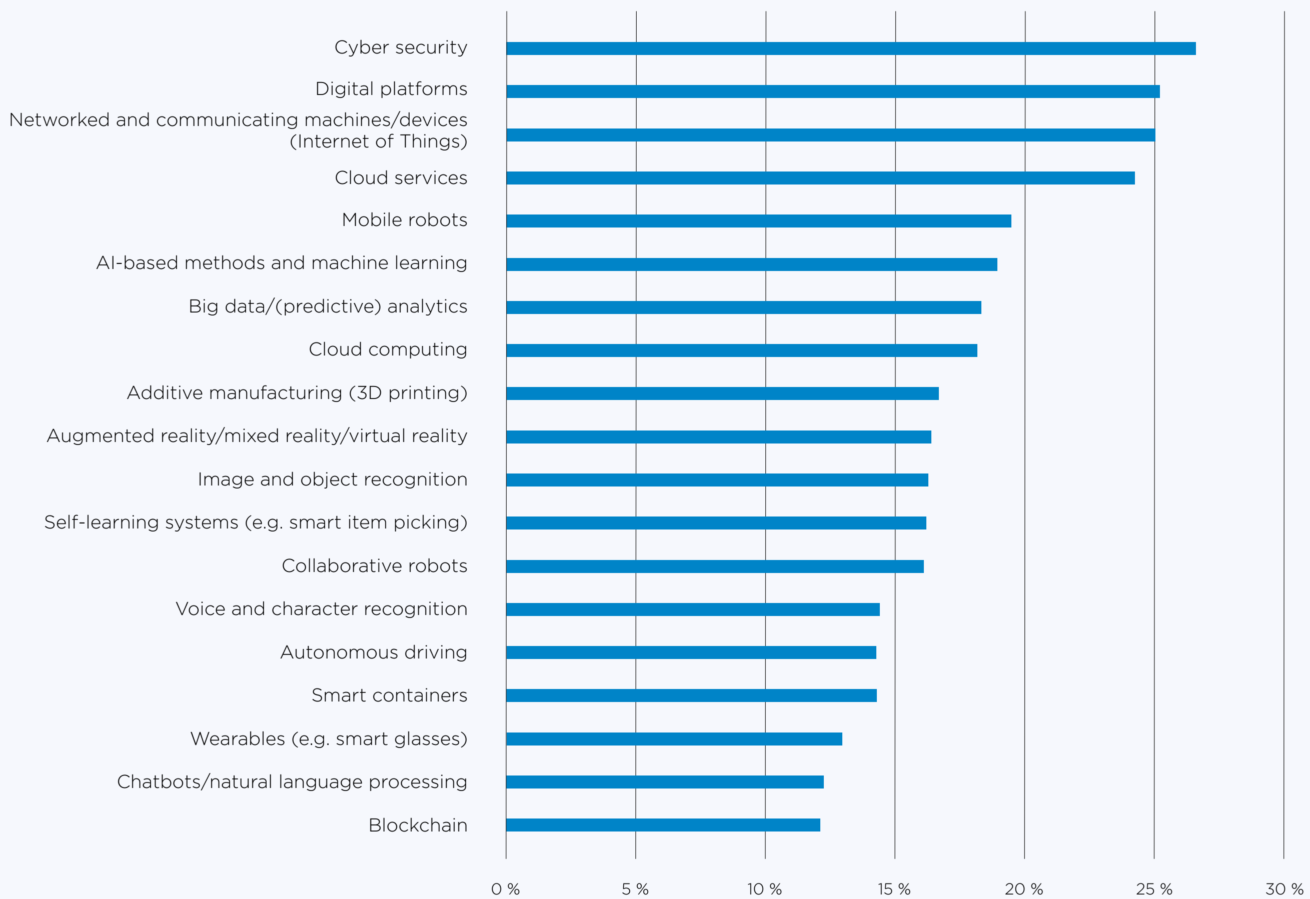
Essentially, the digitisation of production encompasses the transformation of processes – from production processes on machines to the way in which employees work. The use of new, digital technology is the starting point for this transformation. Processes are changing as companies introduce new applications, solutions and business models. The transformation of production can encompass numerous types of technology, the relevance of which can vary in the eyes of companies and which have already been implemented to varying extents.

3.3.1 Expected relevance of innovative technology to the production of the future and its implementation

Image 7: Important future technologies in production

Proportion of surveyed corporate decision-makers, in %

Multiple answers can be given



According to most of the surveyed companies in Europe – a little more than one quarter – cybersecurity is a particularly important aspect of Industry 4.0 (see image 7). Likewise, digital platforms, the Internet of Things and cloud services are exceptionally relevant. Around one quarter of companies in the ten surveyed countries see each of these technologies as a key pillar of the digitisation of production. It is evident across all of the technologies that companies which have already made good progress with digitisation weight the technologies more heavily.

In contrast, blockchain, chatbots and wearables tend to be considered less significant, occupying the bottom three places out of the 19 technologies in question. Although, for example, smart glasses in manufacturing are not considered an important technology by many companies, the situation is different with regard to the related applications – augmented reality, mixed reality and/or virtual reality. These are ranked tenth out of the 19 possible answers.

Looking at all the technologies as a whole, it is evident that they are seen as somewhat more relevant by companies in Spain, Italy and Poland in particular compared to other countries, and in turn the national average (see image 8). In contrast, their estimated relevance is below average in the United Kingdom, Denmark and Sweden. In deviation from the aggregate perspective,

- pattern recognition (image/object and voice/character) plays a slightly more important role in Germany,
- collaborative robots play a slightly more important role in Spain,
- self-learning systems play a slightly more important role in Italy,
- image and object recognition plays a slightly more important role in Sweden,
- wearables play a slightly more important role in Norway.

According to the surveyed companies, the various technologies will not only play roles of varying importance in manufacturing in the future. They are also, or soon will be, implemented by companies to varying different extents. However, there is a certain correlation between two aspects: The technologies which are considered more important also see more frequent use. For instance, more companies use cloud services and cloud computing, cybersecurity and digital platforms in their production than any other innovative technology (see image 9). However, there is still great potential for further rollouts. For example, cloud services and cybersecurity are only being used by around half of the surveyed companies in Europe which consider each of these types of technology important to the production of tomorrow.

Additive manufacturing, mobile robots, chatbots, artificial intelligence, big data and blockchain have tremendous potential in the short and medium terms because an exceptionally large number of companies hope to implement them in the next one to two years.

