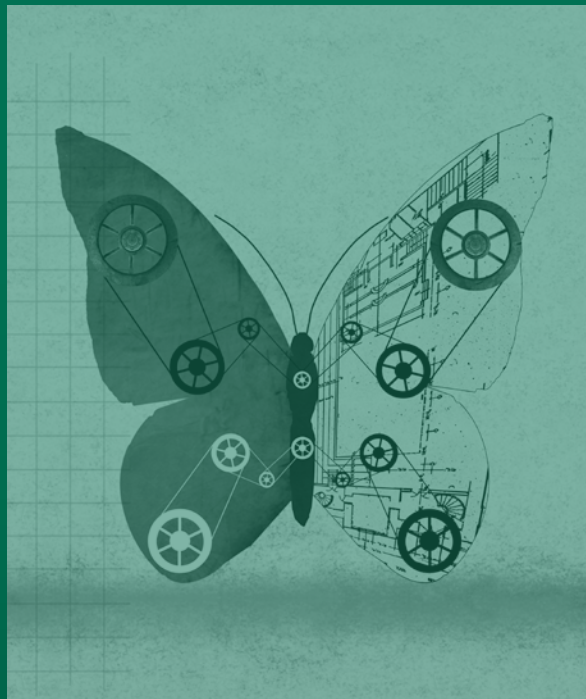


WINNING THE INDUSTRY 4.0 RACE

HOW READY ARE DANISH MANUFACTURERS?

The Boston Consulting Group (BCG) is a global management consulting firm and the world's leading advisor on business strategy. We partner with clients from the private, public, and not-for-profit sectors in all regions to identify their highest-value opportunities, address their most critical challenges, and transform their enterprises. Our customized approach combines deep insight into the dynamics of companies and markets with close collaboration at all levels of the client organization. This ensures that our clients achieve sustainable competitive advantage, build more capable organizations, and secure lasting results. Founded in 1963, BCG is a private company with 85 offices in 48 countries. For more information, please visit bcg.com.



Innovation Fund Denmark provides public capital for developing cutting edge knowledge and innovative solutions in Denmark. Our aim is to benefit growth and employment and to solve societal challenges by moving Denmark to the forefront of innovation. We are ready to invest, where others might not yet be willing to run the risk. We demand great ideas, leadership and organization, top research and results – and above all: great potential for creating value for the Danish society. Industry 4.0 is a major focus area for Innovation Fund Denmark with investments in e.g. cyber-physical systems, control of robots, digitalization and big data. Our programs strongly support the conversion of SME's to a new area of industry 4.0. On the background of this report's conclusions Innovation Fund Denmark is preparing a new investment strategy on Industry 4.0 to be revealed early 2017. For more information please visit innovationsfonden.dk/en. In 2016 the budget of Innovation Fund Denmark is 1.2 bn kroner.

WINNING THE INDUSTRY 4.0 RACE

HOW READY ARE DANISH MANUFACTURERS?



IAN COLOTLA

PETER HØNGAARD ANDERSEN

ANDERS FÆSTE

TORE DUVOLD

AILKE HEIDEMANN

MICHAEL HANSEN

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PREFACE

BCG and Innovation Fund Denmark have joined together to assess the adoption of Industry 4.0 technologies in Denmark.

THE NEXT REVOLUTION

We are at the tipping point of an industrial revolution that will turn the industry on its head. At the center is the cyber-physical system, which turns isolated, physical operations into integrated, digital solutions. New technologies – from collaborative robots to 3D printers – will play a crucial role in this industrial paradigm that promises improvements to every pillar of production and entirely new business models.

A BURNING PLATFORM

The manufacturing sector is an important driver of growth in the Danish economy, but employment has slumped in the past decade. More recently, our competitiveness and innovation has slipped in international rankings.

In contrast, Germany has taken a lead in the industrial race, while we are still catching up.

STATE OF THE NATION

Through a survey of 500+ Danish companies and interviews, we found that companies expect Industry 4.0 to change their business models, placing an emphasis on speed, flexibility, and customization. Productivity will jump, yet not at the expense of jobs, although the capability mix is expected to shift away from manual labor. When it comes to actually implementing Industry 4.0 solutions, large and medium-sized Danish companies outpace smaller companies. But German companies trump the larger Danish manufacturers in a like-for-like comparison of Industry 4.0 adoption rates. The path forward is riddled with obstacles. Above all, we found that lack of Industry 4.0 knowledge, capabilities, and funding ranked as the largest barriers to Industry 4.0 adoption.

ACCELERATING DENMARK

Industry 4.0, taken seriously, promises growth, jobs, and a fighting chance in the international arena. To get a lead in the race, policy-makers should tackle the main obstacles by building a coordinated ecosystem, planning the future workforce, and increasing funding to incentivize risky Industry 4.0 projects. Yet the task of adopting Industry 4.0 does not fall on policy-makers alone. Manufacturers should take a proactive stance, partner with other firms and universities, and seek out expert help for funding the journey. With a concerted effort, Denmark will be well prepared to win the race.

EXECUTIVE SUMMARY

WE ARE AT THE TIPPING POINT of a fourth industrial revolution. In this report, we take a close look at how well Danish manufacturers are preparing for the disruption to come and we propose a national action plan leading towards 2025. If we want to join the winning team, now is the time to buckle up. There will be no participation medals.

A new version of your industry is available. In the last ten years, the cost of sensors, cloud infrastructure, bandwidth, and processing power has plummeted. Much of the progress in cutting-edge technology is now making its way into mainstream manufacturing. This blurs the lines between the physical and the digital domains. At the center, the fourth industrial revolution – or Industry 4.0 – promises deeply integrated, intelligent, cyber-physical systems. Above all, nine drivers are transforming industrial production: Advanced robotics, additive manufacturing, augmented reality, simulation, horizontal/vertical supply chain integration, the Industrial Internet of Things, cyber security, the cloud, and Big Data & analytics. Each pillar of production will get a facelift, leading to improved quality and soaring productivity combined with a flexible and fast production line.

Take the red pill. We desperately need our manufacturing sector. At the current rate, it accounts for around 60% of both exported goods and also private R&D spending, it grows at a respectable 2% a year (GVA), and it drives 70% of private sector productivity. Employment, however, has fallen to an all-time low of 10% of the workforce during the last decade. More recently, our competitiveness and innovation has slipped behind that of our peers in the rankings. Like other industrial revolutions, this one promises growth and employment, but not if we just sit on our hands. When the gale of creative destruction blows hardest, textile weavers and blacksmiths go unrewarded.