Image 8: Important future technologies in production – comparison of countries

Multiple answers can be given

Proportion of surveyed corporate decision-makers, in %

Highlighted: Proportion above the national average of European countries

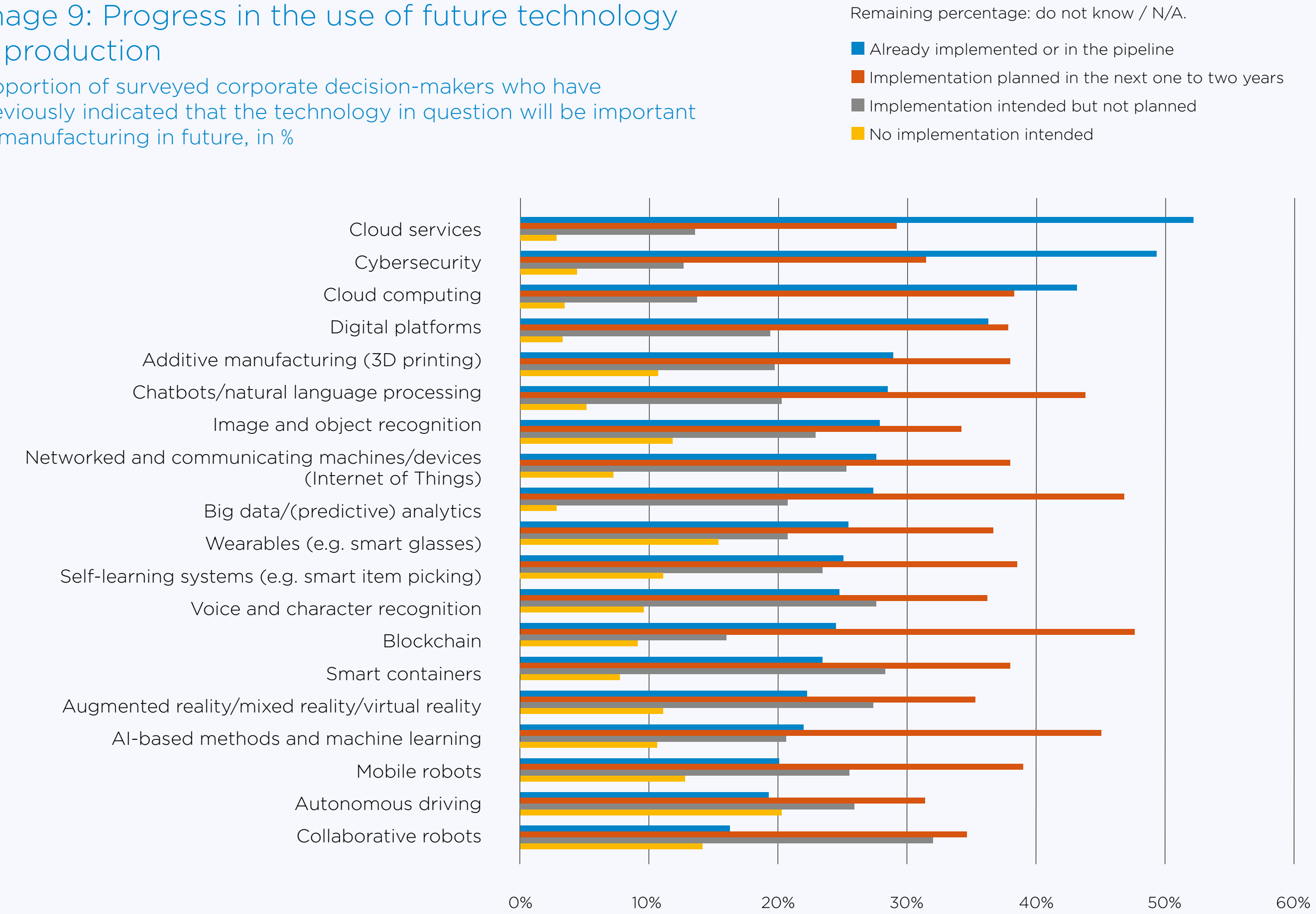
	ø	DE	UK	FR	ES	IT	DK	SE	NO	NL	PL
Cybersecurity	27%	25%	14%	24%	28%	32%	25%	19%	23%	35%	34%
Digital platforms	25%	26%	20%	17%	29%	27%	29%	24%	23%	32%	29%
Networked and communicating machines/ devices (Internet of Things)	25%	22%	24%	23%	30%	31%	17%	21%	23%	28%	25%
Cloud services	24%	23%	16%	21%	27%	24%	16%	24%	19%	31%	33%
Mobile robots	19%	17%	14%	21%	25%	19%	11%	19%	19%	17%	26%
AI-based methods and machine learning	19%	19%	17%	19%	26%	22%	9%	14%	23%	13%	18%
Big data/(predictive) analytics	18%	22%	18%	18%	24%	21%	11%	5%	14%	17%	18%
Cloud computing	18%	15%	18%	17%	26%	19%	10%	12%	18%	21%	19%
Additive manufacturing (3D printing)	17%	20%	15%	16%	25%	14%	9%	16%	11%	12%	16%
Augmented reality/mixed reality/virtual reality	16%	17%	10%	19%	22%	20%	9%	14%	11%	10%	17%
Image and object recognition	16%	21%	12%	14%	17%	21%	15%	20%	7%	13%	15%
Collaborative robots	16%	16%	8%	21%	22%	17%	10%	12%	14%	16%	13%
Self-learning systems (e.g. smart item picking)	16%	19%	11%	14%	19%	20%	14%	15%	12%	17%	15%
Voice and character recognition	14%	18%	9%	18%	14%	15%	3%	11%	14%	15%	16%
Smart containers	14%	14%	14%	16%	18%	15%	6%	13%	12%	14%	14%
Autonomous driving	14%	14%	7%	13%	19%	16%	6%	15%	19%	8%	19%
Wearables (e.g. smart glasses)	13%	10%	8%	14%	19%	17%	2%	5%	25%	9%	16%
Chatbots/natural language processing	12%	13%	8%	15%	18%	11%	7%	8%	7%	13%	12%
Blockchain	12%	13%	10%	9%	18%	11%	6%	11%	9%	14%	16%

As a relatively large number of companies plan to implement autonomous driving, intelligent containers, voice and character recognition, AR/MR/VR and collaborative robots (but have no specific schedules), the markets for these technologies can be expected to grow in the medium to long terms.

Image 9: Progress in the use of future technology in production

Proportion of surveyed corporate decision-makers who have previously indicated that the technology in question will be important to manufacturing in future, in %

Remaining percentage: do not know / N/A.



3.3.2 Decision criteria in the selection of technology providers

Companies often rely on external providers to implement new technology. If there is a selection of technology providers, doubtful companies must choose one provider. A decision can be based on a lot of different criteria. For some companies, the price might be the decisive factor. Others might focus on quality or the scope of the application's services. Likewise, the provider's references could be critical.

For most of the surveyed companies in Europe – one fifth – clear and flexible pricing is the important criterion when it comes to selecting a technology provider (see image 10). The priority is not to find the lowest price possible, but rather clear prices which can be adapted to meet specific requirements when a quotation is prepared. Security and the availability of advice, support and professional services are also exceptionally important aspects. Certain differences are evident for some company types. For instance, pricing and advice are of particular importance to smaller companies. This is perhaps because they have fewer financial resources at their disposal and relatively little know-how due to limited numbers of personnel.

Image 10: Important decision criteria in the selection of technology providers

Proportion of surveyed corporate decision-makers, in %

Multiple answers can be given

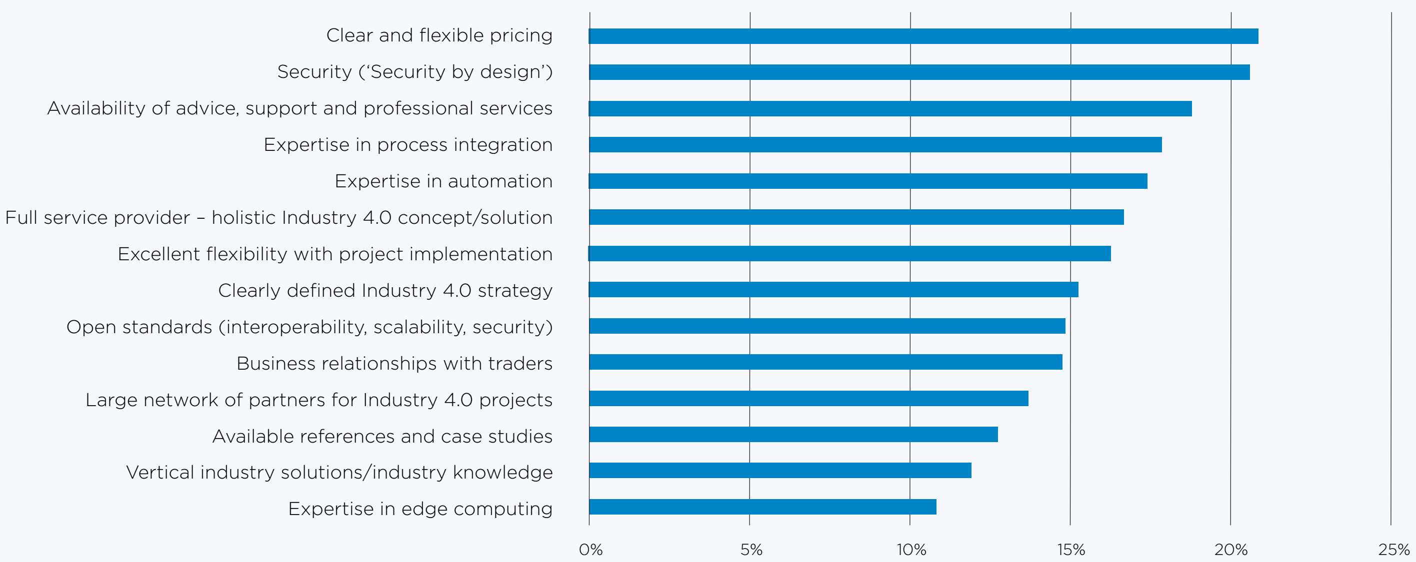


Image 11: Important decision criteria in the selection of technology providers – comparison of countries

Proportion of surveyed corporate decision-makers, in %

Highlighted: Proportion above the national average of European countries

Multiple answers can be given

	ø	DE	UK	FR	ES	IT	DK	SE	NO	NL	PL
Clear and flexible pricing	21%	16%	18%	19%	18%	20%	32%	22%	32%	29%	20%
Security (‘Security by design’)	21%	21%	15%	23%	17%	19%	34%	21%	21%	23%	18%
Availability of advice, support and professional services	19%	18%	11%	21%	24%	23%	17%	14%	14%	9%	24%
Expertise in process integration	18%	14%	15%	17%	15%	26%	14%	13%	26%	19%	19%
Expertise in automation	17%	11%	15%	15%	21%	19%	17%	12%	19%	27%	21%
Full service provider – holistic Industry 4.0 concept/solution	17%	20%	15%	15%	21%	19%	9%	9%	11%	12%	21%
Excellent flexibility with project implementation	16%	17%	15%	10%	16%	21%	13%	19%	16%	21%	18%
Clearly defined Industry 4.0 strategy	15%	16%	9%	14%	20%	18%	6%	9%	16%	17%	18%
Open standards (interoperability, scalability, security)	15%	17%	15%	14%	16%	13%	17%	14%	11%	12%	16%
Business relationships with traders	15%	18%	13%	15%	15%	10%	3%	12%	18%	17%	22%
Large network of partners for Industry 4.0 projects	14%	16%	2%	19%	18%	15%	1%	9%	16%	11%	14%
Available references and case studies	13%	14%	9%	13%	19%	13%	7%	8%	14%	8%	15%
Vertical industry solutions/industry knowledge	12%	12%	8%	12%	15%	14%	5%	6%	4%	15%	16%
Expertise in edge computing	11%	13%	5%	15%	11%	15%	5%	7%	11%	6%	9%

For companies which have already made progress with the digitisation of their production, security is more decisive than pricing and, unlike other companies, they focus more heavily on an Industry 4.0 partner network and flexibility when it comes to project implementation. For technology providers, this means that they do not just have to be ‘good’ at one or two criteria, but rather a full range, in order to be considered by as many different companies as possible.