We are not getting any younger. Germany has already taken decisive steps towards Industry 4.0 – or Industrie 4.0, as they originally coined

it – with specific policies, institutions, and financing. Our survey of more than 500 manufacturers reveals that Danish expectations for the future already are in line, even though our actions are not. First, companies expect to update their business models over the next decade because of Industry 4.0, placing an emphasis on speed, flexibility, and customization, while also expecting strong productivity gains. At the same time, employment is expected to rise, although the capability mix will tilt towards engineers, scientists, and IT technicians. At the current rate, the consensus is that future demand for highly skilled workers will outstrip supply. We also found that larger Danish companies have already implemented – or are planning to implement – more Industry 4.0 technologies than smaller companies, yet the German “Mittelstand” (large and medium-sized companies) trumps the Danish companies in a like-for-like comparison. A broad range of barriers hinders companies from taking on Industry 4.0 technologies. Both our survey and interviews show that a lack of knowledge, capabilities, and funding constitute the main barriers to further Industry 4.0 adoption.

Roll the dice. We need an action plan for Danish manufacturing, leading towards 2025. This report identifies three focus areas: (1) Strengthening the Industry 4.0 ecosystem, (2) Strategically planning the workforce, and (3) Increasing funding. In total, we have nine key recommendations for both the short and long term.

Strengthening Denmark's Industry 4.0 ecosystem. The success of Industry 4.0 hinges on a streamlined collaboration between manufacturers, research & technology organizations, and universities. We recommend:

1. *Building awareness of Industry 4.0* by setting up demonstration centers and dedicated Industry 4.0 task forces
2. *Enabling horizontal partnerships* between like-minded SMEs
3. *Facilitating knowledge partnerships* between companies, research & technology organizations, and universities

Planning the workforce. At the moment, our workforce is out of date. Denmark educates too few robot technologists and too many social scientists. We recommend:

1. *Determining the demand-supply gap* of the future workforce.
2. *Closing the gap* by promoting technical backgrounds, working to attract foreign talent, and rethinking the traditional work model.
3. *Continuously upgrading the workforce* through specialized university courses, further education, and alternative learning platforms

Increasing funding. Compared with our peers, we spend far too little on innovation. If we wish to be at the frontier, we need to invest accordingly. We recommend:

1. *Increasing the pool of government-funded risk capital*

2. *Facilitating access to special loans* from private institutions
3. *Provide funding for the Industry 4.0 ecosystem* as a whole

Yet manufacturers themselves also need to play a part. Business-as-usual is not a viable option. Instead, we recommend that SMEs actively seek inspiration from demonstration centers, knowledge networks, and factory visits. We recommend partnering with industry associations and universities in order to leverage external knowledge. In addition, we find that Industry 4.0 change should be driven by executive management decisions. Finally, when financing the investment, we recommend seeking guidance from dedicated Industry 4.0 experts on how to build a solid business case.

Ready, set, grow. We are a small, agile nation with the capacity to adapt and to position ourselves competitively. The race is on and if we do not make the hard decisions now, our competitors will make them for us.

THE NEXT REVOLUTION

AND THE OPPORTUNITIES FOR DANISH MANUFACTURING

WE ARE ON THE BRINK of a fourth industrial revolution. Like the first three, this one promises to turn the industry on its head. But in an era of exponential technologies, the early bird catches the worm. At this fork in the road, Denmark must decide to join the race or stand back. The position of this report is clear: Sticking with the status quo is not in the cards. Cross the Rubicon and don't look back.

Brave New World. Management theorist and professor at the University of Southern California, Warren Bennis, said: "The factory of the future will have only two employees, a man and a dog. The man will be there to feed the dog. The dog will be there to keep the man from touching the equipment." By any stretch of the imagination, we are not quite there yet. But such a concept is no longer the stuff of fiction.

The basis for a technological revolution is well established. Since the release of the first iPhone almost ten years ago, the cost of sensors has halved, cloud infra-structure costs have dropped twenty-fold, bandwidth costs have dropped forty-fold, and the cost of processing power has dropped fifty-fold. We are also overwhelmed by data with 90% of it all generated during the last two years alone.

At a time when Big Data, Artificial Intelligence, self-driving cars and other miracles of

technology claim the headlines, the manufacturing sector has yet to steal the limelight. Now, a fourth great change is gathering pace. As traditional production lines merge with cutting-edge technologies, factory floors smarten up, while production plants scale down. The attention will be unblinking.

A brief history of manufacturing. Manufacturing revolutions have fuelled all major productivity booms. The first industrial revolution took place during the late 18th century and introduced mechanical production plants driven by water and steam power. Productivity ballooned as jobs previously done by hand were centralized and mechanized. Cotton mills replaced textile weavers – and the factory was born.

The early 20th century saw the introduction of work-division and mass production enabled by electricity. This second revolution reshaped factories around scale: Success involved cranking out millions of identical products. As Henry Ford put it, customers could have any variant they liked, as long as it was black.

During the early 1970s, the industry transformed for the third time when digital electronics replaced their analogue counterpart, ushering in the Information Age and the use of IT to automate production.

Now, we are on the edge of a fourth revolution in the history of manufacturing, which is based on *cyber-physical* systems – a revolution popularly known as Industry 4.0, Smart Manufacturing, or the Industrial Internet.

In essence, the cyber-physical system means that physical production plants are linked together in an open network. The point is to connect the dots and build a fully autonomous value chain that is unlike today’s hermetically sealed production cells. Data will be exchanged seamlessly from design to production. Machines will be able to communicate effortlessly with each other. And suppliers will automatically be kept in the loop, as though they were an integral part of the manufacturer itself.

Industry 4.0 goes beyond automation and digitization. For many firms, the components of the value chain are already highly auto-

mated. For some, they may also be digitized (See *Digitizing Denmark: How Denmark Can Drive and Benefit from an Accelerated Digitized Economy in Europe*, BCG & Google, September 2016). What separates Industry 4.0 from past technological advances is an emphasis on *integration* over *isolation*.

Nine Technology Drivers

Stranger things have happened. Going beyond the cyber-physical system described in the abstract, Industry 4.0 will manifest itself through nine technologies, themes, and trends. Rather than centering on a single new invention, such as steam power or electricity, the cyber-physical system is the common thread in all the Industry 4.0 drivers (see Exhibit 1).

Advanced robotics. Today’s robots are blunt instruments surrounded by cages in order to

EXHIBIT 1 | Nine technology drivers enable production of the future



Source: BCG Experts

WHAT IS INDUSTRY 4.0?

The fourth industrial revolution generally refers to a new wave of digital industrial technology. More specifically, it centers on the “cyber-physical system”: The integration of virtual and physical production

systems. It fuses technologies together, blurring the lines between physical and digital domains. The goal is to create an integrated, automated, and optimized production flow.

prevent workplace accidents. In the future, these robots will be replaced by “cobots”, a breed of intelligent robots that collaborate seamlessly with other robots and, in particular, also with humans.

Additive manufacturing. Ask a traditional factory to manufacture a single, customized fuel nozzle and the bill will be prohibitively expensive. For a 3D printer, however, scale is irrelevant. Production can be tweaked and calibrated in any number of ways without hurting efficiency. It has already made headlines in plastic manufacturing, especially in the fields of aviation and Medtech.

Augmented reality. By displaying supporting information through a pair of glasses, this technology allows even inexperienced workers to perform highly complex tasks, like helicopter maintenance. More generally, it can successfully be used for training purposes.

Simulation. Simulation is already a widely-used tool for testing and optimization, e.g. for products, materials, and production processes. It is even used for factory design. But in the future, this technology will also be used for advanced real-time simulation of the physical world in a virtual model. This will allow firms to test work processes even before factories have been erected, e.g. by training maintenance staff through various training simulations.

Horizontal/vertical integration. Horizontal and vertical integration of the supply chain will bring cross-company, universal data integration. This is a prerequisite for a fully automated value chain that extends from suppliers to customers.

Industrial Internet of Things. Above all, the Industrial Internet of Things embodies the spir-

it of Industry 4.0. This breed of technology promises to link machines, products, processes, and systems together in real-time. More devices will be embedded with sensors and computing. This helps to decentralize analytics and decision-making, enabling real-time responses.

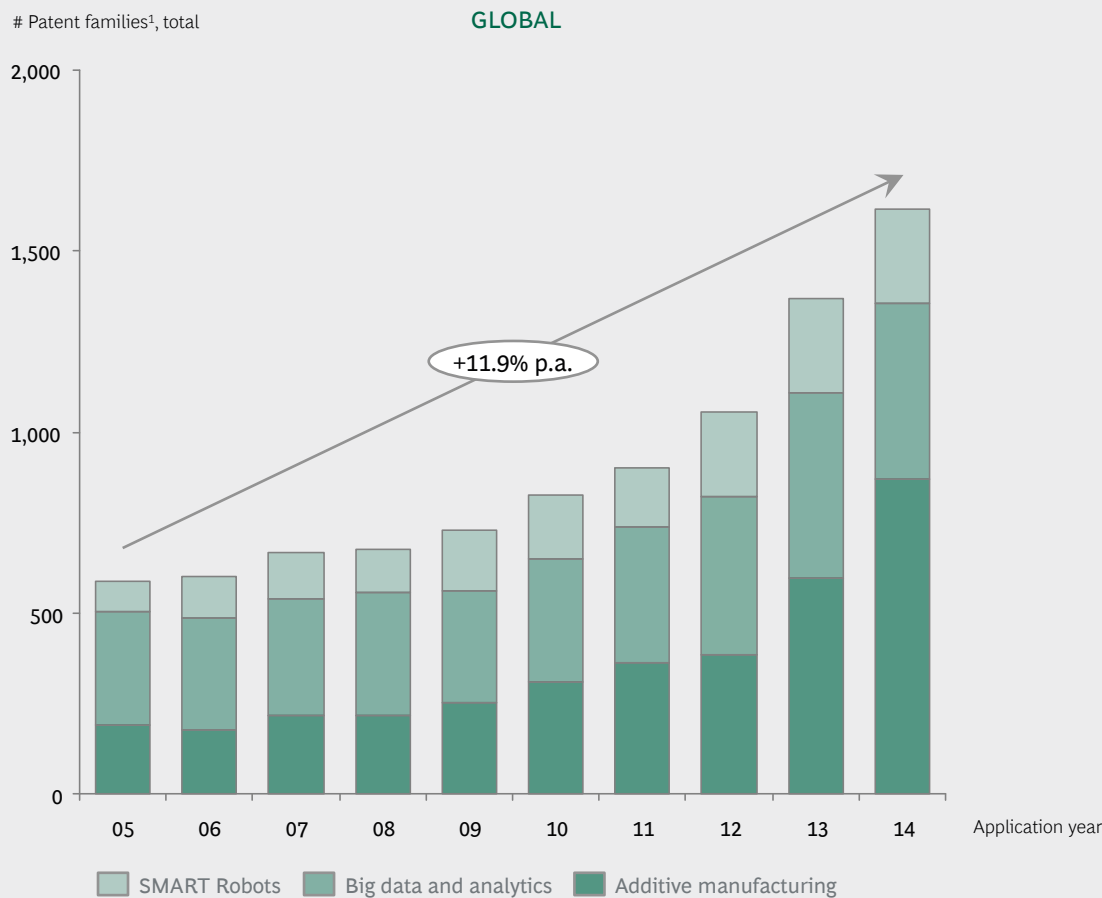
Cyber security. On the flipside, open and integrated networks are vulnerable to malicious attacks. As a result, factories will have to emphasize cyber security in order to protect industrial systems and manufacturing lines.

The Cloud. Cloud systems will manage huge volumes of data in open systems, allowing instantaneous communication with production systems. Software can be hosted in the cloud, rather than locally, for easy, continuous upgrading and backup.

Big Data and analytics. Meanwhile, analytics powered by ‘Big Data’ will mature to deliver comprehensive evaluations of many available data sources, such as ERP, SCM, and CRM systems. This will provide fresh insights and real-time decision-making support.

A patent improvement. The most striking feature of this list is that all of it is more science than fiction. Many of the items are already in production. This also means that companies, research organizations, and universities are accumulating intellectual property rights in these areas. We looked at the worldwide flow over time of patent applications for robotics, additive manufacturing, and big data analytics, and found that all three showed strong activity: We are seeing an increasing number of patent applications in the world, with an average growth rate of 11.9% per year – and with a notable jump in the last few years (see Exhibit 2).

EXHIBIT 2 | Patents for industry 4.0 technologies have increased significantly over the last decade Especially within Additive manufacturing



Source: Thomson Innovation, BCG Center for Innovation Analytics.

¹ A patent family is a group of related patents. E.g. if the inventor files for protection in several countries or if a single invention has multiple patents.

The Impact of Industry 4.0

What's not to like? The Industry 4.0 technology drivers offer benefits to every bit of the production process.

Quality. For a start, the quality of products benefits from additional sensors and actuators that monitor production in real time. In the event of errors, useful information is quickly dispatched to the appropriate recipient (e.g. the designer).

Productivity. Productivity increases not only because automation reduces production time, but also because assets are better used and inventory is better managed. For example, by reducing downtimes through predictive maintenance.

Speed. Manufacturers can shorten time-to-market by quickly prototyping new ideas and simulating various scenarios.

Flexibility. All of this happens flexibly with machines and robots that are easily retooled to work on a large variety of products, which can be produced in a one-piece flow.

Overall, BCG estimates that Industry 4.0 will lead to 30% faster and 25% more efficient production systems (See *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries*, BCG, April 2015).

Other benefits come about in areas such as safety, working conditions, accessibility, and environmental protection. For example, advanced robots help to reduce the physical

burden for many workers, allowing older employees to stay in the workforce for longer. Environmentally, local production will reduce carbon emissions during transport and more efficient processes will lead to lower energy consumption.

Coming soon to a factory near you. In a traditional sense, Industry 4.0 improves production by lowering costs. Labor costs decrease through the introduction of advanced robots, logistics costs decrease

Such changes to the business model can be incremental, for example, when companies like Zara and Amazon bypass steps in the value chain, leaving competitors in great difficulties. But they can also be disruptive, turning industries upside-down. On the latter point, Universal Robots is working to introduce service robots into health care systems to work alongside humans during surgery and patient rehabilitation. A successful implementation promises to turn the industry on its head (see Case Study 1).