Companies are generally less dependent on references and showcases, for example. This creates potential opportunities for start-ups and businesses from different market segments too.

There are some differences between the individual countries (see image 11). For example, expertise in process integration is most important to Italian companies. Expertise in automation is most important to Dutch companies. And Polish companies prioritise existing business relationships with the traders more heavily than companies from the other countries.

3.4 Internet of Things – potential applications

Around 78 per cent of companies in Europe see potential applications for the Internet of Things in production (see image 12). Despite this, fewer than 30 per cent have started to network machines and objects so far (see image 9). As such, there remains tremendous market potential for IoT applications. The rates of acceptance are exceptionally high in Poland, Spain, Italy, Germany and the Netherlands. Among the countries that definitely see potential for the Internet of Things in manufacturing, Germany and Spain are very much at the top. In contrast, the United Kingdom, France and the Scandinavian countries (Denmark, Norway and Sweden) are not fully convinced, as the decision-makers in these countries tend to be sceptical about IoT applications in manufacturing.

The expected benefits of networked production tend to increase along with company size (see image 13). A healthy 48 per cent of companies in Europe with at least 250 employees agree that there are definitely potential applications for the Internet

Image 12: Potential IoT applications in production by country

Proportion of surveyed corporate decision-makers, in %

Highlighted: Proportion above the national average of European countries

Remaining percentage: do not know / N/A.

	ø	DE	UK	FR	ES	IT	DK	SE	NO	NL	PL
There are definitely potential applications	36%	50%	25%	34%	49%	40%	17%	34%	26%	31%	31%
There are some potential applications	42%	34%	33%	40%	41%	49%	29%	31%	37%	50%	59%
No potential applications	13%	10%	24%	20%	5%	8%	24%	20%	21%	12%	6%

of Things, compared to just 28 per cent of small and medium-sized companies. This discrepancy might be due to larger companies normally controlling more complex production processes, where a seamless network of machines, people and products can be of considerable coordinative value.

Companies throughout Europe that generally see a role for the Internet of Things in production prioritise the automation of order processes, M2M communication and predictive analytics/maintenance as the top three IoT applications (see image 14). However, these priorities do vary from country to country. An above-average number of different applications are cited by corporate decision-makers in Spain, Italy, the United Kingdom and the Netherlands.

Two thirds of companies in Europe are already using one or more IoT platforms. Most of them say that they utilise applications from external providers (see image 15). Significantly fewer decide to go down the path of a proprietary development. Spain, Poland, Italy and Germany are pioneers with regard to the use of IoT platforms. Companies in Denmark, the United Kingdom, Sweden and Norway admit that their production processes are currently particularly poorly networked. This coincides with the fundamental scepticism of corporate decision-makers in these countries towards potential applications of the IoT in production, as shown in image 12 (see page XX). Moreover, the prevalence of IoT platforms is dependent on company size. Whereas almost 85 per cent of companies in the surveyed European countries with at least 250 employees are using one or more IoT platforms, over 40 per cent of small and medium-sized companies with fewer than 250 employees say that they are not operating any such platform (see image 16).

With regard to connectivity for their IoT initiatives, the companies in Europe are currently reliant mainly on wired connections (e.g. fibre optic), followed by short-range wireless connections (e.g. Bluetooth, WLAN and Zigbee) and mobile networks (e.g. 4G or 5G) (see image 17). These findings are

Image 13: Potential IoT applications in production depending on company size

Proportion of surveyed corporate decision-makers, in %

Remaining percentage: do not know / N/A.

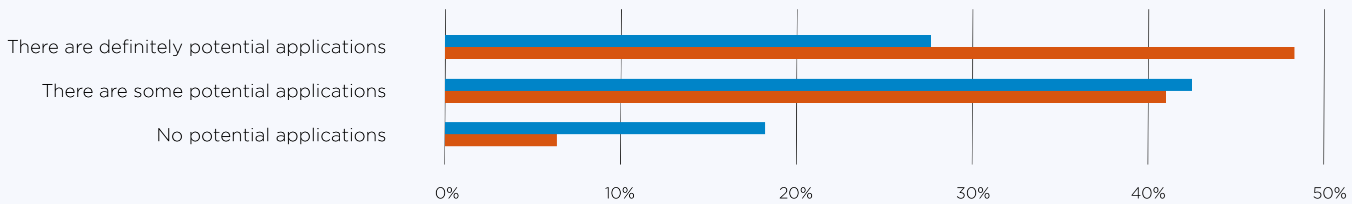


Image 14: Specific potential IoT applications in production

Proportion of surveyed corporate decision-makers who generally see potential IoT applications in their production, in %

Highlighted: Proportion above the national average of European countries

Multiple answers can be given

	ø	DE	UK	FR	ES	IT	DK	SE	NO	NL	PL
Automation of ordering processes	37%	33%	35%	31%	41%	39%	38%	35%	28%	42%	41%
Machine-to-machine (M2M) communication	33%	33%	44%	23%	37%	44%	25%	29%	36%	33%	28%
Predictive analytics/predictive maintenance	32%	32%	37%	26%	41%	34%	40%	18%	25%	34%	26%
A single dashboard with information about all production facilities	31%	33%	29%	32%	36%	32%	28%	18%	33%	25%	32%
Remote machine control	31%	24%	24%	31%	29%	36%	43%	31%	25%	30%	35%
Use of mobile robots	26%	27%	19%	23%	28%	31%	20%	25%	19%	26%	30%
'Digital twins' to simulate production processes	24%	24%	27%	22%	29%	19%	13%	36%	25%	22%	24%
Use of autonomous vehicles	22%	28%	25%	20%	21%	25%	10%	16%	14%	26%	19%

Image 15: Use of IoT platforms in companies

Proportion of surveyed corporate decision-makers, in %

Highlighted: Proportion above the national average of European countries

Remaining percentage: do not know / N/A.

	ø	DE	UK	FR	ES	IT	DK	SE	NO	NL	PL
Use of a proprietary IoT platform	20%	30%	15%	25%	20%	20%	7%	18%	9%	20%	15%
Use of the IoT platform of an external provider	35%	35%	16%	30%	53%	40%	20%	24%	35%	27%	48%
Use of multiple IoT platforms	12%	11%	10%	11%	8%	18%	6%	8%	12%	15%	17%
No use of IoT platforms	27%	21%	43%	30%	16%	20%	56%	36%	35%	32%	12%

Image 16: Use of IoT platforms depending on company size

Proportion of surveyed corporate decision-makers, in %

Remaining percentage: do not know / N/A.