CASE STUDY 1 – RISE OF THE ROBOTS UNIVERSAL ROBOTS

In the last decade, a cluster of robotics manufacturers has emerged on the island of Funen. Already, more than 80 businesses and 2,300 employees have made their home in Odense and the sector is projected double-digit growth rates for years to come.

Trust me, I'm a robot

Whereas the robots of the third revolution were bulky, expensive, and stole away jobs, modern robots are a different breed altogether. As the leader of the Funen hub, Universal Robots pioneered the lightweight and flexible cobot. Founded in 2005 by three academics from the University of Southern Denmark, the robot manufacturer quickly stole the international spotlight. "We have turned robotics into a tool that helps workers perform their jobs more

efficiently", says Chief Technological Officer, Esben Østergaard. More often than not, firms that acquire cobots end up hiring more workers as well: "In reality, the combination of a worker and a robot is better than the sum of its parts."

Since 2007, the Innovation Fund Denmark has supported Universal Robots and the creation of the Funen robotics hub. In 2008, the Danish Growth Fund placed a sizeable investment in Universal Robots, bringing them from a handful of employees to more than a hundred in a few years. Universal Robots were sold to Teradyne for \$285M in 2015, but the production remains in Denmark. Now, the issue is not about stoking demand for the Funen robots, but solving the shortage of qualified labor.

through optimized supply systems, and operational costs decrease through lower setup costs in the event of sudden changes. More generally, costs decrease through reductions in waste, bottlenecks, and information flow disruptions.

Conversely, new business models will emerge. Revenue will increase from the ability to offer customized and locally manufactured products, from employees with more capacity to focus on value creation and innovation, and from targeted sales through the use of CRM, marketing automation and content management.

Producers can leverage Industry 4.0's potential to develop new business models. This typically happens through extended product offerings and software integration projects. Another lever is to develop new products by investing in intelligent manufacturing equipment and integrating IT infrastructure. This allows companies to collect vast amounts of real-time data closer to the point of sale, enabling true customer centricity, and a flexible supply chain. Moreover, companies will also have to increase spend on data security and make important decisions on what data they wish to share. Suppliers will further develop software competencies for intelligent ware-

housing. Meanwhile, even highly qualified employees will face increased requirements for development and training.

Yet, for all its allure, Industry 4.0 also brings a fiercely competitive market. Producers, suppliers, and employees may wind up getting the short end of the stick if we sit on our hands. As this report stresses, there is a desperate need for the government to supply growth-oriented and forward-looking capital on an arm's length basis (see Section "Accelerating Denmark").

Towards the Promised Land. Global growth and productivity trends are slowing, so the marriage of manufacturing and technology is a welcome sight. Today, only 8% of tasks in a factory are automated – and only the repetitive ones. This number will increase to 25% in 10 years. That is not to say that we should

blindly splash out on fancy new technology. As this report will stress, a model for Industry 4.0 should flow from companies' specific needs and pain points.

Beyond improving throughput numbers, Industry 4.0 promises to bring manufacturing out into the limelight. The next industrial era will offer an upside-down world in which speed trumps scale, factories return to home markets, and trade flows center on regions. Firms must respond to this transforming world, or perish.

This is not futuristic speculation, but an industrial transformation already underway. For Danish manufacturing to migrate towards the sunlit industrial uplands, we need to act intelligently and in good time.

THE BURNING PLATFORM

EVEN FOR WEALTHY COUNTRIES like Denmark, manufacturing's heft matters. So the advent of Industry 4.0 should be taken seriously. Handled well, it presents an opportunity to advance Denmark's economy. Failing to adapt, however, and we may find ourselves disrupted. In this fast-paced environment, the countries that are willing to take risks will stay ahead of the curve.

Made in Denmark. Manufacturing contributes significantly to the Danish economy. According to Statistics Denmark, manufacturing accounted for 14% of gross value added (GVA) and around 60% of both exported goods and private R&D spending. On the whole, Danish manufacturing is doing well. In an otherwise nearly flat economy, manufacturing pulls its weight with GVA growing at 2% a year. To this end, 70% of private sector productivity was driven by manufacturing between 2009 and 2014 (OECD).

The sector employs roughly 10% of the work force, just short of 300,000 people. Better yet, employment in the manufacturing sector has a positive 'multiplier effect'. When employment rises, it ripples throughout the economy: Every job in manufacturing creates another one elsewhere. Moreover, the manufacturing multiplier trumps the service multiplier: Changes to manufacturing employment have a significant impact on the

economy (See *Revitalizing Nordic Manufacturing*, BCG Perspective, August 2013)

Not so rosy. We may be a few laps ahead, but we are also running out of steam. A new report on competitiveness by the World Economic Forum shows that Denmark has lost its pole position. In 2009, we scored third place ahead of Sweden and Germany. Seven years on, Denmark is outside the top 10, trailing behind Sweden, Germany, the Netherlands, and others.

Compared with our Nordic peers, productivity in manufacturing is lagging behind. The 2016 Global Innovation Index still places Denmark in the top 10 for innovation, but with a drop from the top 3 in 2010. Slashing costs to boost productivity is not an option: Factory costs may be high, but they are unlikely to fall. So declining performance in innovation is a particularly worrying sign.

We also suffer in terms of scale: A report from the Danish Business Authority concludes that no large companies with more than 1,000 employees have been created between 1996 and 2015. There were no tech mastodons, manufacturing titans, or start-up unicorns like Sweden's Spotify. Our potential candidates, such as E-conomic and ZenDesk, tend to be sold off before they mature, often because they struggle to find funding in Denmark.

Employment in the manufacturing sector has been on the decline for more than a decade. Since 2000, 112,000 manufacturing jobs have been lost. Indirectly, another 104,000 supporting jobs have disappeared as well through the multiplier effect, though a recent jump in manufacturing employment has cushioned this fall. Further analysis raises concern for future employment: Results from a survey of companies, conducted by the Confederation of Danish Industry's business panel, show that a quarter of companies expect to move their production abroad. Nearly a third had already done so.

Meanwhile in Germany. Already in 2011, the German Federal government launched the "Industrie 4.0" initiative as part of a high-tech action plan to promote the marriage of technology and manufacturing.

The German Federal government was worried about the impact of digitization on their manufacturing sector. In response, they took a proactive stance with a national, long-term strategy and plenty of funding to boot. Their chief aim was to provide a framework for cooperation between all stakeholders. One institution that evolved as a result was the *Plattform Industrie 4.0* – a single institution to transcend all association boundaries.

The *Plattform* provides recommendations that work in favor of all stakeholders, rooted in a consistent and reliable structure. They produce and distribute knowledge, initiate and support demonstration centers (without running them) and assist policy-makers in building the necessary legal infrastructure. Importantly, they do not favor single, isolated technologies, but prefer to think in terms of *use cases*, i.e. composites of several technologies that are logically connected. They regularly update a map that plots how Ger-

man manufacturers put various use cases in place.

Even China, typically seen as a "low-cost" manufacturing hub, has a very aggressive, national strategy for Industry 4.0. Already, they have planned to set up 40 manufacturing innovation centers by 2025.

In Denmark, Industry 4.0 has moved up on the agenda, but has yet to steal the spotlight. While reviewing the literature, we found that most publications addressed the topics of *automation* and *digitization*. Both topics are highly relevant in today's society, yet don't come to grips with the forward-looking themes presented by Industry 4.0, such as intelligent systems interacting with one another.

Once more unto the breach. The Danish manufacturing platform has not fully caught on fire, but the embers are glowing. To stay ahead of the curve, policy-makers and pundits must steer clear of complacency.

In the next section, we will present the findings of our survey and interviews. They tell the story of a country with an awareness of new technological trends, yet also a resistance towards acting on it. Charting the path forward requires a deeper understanding of these obstacles to action. And there needs to be a path forward: Denmark's foundation may be strong, but the walls are crumbling. If we don't take the development seriously, our global competitors certainly will.

And should we fall behind in the race because we failed to consider the opportunities offered by Industry 4.0, then the fault will not be in our stars, but in ourselves. As for now, there is still time. But the clock is ticking.

STATE OF THE NATION

FROM GERMAN *MITTELSTAND* TO DANISH MAINSTREAM

ALREADY, GERMANY HAS SET SAIL for open waters, while we are still moored in an old riverbed. This is our starting point. On that account, this report aims to put Industry 4.0 on the national agenda, place the discussion on a rational footing, and prepare Danish manufacturers for successfully navigating a transformed industry.

To accomplish this, we conducted a broad survey of Danish manufacturers in order to better understand the industrial landscape. In addition, we carried out in-depth interviews with manufacturers that develop or implement Industry 4.0 technologies to add nuanced perspectives to our survey results.

In short, we found the following key takeaways on the expected impact of Industry 4.0: (1) Companies expect to update their business models during the next decade, placing an emphasis on speed, flexibility, and customization, while also expecting strong productivity gains. At the same time, (2) employment is expected to rise, although the capability mix will tilt towards engineers, scientists, and IT technicians. Already, (3) larger Danish companies have implemented – or plan to implement – more Industry 4.0 technologies than smaller companies, yet (4) the German “Mittelstand” (a term for large and medium-sized companies) trumps the Danish companies in a like-for-like comparison. Finally, we found that (5) a broad range

of barriers are hindering companies from adopting Industry 4.0 technologies, particularly lack of knowledge, capabilities, and funding.

The survey and interviews underline the need for a dedicated, national action plan to address structural challenges from funding gaps to shifting capability requirements. At the same time, there is also a call for clear, immediate action: Germany has not lingered; neither should we.

Changing Business Models

Danish manufacturers are well aware that something is in the air: 85% of respondents expect Industry 4.0 to change their business model in some shape or form, a sentiment broadly shared by all types of firms.

Size matters. There are, however, important differences. Above all, larger companies stand out, with 96% expecting their business model to change. The reason for this is that larger firms are generally more resourceful and exposed to international competition, which motivates them to respond to emerging threats and opportunities. It would, however, cut little ice with the facts to paint smaller firms as conservative or inflexible. Their business models were threatened during the financial crisis in 2008, when the economy tanked and GVA dropped by 5%. In

ABOUT THE SURVEY

In October 2016, BCG and Innovation Fund Denmark (IFD) conducted a survey of manufacturers. The purpose was to evaluate the status quo and the adoption of Industry 4.0 technologies. The survey received 530 responses from Danish manufacturers with roughly 60% holding C-level positions. Respondents came from varied backgrounds: Across all major industry groups, all regions, and all company sizes.

The survey assesses the relevance and adoption of Industry 4.0 in Denmark, the barriers to implementation, and the expected impact on productivity and employment. It quizzed all respondents on their attitude towards a list of 16 technologies across 4 dimensions: (1) Operational improvements, (2) Performance improvements, (3) People involvement, and (4)

Industry 4.0 Foundation. Technologies in the dimension of *Operational improvements* involve advanced robots, assistance systems, SMART products, decentralized production planning, digital factory design, digital logistics, SMART warehousing, horizontally integrated supply chains, predictive maintenance, and 3-D printing. For Performance improvements, we looked at real-time performance measurements on mobile units and electronic performance boards. The third dimension of *People involvement* focused on virtual reality training and social media in a business context, i.e. using social media for real-time communication with employees and suppliers. Finally, the *Industry 4.0 Foundation* refers to the backbone that supports further implementation projects and includes data security and data infrastructure.

particular, manufacturing was hit much harder, with GVA falling by 12%.

In one interview, a small manufacturer pointed to the 2008 crisis as their “wake-up call”. A data-driven transformation returned them to profitability, but the scars remained. The shock made them look towards automation, digitization and, ultimately, Industry 4.0-related topics, such as 3D-printing. What used to be one of the most traditional factories in Denmark now ranks among the most ambitious.

Yet this also means that roughly 15% of small-er companies expect no changes of *any kind* to their business model in the next decade – an attitude that appears heroically optimistic in the light of an industry in flux.

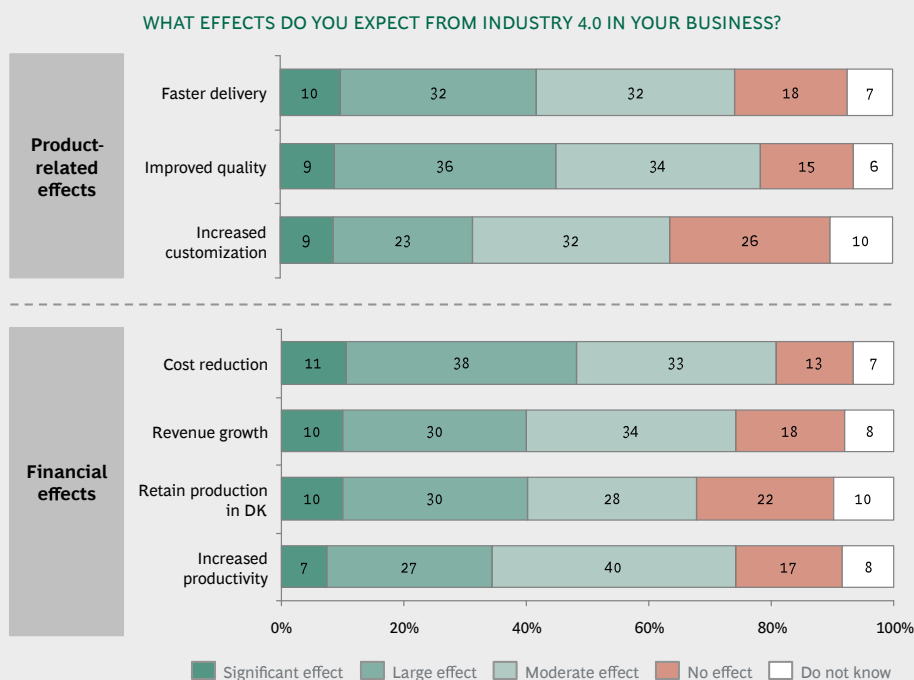
The customer is always right. In terms of how Industry 4.0 would impact business models, more than 2 out of 3 placed flexibility, speed, and customization among the key aspects of expected changes (see Exhibit 3). This finding is largely in line with our understanding of Industry 4.0: New technologies allow firms to customize products with little loss of efficien-

cy, enabling them to place the customers’ needs at the core.