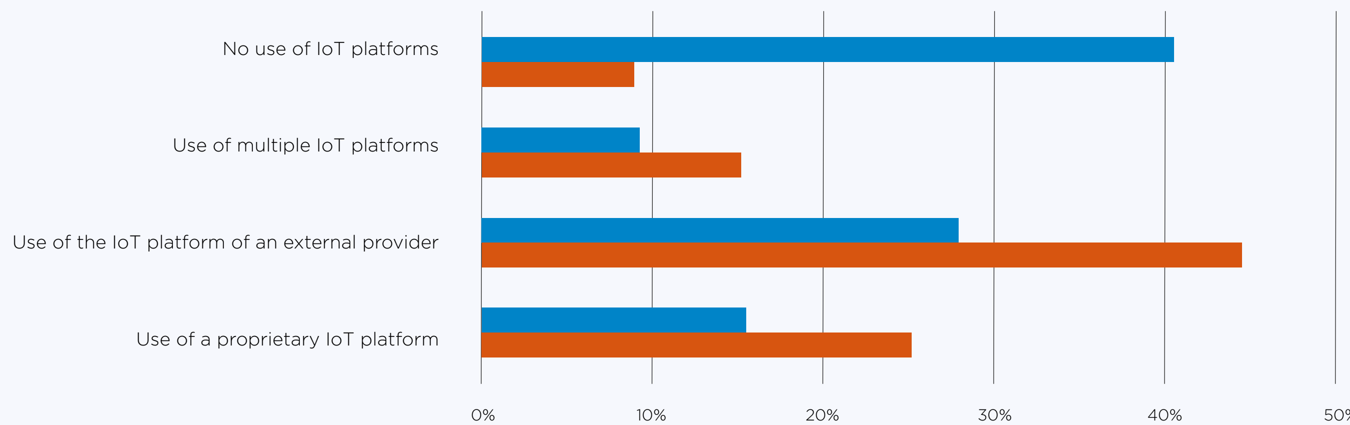
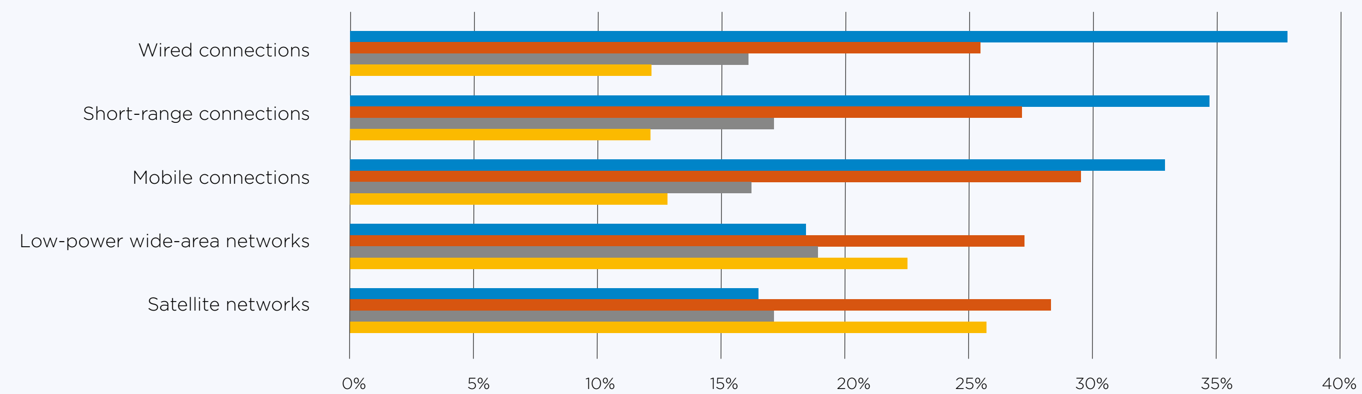


Image 17: Selected connectivity for IoT initiatives in companies

Proportion of surveyed corporate decision-makers, in %

Remaining percentage: do not know / N/A.

- Already implemented or currently being implemented
- Implementation in the next one to two years
- Implementation is planned but has not yet been examined in detail
- No implementation planned



surprising as the wireless standard 5G is being treated as a key enabler of the Internet of Things, and might hint at weaknesses in the mobile infrastructure. After all, network availability and stability are critical to production.

3.5 Augmented reality – potential applications

More than 70 per cent of companies in Europe expect there to be potential applications for augmented reality in production (see image 18). However, fewer than one quarter of them have actually rolled out AR, VR or MR applications in their production (see image 9). An above-average number of opportunities are seen in Spain, Italy, Poland and Germany, whereas companies in the United Kingdom and Scandinavian countries (Denmark, Sweden and Norway) tend to be dismissive.

Image 18: Potential applications for augmented reality in production by country

Proportion of surveyed corporate decision-makers, in %

Highlighted: Proportion above the national average of European countries

Remaining percentage: do not know / N/A.

	ø	DE	UK	FR	ES	IT	DK	SE	NO	NL	PL
There are definitely potential applications	30%	42%	17%	34%	36%	29%	10%	28%	19%	19%	35%
There are some potential applications	40%	36%	27%	34%	51%	53%	29%	29%	35%	46%	46%
No potential applications	23%	18%	41%	26%	11%	15%	37%	34%	32%	28%	16%

The estimated value of AR tends to increase along with the size of the company (see image 19) and with the amount of progress made so far with the digitisation of production (see image 20). This points to economies of scale when the technology is used on the one hand, and to learning curve effects when the new digital technology is dealt with on the other.

Image 19: Potential applications for augmented reality depending on company size

Proportion of surveyed corporate decision-makers, in %

Remaining percentage: do not know / N/A.

- Company with up to 249 employees
- Company with at least 250 employees

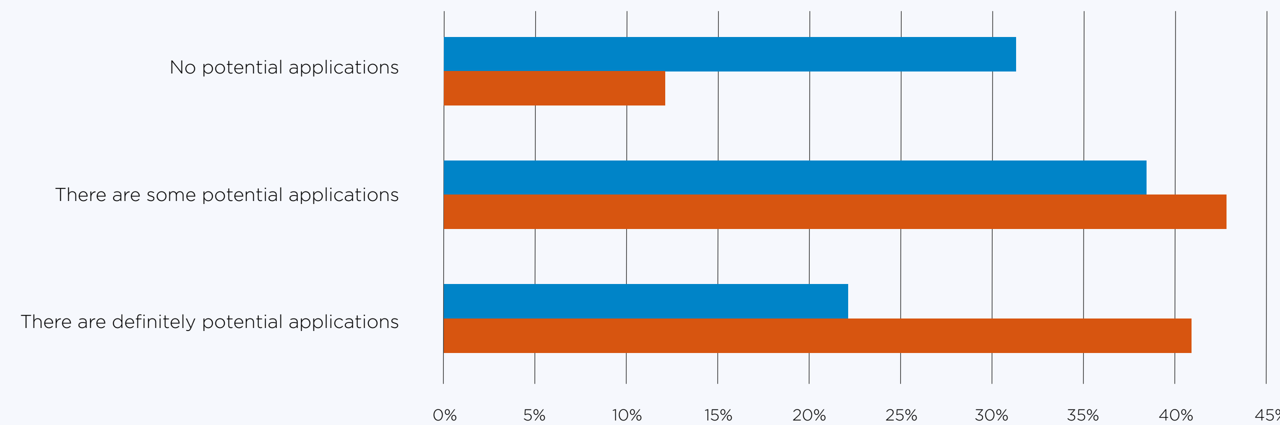
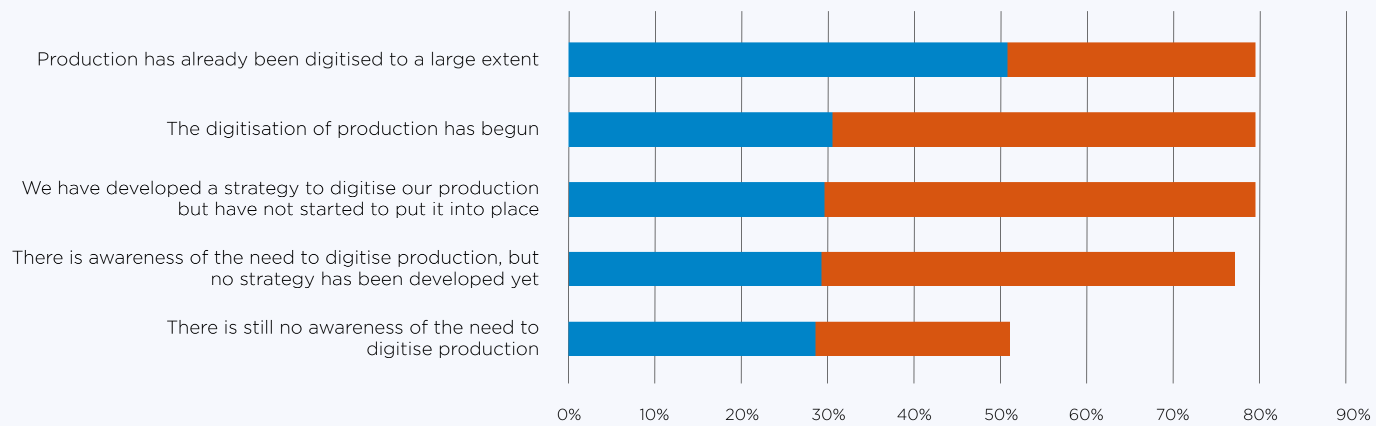


Image 20: Potential applications for augmented reality depending on company size

Proportion of surveyed corporate decision-makers, in %



Quality assurance, installation, maintenance and repair services and the optimisation of production processes are described as the most important potential applications throughout Europe (see image 21). It is noticeable that corporate decision-makers in the various countries have different priorities. Companies in the United Kingdom which see at least some potential applications for AR in their production prioritise the training and integration of employees. This stands in contrast to remote support for remote expert assistance in France, assembly, maintenance and repair services in Germany, Spain and Sweden and the optimisation of production processes in Italy (see image 22).

The discrepancy between the current and expected use of AR in production can be

Image 21: Examples of applications for augmented reality in their own company's production

Multiple answers can be given

Proportion of surveyed corporate decision-makers who generally see potential AR applications in their production, in %

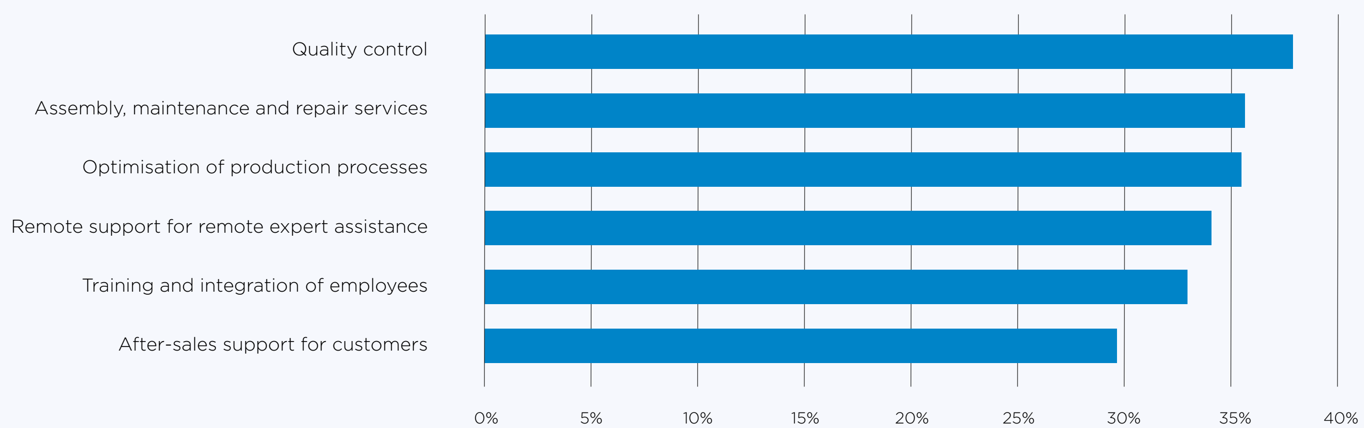


Image 22: Examples of applications for augmented reality in production by country

Multiple answers can be given

Proportion of surveyed corporate decision-makers who generally see potential AR applications in their production, in %

Highlighted: Proportion above the national average of European countries

	ø	DE	UK	FR	ES	IT	DK	SE	NO	NL	PL
Quality control	38%	39%	41%	28%	33%	41%	44%	37%	48%	51%	41%
Assembly, maintenance and repair services	36%	42%	27%	31%	43%	33%	29%	45%	19%	24%	39%
Optimisation of production processes	36%	32%	20%	32%	37%	42%	32%	33%	26%	48%	38%
Remote support for remote expert assistance	34%	35%	39%	40%	36%	34%	41%	31%	13%	20%	32%
Training and integration of employees	33%	34%	43%	31%	33%	36%	21%	33%	29%	28%	35%
After-sales support for customers	30%	24%	37%	25%	23%	29%	35%	39%	39%	42%	35%

explained in a variety of ways: Not all potential users might be sure of the business potential at the moment – the additional revenue from the potential applications might not (yet) outweigh the costs. Alternatively, the currently available tools are not advanced enough, require too much consultation and/or are not well enough known due to a lack of market transparency.

3.6 Artificial intelligence – potential applications

On a European level, around 73 per cent of decision-makers see potential for artificial intelligence in their company's production (see image 23). The respondents from Poland were ranked highest at 88 per cent, followed by Spain (87 per cent), Italy (82 per cent) and Germany (74 per cent). In contrast, over 40 per cent of companies in both Denmark and the United Kingdom see no potential applications of any kind for AI in their production.

Image 23: Potential applications for artificial intelligence in production by country

Remaining percentage: do not know / N/A.

Proportion of surveyed corporate decision-makers, in %

Highlighted: Proportion above the national average of European countries

	ø	DE	UK	FR	ES	IT	DK	SE	NO	NL	PL
There are definitely potential applications	30%	38%	24%	32%	36%	34%	13%	29%	16%	23%	32%
There are some potential applications	42%	36%	25%	39%	51%	48%	31%	36%	39%	47%	57%
No potential applications	21%	22%	41%	24%	9%	14%	43%	25%	33%	23%	9%

Image 24: Potential applications for artificial intelligence depending on company size

Proportion of surveyed corporate decision-makers, in %

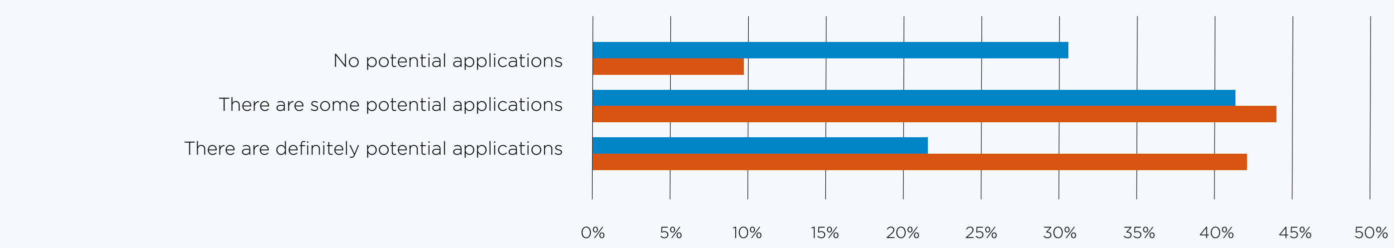


Image 25: Potential applications for artificial intelligence depending on company size

Proportion of surveyed corporate decision-makers, in %

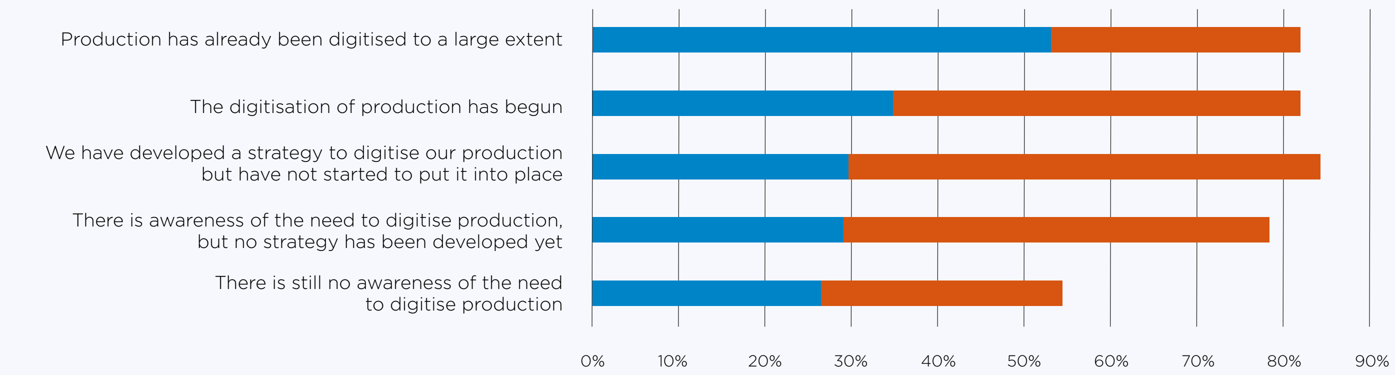
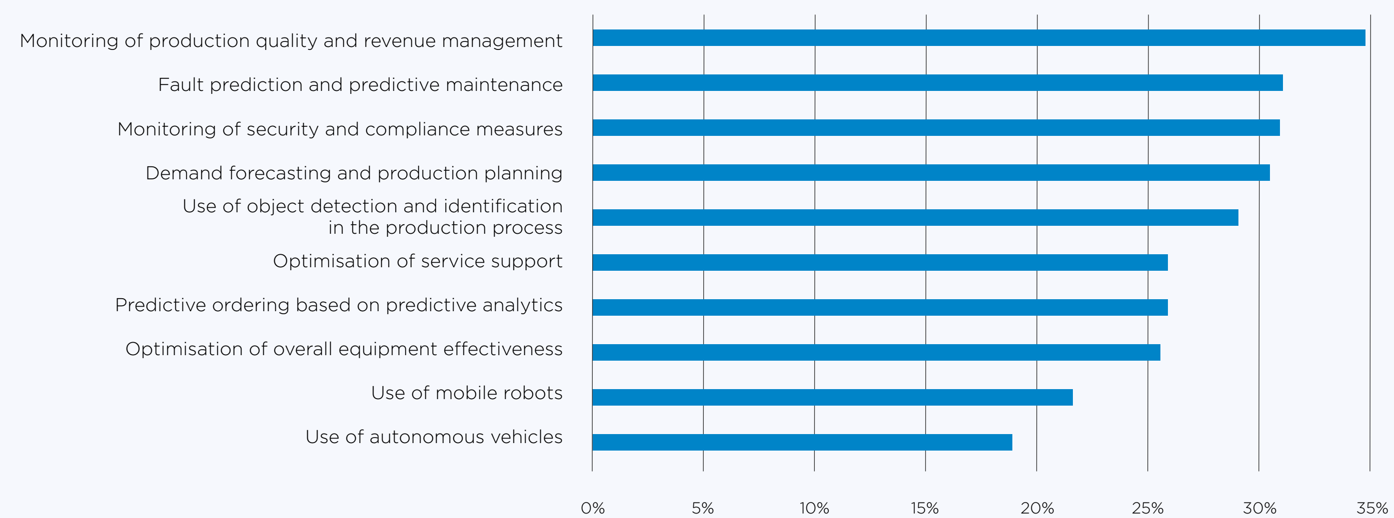


Image 26: Examples of applications for artificial intelligence in their own company's production

Proportion of surveyed corporate decision-makers who generally see potential AI applications in their production, in %



The estimated value of AI tends to increase along with the size of the company (see image 24) and with the amount of progress made so far with the digitisation of production (see image 25).