This also resonates with the many manufacturers and knowledge institutions we interviewed. One knowledge institution argued that Danish production could never hope to rival Germany’s scale. Instead, we should play to our strengths and emphasize flexibility, customization, and speed. A Danish model of manufacturing could benefit by focusing on the technically advanced, customized “batch-of-one” production. For one producer of highly customized industrial goods, this is already being planned. During an interview, it was explained how a new system will allow clients to design their own equipment in an app. The blueprint is then sent directly to the factory, where engineers and robots are on standby to build it from scratch.

Besides these product-related effects, 3 out of 4 respondents expect cost reductions and increased productivity as a result of Industry 4.0. Hence, the majority of respondents expect to improve their offerings while reducing costs at the same time: Like other technological revolutions, Industry 4.0 provides a free

EXHIBIT 3 | INDUSTRY 4.0 LEADS TO BOTH PRODUCT-RELATED EFFECTS AND FINANCIAL EFFECTS



Source: IFD/BCG online survey

Note: Because of rounding, not all percentages add up to 100

lunch, of sorts, where companies are not faced with the conventional trade-off between slimming costs and improving quality.

Easy money: 30bn to the bottom line. Overall, 47% of respondents expect productivity to increase by more than 10% over the next 5-10 years as a result of Industry 4.0 (see Exhibit 4). As the exhibit shows, many respondents are more optimistic: 11% of them put expected productivity growth at 20%-30% and 13% think that this number will be above 30%. These estimates are beyond the productivity growth that would take place organically and adds roughly DKK 30bn to the nation's GVA. Interestingly, expectations are stable across all industries.

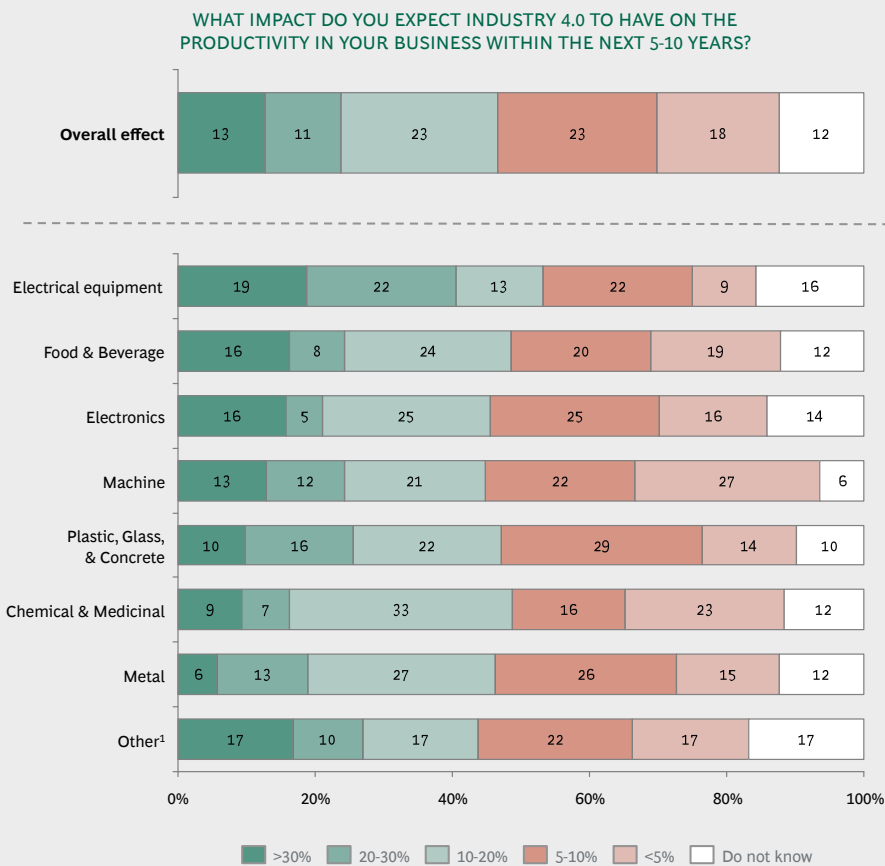
Rising Demand for New Skills

The more, the merrier. Like previous industrial revolutions, the productivity gains of the fourth revolution do not imply a general loss of jobs. In the survey, only 9% of respondents expect to downsize employment (see Exhibit 5). This is driven by larger and medium-sized companies. In particular, more than 1 in 3

large companies expect to employ fewer people in the decade to come. One reason for this is scale. In larger firms, some jobs are easier to replace than in smaller firms, for example by replacing people with robots.

But one of the most striking results of the survey is that more than 50% of the respondents have a positive outlook on employment due to Industry 4.0. Increased revenue growth in the industry offers gains in both employment and productivity. As our survey details, high employment expectations go hand in hand with higher expected revenue. These revenue streams could result from higher customization through flexible production lines, robotics, and 3D printing; innovative business models that help businesses tap into new markets (e.g. selling machines as a service); and by using augmented reality to expand after-sales service. Above all, manufacturers that expect their business model to change also expect to employ more people. It is important to note that these expectations are rooted in an optimistic and positive outlook for the future. If we fail to lead in this area, we may end up losing jobs rather than creating them.

EXHIBIT 4 | HALF OF THE COMPANIES EXPECT PRODUCTIVITY GAINS >10% FROM INDUSTRY 4.0 ADOPTION



Source: IFD/BCG online survey
Note: Micro = revenue less than DKK 15m, Small = revenue between DKK 15-75m, Medium = revenue between DKK 75-375m, Large = revenue larger than DKK 375m
¹Textile, tree & paper, oil, transportation and furniture

Imagine all the people. While robots and printers promise to replace primarily unskilled workers, demand for highly qualified labor will soar (see Exhibit 6). In our survey, 35% of the respondents would require fewer people in manual processing. In contrast, more than half would need more people who could produce new manufacturing processes, manage data, and develop software. This raises concern that future demand for highly skilled workers will outstrip supply.