Companies that do have potential applications for artificial intelligence in their production name the following fields in particular, each of which has a rate of acceptance of over 30 per cent: Monitoring of manufacturing quality and revenue management, fault prediction and predictive maintenance, monitoring of security and compliance measures, demand forecasting and production planning (see image 26).

Some of the main focal points in terms of the potential applications of AI in the production process vary from country to country. For instance, companies in Italy and France prioritise demand forecasting and production planning, whereas the use of object detection and identification is in first place in the United Kingdom (see image 27).

Image 27: Examples of applications for artificial intelligence in production by country

Multiple answers can be given

Proportion of surveyed corporate decision-makers who generally see potential AI applications in their production, in %

Highlighted: Proportion above the national average of European countries

	ø	DE	UK	FR	ES	IT	DK	SE	NO	NL	PL
Monitoring of production quality and revenue management	35%	31%	28%	29%	35%	37%	42%	34%	29%	49%	38%
Fault prediction and predictive maintenance	31%	36%	31%	23%	31%	35%	50%	21%	19%	33%	32%
Monitoring of security and compliance measures	31%	30%	24%	28%	31%	29%	29%	34%	32%	38%	36%
Demand forecasting and production planning	31%	29%	31%	30%	33%	37%	24%	18%	32%	28%	30%
Use of object detection and identification in the production process	29%	29%	37%	28%	30%	36%	24%	21%	23%	25%	27%
Optimisation of service support	26%	22%	19%	23%	24%	28%	37%	32%	19%	30%	29%
Predictive ordering based on predictive analytics	26%	31%	28%	24%	25%	28%	18%	25%	29%	26%	21%
Optimisation of overall equipment effective-ness	26%	26%	24%	28%	30%	26%	29%	18%	19%	20%	22%
Use of mobile robots	22%	17%	13%	21%	22%	25%	26%	18%	32%	17%	26%
Use of autonomous vehicles	19%	21%	15%	19%	19%	18%	18%	21%	23%	20%	17%

The algorithms for AI and machine learning require large amounts of operating data. When it comes to where most of this data is to be stored and processed in future, more than two thirds of companies in Europe choose an on-site location, either core storage (37 per cent), such as in a company-owned data centre, or edge storage (30 per cent). At 32 per cent, only decision-makers in Denmark largely prefer cloud storage or storage outside of the company (see image 28).

Image 28: Storage and processing of operating data for use in AI/ML algorithms in future
Proportion of surveyed corporate decision-makers, in %

Remaining percentage: Don't know / N/A

	ø	DE	UK	FR	ES	IT	DK	SE	NO	NL	PL
Edge storage on site (right on the devices or an edge server)	30%	39%	15%	34%	41%	33%	15%	22%	25%	25%	26%
Core storage on site (internal data centre or server room)	37%	43%	26%	32%	44%	36%	24%	31%	40%	32%	51%
In the cloud/outside of the company	19%	9%	21%	20%	10%	20%	32%	24%	19%	32%	15%

3.7 Changing processes

Although the digitisation of production is centred on the implementation of digital technology, it goes beyond the mere use of new applications. Employees' work processes and overall production processes are also evolving. This brings with it a new or adapted set of qualification requirements for employees in manufacturing sectors.

Around 77 per cent of companies expect the digitisation of production to cause IT skills and soft skills to be increasingly important for production workers (see image 29). Almost the same proportion of companies also agree that employees will increasingly work 'hand-in-hand' with machines and robots in future (75 per cent), and that employees themselves will presumably carry out production processes less frequently, controlling and monitoring them instead (74 per cent). The expectation, voiced by 61 per cent of corporate decision-makers in Europe, that not much will change for most production workers contradicts this to a certain extent.

Employers clearly see the evolution of processes brought about by digitisation, yet expect that the majority of their workforce can overcome it without having to adapt too much.

Image 29: Storage and processing of operating data for use in AI/ML algorithms in future
Proportion of surveyed corporate decision-makers who (tend to) agree with each aspect, in %
Highlighted: Proportion above the national average of European countries

	ø	DE	UK	FR	ES	IT	DK	SE	NO	NL	PL
IT skills and soft skills will become increasingly important for production workers.	77%	80%	66%	77%	79%	78%	72%	67%	79%	78%	79%
Employees will increasingly work 'hand-in-hand' with machines and robots in future.	75%	79%	64%	76%	75%	80%	68%	65%	77%	76%	82%
In future, employees will probably control and monitor production processes instead of performing them themselves.	74%	76%	59%	76%	80%	77%	56%	62%	68%	79%	81%
We are completely reorganising the production processes in our company due to Industry 4.0.	64%	69%	42%	70%	73%	76%	32%	40%	63%	55%	78%
Not much will change for most production workers.	61%	63%	47%	61%	70%	65%	40%	48%	53%	65%	72%
Manual skills and technical knowledge will be less and less important for production workers.	60%	67%	40%	62%	76%	64%	38%	44%	53%	58%	65%

3.8 Interpretation of the results

As also shown by the survey on Logistics 4.0, the survey on Industry 4.0 shows that the surveyed companies have made widely different amounts of progress with the digitisation of their production.

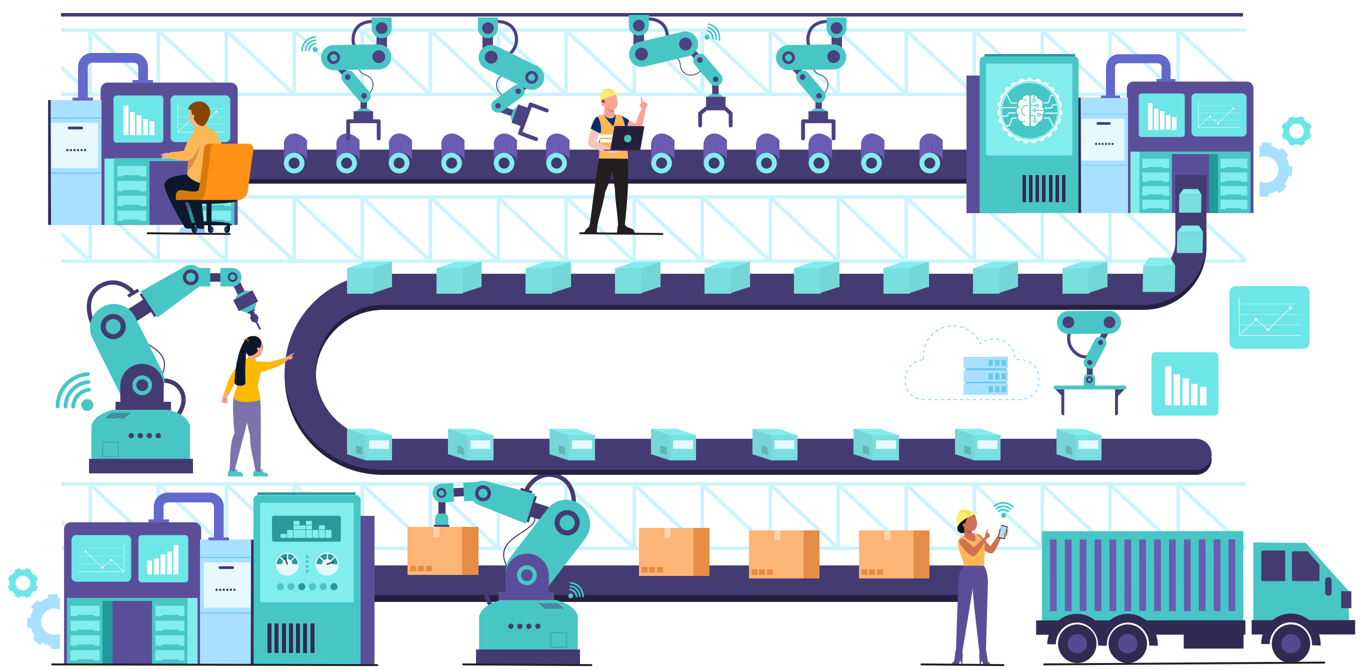
The identified challenges of the transformation process could certainly be expected to play a more significant role. The time and costs alone will certainly obstruct the process in less wealthy companies.

Regarding the three applications that were examined in more detail, we see the following: Overall, the proportion of companies which are already using the Internet of Things, augmented reality or artificial intelligence in their production is lower than the proportion of companies which can, in principle, see potential applications for these technologies. The market therefore remains in a phase of expansion.

In some cases, some companies are still not convinced about the economic benefits of the tools that are available in the market, even though they are generally open to the idea of using digital technology in their production. Expectations regarding digitisation are exceptionally high in Poland, Italy and Spain, whereas companies in the United Kingdom and the Scandinavian countries (Denmark, Sweden and Norway) tend not to have made up their minds yet.

There are also significant differences with regard to company size: Larger companies with more than 250 employees tend to see more potential applications for the IoT, AR or AI than small and medium-sized companies. The reason for this might be that the relevance and complexity of manufacturing processes tend to increase with the size of the company. Although production is also important to the surveyed smaller and medium-sized companies, it is much more manageable and less complex than in large companies if at all possible.

The fact that the estimated value of the benefits of digital applications tends to increase along with the progress of digitisation within a company could point to certain learning curve effects: The greater the experience with the new technology, the higher the potential additional value attributed to it. This might also apply to the digitisation of production overall.



4 Practical examples

Numerous companies have already implemented their own Industry 4.0 applications to varying degrees. They use a range of different technologies such as artificial intelligence and augmented reality. The following practical examples illustrate the form these applications might take in practice.

AGCO/Fendt

The agricultural engineering firm AGCO has given its factory in Asbach-Bäumenheim, where Fendt tractor cabins and engine hoods are manufactured for all of the group's agricultural vehicles, a new digital infrastructure. For example, it uses tablets and has installed screens at workstations to maintain its digital quality process. Forms have been replaced by a user-friendly smartphone app. If a worker discovers a defect, they photograph, document and categorise it with a smartphone and send it straight to the sector responsible for it. Digital solutions like these improve documentation while also making product changes flexible.

Likewise, complete digital factory planning and simulation with a digital twin are at the heart of the factory. This digital twin is based on 3D models of systems, equipment and products, and uses a VR application to simulate work processes. Additionally, an MES (manufacturing execution system) backbone ensures end-to-end data management, enabling all employees in the factory to access a consistent source of information. This avoids redundant data storage. As the machines and systems built by AGCO have to be flexible, first and foremost, many Fendt tractors are one of a kind, having been configured by customers. To make this possible, the factory uses a highly flexible assembly system so that all variants of tractor series and models can be built to customer specifications, enabling the factory to react to current market requirements with both speed and flexibility.

The factory even paints mounted parts which are then mounted in other factories belonging to the AGCO Group. A smart painting system was installed in the factory to minimise human error and in turn wastage. In order to prevent the wrong colours from being mixed or avoid confusion between powder and liquid coatings, the order and its pieces are scanned and visualised for the workers by data glasses as soon as the production parts arrive. The data is sent to the company's own control system FendtView via an interface. Rule-based checks are run on the program number and colour in order to detect anomalies and prevent potential errors in a painting process, such as two colours being mixed.

BASF

The chemical company BASF uses predictive maintenance to predict things such as the functional status of systems. Sensors collect operational condition data in real time which is then analysed by special software. The goal is to predict the optimal moment for maintenance, so as to reduce unexpected repairs and breakdowns and optimise the way in which maintenance and production processes are coordinated.

BASF even attempts to network its internal supply chains with those of its customers in order to improve the reliability of deliveries and cut the costs of the entire supply chain. Customers provide specific digital information about the deliveries they need. BASF evaluates global transport data on a digital platform and, for example, links the data with weather forecasts and other news. This enables BASF to respond more quickly to events that affect the supply chain and reduce the number of delays.

In terms of research, BASF has set up a digital laboratory. The laboratory uses smart devices which can perform measurements autonomously and then document the data automatically. The data can then be shared with other devices through a cloud.

Project 'Kraftwerk 4.0' optimises the energy production of BASF's main production facility in Ludwigshafen, which is the world's largest integrated chemical complex and has three of its own power stations. The energy requirements of the site are roughly equivalent to the energy requirements of all private households in Switzerland. As such, energy has to be produced quickly with as little reserve capacity as possible. So as to be able to schedule electricity purchases more effectively in spite of this, however, BASF automated demand forecasting – both for production and procurement – and, using an analytics tool based on big data, transitioned to an algorithm which factors in historical demand, weather data and current energy prices. This way, if a new deal is closed with a customer, the new demand is calculated automatically for the power stations. The accuracy of predictions has increased from between 70 and 80 per cent to 95 per cent as a result.

For a few years now, BASF has also been in possession of a supercomputer known as Quriosity which can run various simulations to optimise products and generate innovations. For example, it can calculate how pesticides will interact with the soil and how they will penetrate into the groundwater. Complex environmental simulations like these are necessary in order to register pesticides with authorities and can be performed in just a few hours instead of years.

Benzinger

Benzinger is a manufacturer of turning and milling machines which are mainly used in optics, precision mechanics, medicine, dentistry, electrical engineering, control engineering, fluid engineering, warehouse technology, the automotive supply industry, aviation, aerospace and the watch and jewellery industries. The company provides everything under one roof, from engineering, building and setting up machine tools to customer-specific workpieces and after-sales services.

As the majority of its long-lived machines were not originally designed to have Internet access, the machines cannot be made part of Industry 4.0 without receiving a few modifications first. Benzinger therefore launched a modernisation programme to integrate human-machine communication, digital networking and smart machine control systems into the turning and milling machines it had already delivered. Now, customers have a 'smart panel' to securely access their documents (drawings, machine documentation, tooling plans etc.) from anywhere, remind them of upcoming maintenance and provide the manufacturer or service partners with limited, manageable access to the machine controls.

In doing so, Benzinger has improved the way in which older machines in particular are maintained with greater efficiency and faster response times. If one was needed in the past, an Internet connection would have to be set up on an external notebook. This has now been consigned to the past thanks to the built-in IoT module. The tool is compatible with 70 per cent of the machine builder's existing systems. Therefore, the majority of its existing customers have the opportunity to increase their own efficiency considerably. By digitising the old machines, defects can be repaired quickly and without delay, eliminating the need to replace machinery. Moreover, the module does not require a permanent Internet connection; the connection is only active for the duration of the remote maintenance session on a secure, encapsulated channel. If this is not sufficient, augmented reality makes it possible to guide customers through the repair work remotely. Not only is Benzinger introducing new service models with these technologies, it is also boosting customer satisfaction and strengthening its relationships with customers with a full range of customer-centric services.

Bosch

Around 20 years ago, the technology company Bosch rolled out its own Bosch Production System (BPS). As the BPS is scalable, it is compatible with small and large production quantities. The goal is to increase the creation of value and avoid wastage. This goal has now become even more achievable by merging the BPS with Industry 4.0 technologies. Processes can be recorded down to the smallest detail with Industry 4.0 applications. Deviations from expected values and room for optimisation can be identified quickly. This occurs on the basis of Bosch's proprietary Nexeed Industrial Application System.

Nexeed makes it simple to monitor and optimise the production of Bosch's subsidiary BSH Hausgeräte GmbH. The software collects and harmonises data from the individual machines. If a temperature or pressure value should deviate from the norm, the system automatically notifies an employee who is then able to take action. This prevents downtime, production outages and subsequent damage.

In its factory in Bamberg and its sister factories around the world, Bosch has fully automated its petrol and diesel engine component and fuel cell production lines and installed the Nexeed Manufacturing Execution System. This makes it possible to compare production line data across all factories in the international manufacturing network and implement improvements. Information about the status and functions of all manufactured components is obtained. If, after each production stage, a product exceeds or falls short of a predefined tolerance threshold, the application raises an alarm. This information is available to the workers in every factory in the manufacturing network. This means that if a problem should occur in one factory, it is possible to determine whether a similar problem has occurred before in the same or a different factory. If yes, the workers see how their colleagues solved the problem – this reduces the time needed to resolve the issue. Bosch has rolled out something similar to what it has in its factories in Homburg, Feuerbach and Bamberg for its international manufacturing network of eleven sites which manufacture ABS/ESP brake control systems, and it is controlled from the primary facility in Blaichach. The productivity of the systems there has increased by over 20 per cent per year since 2012.