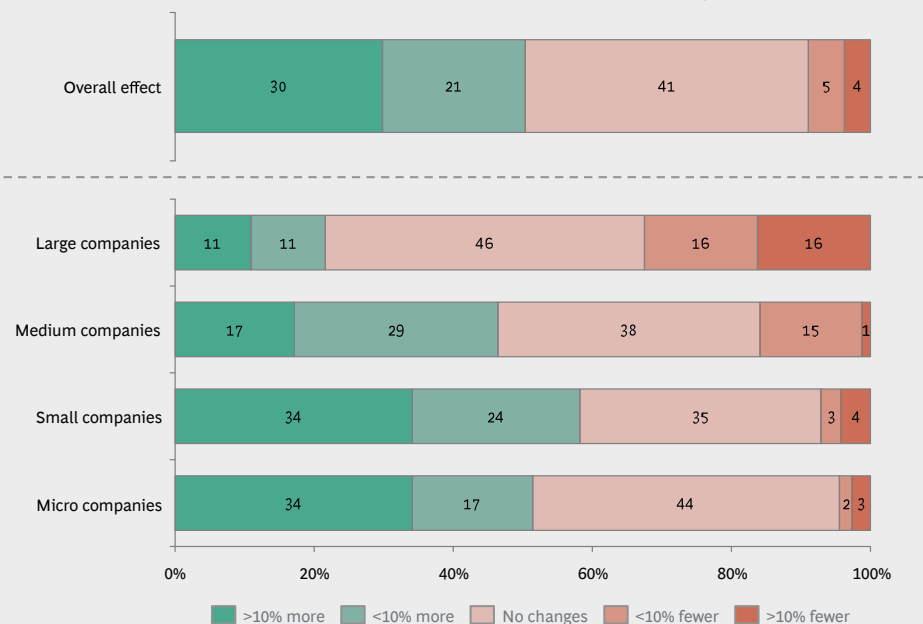
In fact, the consensus on the latter point is remarkable: According to IDA, the Danish society of engineers, there will be an undersupply of 13,000 engineers and scientists by 2025. Højbjerg Brauer Schultz predicts a deficit of at least 19,000 IT specialists by 2030. These numbers do not take into account the added effect of Industry 4.0-trend, which will only

exacerbate the deficit. And BCG’s own analysis estimates a base case need of 4,000 engineers and 7,000 IT experts by 2025 from Industry 4.0. Already now, the Danish Metalworkers’ Union reports that the metal industry is struggling to find qualified labor.

Denmark can hope to recruit foreign workers, but the capability gap is a global phenomenon – the competition for qualified labor will be fierce. With 6 out of 10 survey respondents expecting to recruit people with new competencies rather than retrain their current workforce, this stresses the need to promote the right kind of education in the future workforce (See Exhibit 7). In contrast, German and US companies expect to retrain their current workforce. This can largely be attributed to differences in labor market flexibility in the three countries.

EXHIBIT 5 | HALF OF THE COMPANIES EXPECT TO EMPLOY MORE PEOPLE AS A RESULT OF INDUSTRY 4.0

WHAT IMPACT DO YOU EXPECT INDUSTRY 4.0 TO HAVE ON THE NUMBER OF EMPLOYEES IN YOUR BUSINESS WITHIN THE NEXT 5-10 YEARS?

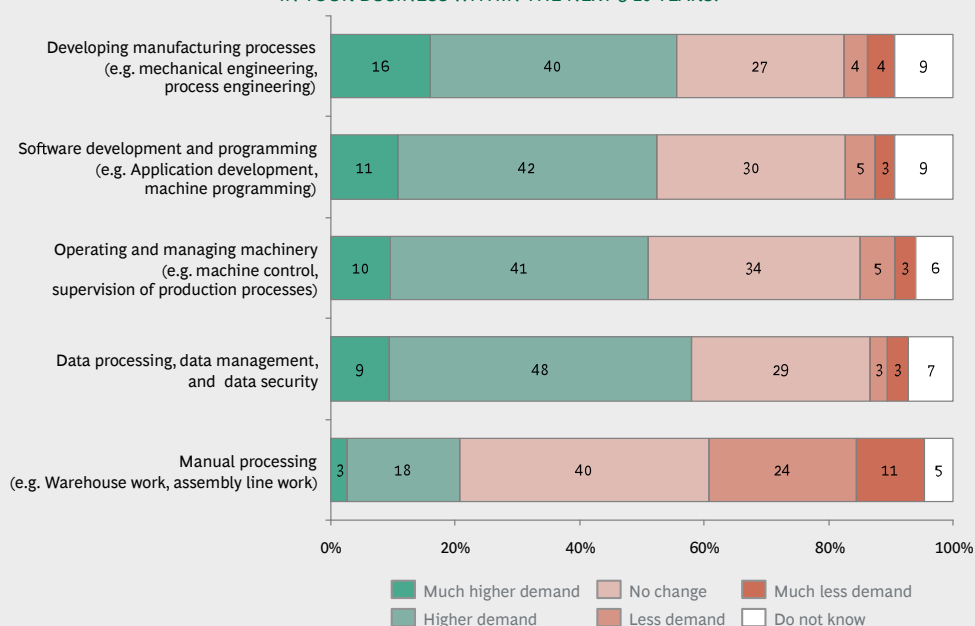


Source: IFD/BCG online survey

Note: Micro = revenue less than DKK 15m, Small = revenue between DKK 15-75m, Medium = revenue between DKK 75-375m, Large = revenue larger than DKK 375m, "Because of rounding, not all percentages add up to 100". Because of rounding, not all percentages add up to 100

EXHIBIT 6 | CAPABILITY MIX EXPECTED TO SHIFT FROM MANUAL PROCESSING TOWARDS ENGINEERING AND IT

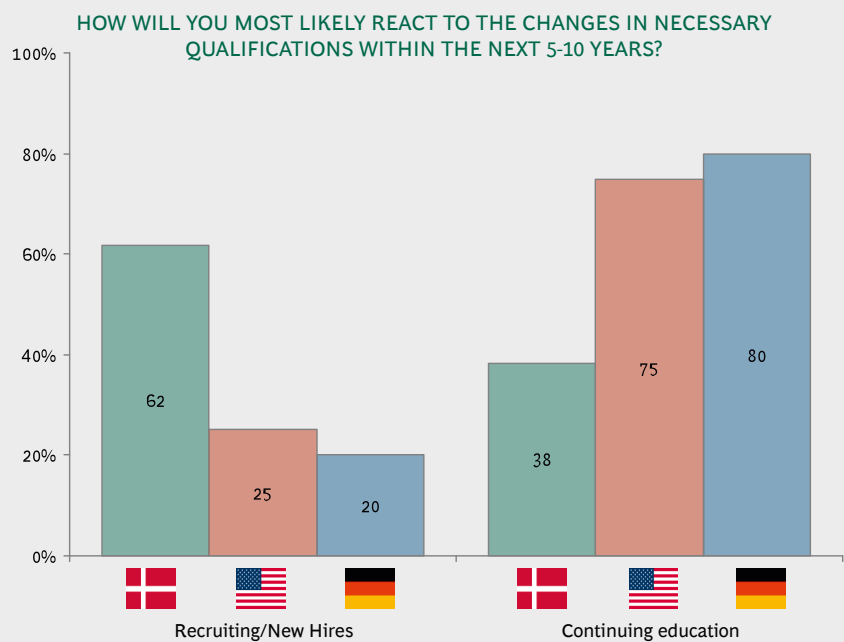
WHICH QUALIFICATIONS WILL BE MORE DEMANDED IN YOUR BUSINESS WITHIN THE NEXT 5-10 YEARS?