As a manufacturer with significant energy requirements, Bosch is striving to make its production environmentally friendly and sustainable and rethink its energy management. As part of this sustainability strategy, the company has developed an Energy Efficiency Toolbox which, designed for efficient energy management, creates a map of its energy requirements and consumption by highlighting all areas that are relevant to production. The Energy Efficiency Toolbox is a compilation of diagnostic measures which can point out potential for optimisation and increase energy efficiency. The toolbox comprises data from 1,200 projects from various Bosch factories, and calculations are performed on the basis of this data. To collect the data, sensors and communication modules are installed on the systems and send the energy data straight to higher-level IT systems. They are linked with the individual process stages and products. They then generate key data which highlights where action has to be taken and where there is potential for optimisation. This process involves smart energy management software. Using the Energy Efficiency Toolbox, Bosch has achieved carbon neutrality for the entire company with over 400 sites around the world since 2020.

Claas

In its factory in Le Mans, France, the agricultural machinery manufacturer Claas has created the conditions necessary to build increasingly complex yet customisable tractors. It had to completely rethink lots of complex processes on its production line to make this happen. When planning the factory, it used virtual reality to simulate all processes digitally, even with tractor models that it was not building. The introduction of automated guided vehicles (AGVs) was a key factor in the automation of its production. These vehicles move tractors that are under construction to each assembly station both autonomously and automatically. The factory uses 40 AGVs which can transport a load of up to 20 tonnes. Moreover, the new logistical infrastructure has made the individual assembly stations more spacious and in turn less prone to errors, as only parts that are needed are delivered on the conveyor belt. As a result, the total production capacity of the factory has increased by around 30 per cent.

Ford

The car maker Ford uses AR solutions to maintain and repair its vehicles, supporting vehicle mechanics in its global dealer network in the process. The mechanics can request assistance from a member of staff at Ford's Technical Assistance Centre (TAC), a centralised team of experts who help mechanics at all Ford and Lincoln dealers around the world with fault diagnostics. Thanks to bidirectional video calls on data glasses, the specialists at the TAC see exactly what the mechanic sees. This enables the TAC personnel to provide the necessary support and show real-time information in the mechanic's field of vision. This can be done, for example, by means of screen comments, tagging live images or handbooks and repair instructions. They are even able to share their own screen with the mechanics and record the session for quality assurance purposes. Using the AR solution helps Ford fix faults more quickly, which in turn has a positive effect on Ford's service promise to its customers.

Leitner

Leitner is a global leader in the development and construction of ropeway systems. As part of the High Technology Industries (HTI) Group, it builds ropeways in cities as well as in the mountains.

Leitner relies on innovation for its economic success. This goes for its products and processes alike. For example, rotor poles which are installed in the ropeway drive system in their hundreds are manufactured by fully automated robots in a manufacturing cell. The robot performs all 20 stages of the manufacturing process and is monitored by means of image processing, supported by high-resolution cameras. For instance, sensors record and evaluate dimensions such as width and height. If there is a deviation in the admissible tolerances, the armature poles in question are declared defective and removed from the manufacturing process automatically.

Leitner ropeways are technically complex. Leitner uses AR-based remote maintenance solutions to minimise the amount of effort involved in regular maintenance and repairs for customers. Based in the service centre in Sterzing, around 100 technical experts provide remote support for more than 2,500 ropeway systems all over the world. Experts connect to the affected system immediately, enabling them to check typical causes of faults quickly or adjust settings if necessary. This means that customers benefit from 24/7 support all year round, wherever a customer might be.

Furthermore, AR enables the customer's personnel on site to assist the Leitner's distant specialists with markers and drawings. Leitner computers connect to a smartphone on site, providing the specialist with the same view of the system as the technician facing the ropeway system. It is often not even necessary to stop the ropeway system in such cases. Language barriers are also not a problem. If necessary, a personal service appointment can be arranged to follow up on the initial immediate troubleshooting session.

thyssenkrupp

In its various lines of business, thyssenkrupp makes use of numerous solutions that fall under the umbrella term ‘Industry 4.0’. For example, thyssenkrupp has digitised production at its factory in Hohenlimburg and networked the processes of suppliers, the factory and its customers together. As the production of primary materials by the supplier is controlled remotely, last-minute customer requests can be fulfilled even from the primary material stage. The network means that customers too can influence the factory’s production in real time and choose when their order is to be manufactured in the IT system. Changes can even be made up to shortly before the start of production. For this purpose, thyssenkrupp has developed its own app for customers to place their orders and add specifications up to shortly before the start of production. This form of networking has made it possible to lower warehousing costs, for example.

To manufacture camshafts at its factory in Ilsenburg, thyssenkrupp has used Industry 4.0 applications such as barcode and matrix code scanners and RFID readers to merge the physical world with the data networks in cyberspace, creating a ‘cyber-physical system’ in order to create a smart factory. The camshafts and the systems that build them are in constant communication. Every camshaft receives its own identity and has to register with every single machine. This way, the system knows whether the product has the right status and whether it can be processed on that system at all, or whether a preceding process stage has been missed.

With a proprietary, scalable IIoT platform, Thyssenkrupp Material Services enable machines from a wide range of manufacturers and generations to communicate with one another, opening the door for applications such as predictive maintenance. The goal is to automate processes all along the supply chain and make them more efficient. The platform enables the machines to communicate and share data with one another and with the IT systems. This makes it possible to schedule and coordinate processes across all sites around the world in a flexible and optimised way. Furthermore, the platform allows for data analysis by not only collecting data, but also analysing the data and making it accessible.

5 Summary

Industry 4.0 has been shaping the manufacturing sector for ten years now. In this time, many companies have accelerated the digitisation of their production. The practical examples presented in this study underline the different forms this can take. For example, by digitising their production processes, companies are increasing productivity and efficiency while lowering costs. These are also the advantages which are particularly important to companies, according to our survey of 1,452 decision-makers in ten European countries.

However, this survey also makes it clear that the situation in terms of Industry 4.0 is still highly heterogeneous with regard to the overall surveyed corporate landscape. While there are a few pioneers, there are also companies which have yet to begin their digital transformation. In some cases, the companies dragging their feet are not yet aware of the significance of Industry 4.0 or they (currently) do not have enough time and money – which they themselves admit is the greatest challenge.

Even though lots of companies are delaying, they cannot avoid digitising their production processes forever if they want to remain successful in the market. Industry 4.0 is one of the keys to increasing competitiveness permanently. It is the only way that companies will have cost-effective, sustainable production processes that are tailored perfectly to customer requirements in future.

Moreover, it is necessary to remember that Industry 4.0 concerns the entire value chains of production. However, these value chains link lots of different companies. As such, it is not enough to only digitise certain sections of a value chain in order to tap the full potential of Industry 4.0. In practical terms, this means that companies which do not digitise their production processes might be unable to be part of a value chain as a supplier, for example, because they are no longer able to integrate into the networked processes of the other partners.

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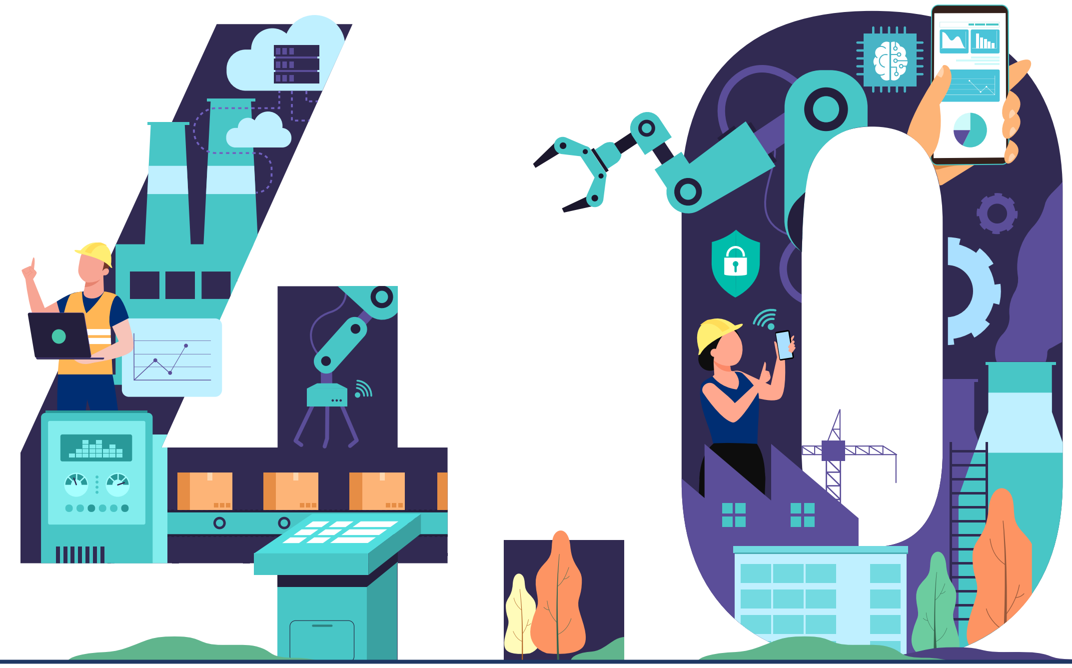

Industry 4.0

How digital technology is changing companies' production processes

Results of a survey in ten European countries

TeamViewer

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