Source: IFD/BCG online survey

Note: Because of rounding, not all percentages add up to 100

EXHIBIT 7 | DANISH COMPANIES EXPECT THAT RECRUITING WILL BE USED TO CLOSE QUALIFICATION GAP



Source: IFD/BCG online survey

As for educating tomorrow’s workforce, we could do better. We educate most of our workforce in the sectors where they are needed the least. Data from the OECD (2014) shows that 35% of Danish graduates have a background in social science, business or law – ahead of all other countries in the study. But with just 20% of graduates, we are lacking people in the fields of science, technology, engineering, mathematics, computing, and manufacturing. We lag behind Sweden, Finland, Germany, and the UK in these technical subjects. During interviews, many smaller manufacturers called for new, innovative solutions, such as job-sharing schemes in which two firms share the same employee.

They also urged for a more modern education system that promotes shorter, technically-oriented degrees and introduces engineering science as a career path to children in secondary school. This is something that companies are desperately calling for. In 2008, 2011, and 2014, the Confederation of Danish Industry surveyed the most research-intensive companies in Denmark and found that they consider the engineering sciences to be the most relevant. In terms of prioritizing re-

search in this area, Denmark is at the bottom of the OECD. At 13% of public research, we lag far behind Germany (at 22%).

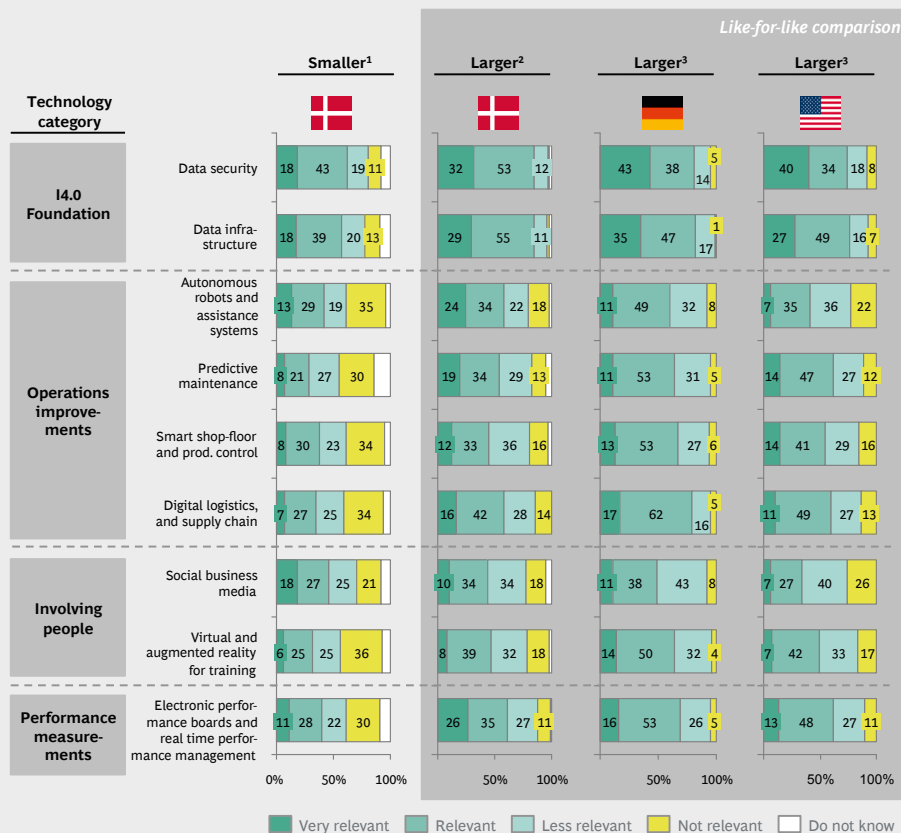
We also confirmed that larger companies tend to face fewer obstacles in recruiting talent, effectively draining the limited pool available and making it more difficult for smaller companies to get the competencies needed. In interviews, smaller companies mentioned that job candidates migrate towards larger, globally-oriented companies in large cities and central hubs. Conversely, larger companies did not express the same concerns, citing their ability to attract international job candidates, strong employer branding and their proximity to large urban areas. Despite this, in recent years many larger companies have found it increasingly difficult to attract foreign talent despite their strong positions.

Larger Companies in Front

In the survey, we quizzed firms on their attitudes towards a broad range of Industry 4.0 technologies. As one would expect, most respondents found the technologies relevant for their businesses in some way or another. In

EXHIBIT 8 | SMALLER COMPANIES FIND INDUSTRY 4.0 LESS RELEVANT THAN LARGER COMPANIES; LARGER COMPANIES ALMOST IN LINE WITH GERMANY/US

WHICH INDUSTRY 4.0 SOLUTIONS ARE RELEVANT FOR YOUR COMPANY WITHIN THE NEXT 5-10 YEARS?



Source: FD/BCG online survey; BCG report “Time to accelerate” (May 2016)

Note: Because of rounding, not all percentages add up to 100

¹Micro/small: Revenue less than DKK 75m (n=411)

²Revenue higher than DKK 75m (n=119)

³More than € 50m in revenue (n=221 for Germany, n=215 for USA)

particular, data infrastructure and data security stood out with more than 80% of respondents marking them as relevant. Companies understand that infrastructure and protection against cyber attacks must precede any specific technology implementation (see Exhibit 8).

Goliath trumps David. Larger firms find Industry 4.0 more relevant than smaller firms. In fact, smaller firms consider twice as many technologies irrelevant. This is perhaps what one would expect. Larger firms tend to have more resources at their disposal and their senior management has more time available for strategic considerations. During interviews, many smaller manufacturers mentioned that they did not conduct enough research or engage in long-term strategic planning because they were strapped for time and money.

Technologies seen as relevant are also more likely to be adopted. Yet, the scale is off: Manufacturers implement far fewer technologies than what they consider to be relevant (see Exhibit 9). As for these adoption rates, the size of the firm matters, too: Smaller companies have adopted – and plan to adopt – fewer technologies than their larger counterparts. A particularly worrying finding is that more than half have no plans to adopt anything for the foreseeable future – a trend that is apparent across all industries.

Lagging Behind Germany

Unfortunately, our medium/large companies lag behind Germany (see Exhibit 8). And unlike the Germans, we are especially keen to label Industry 4.0 technologies as “irrele-

vant”. For the most part, we share the sense of direction, but not the magnitude.

Only a minority of Danish medium/large companies have adopted the new technologies. This is especially noticeable when compared with Germany and the US, which outrank Denmark across all use cases (see Exhibit 9), except for robotics. Germany’s lead is hardly surprising: Not only have they worked on implementing Industry 4.0 for years, they also have the advantage of scale. A production sector 23 times the size of Denmark’s implies a much larger domestic market with so many firms that even customized solutions can be re-sold to more than one client. The difference may also stem from the good publicity that ‘Industrie 4.0’ has en-

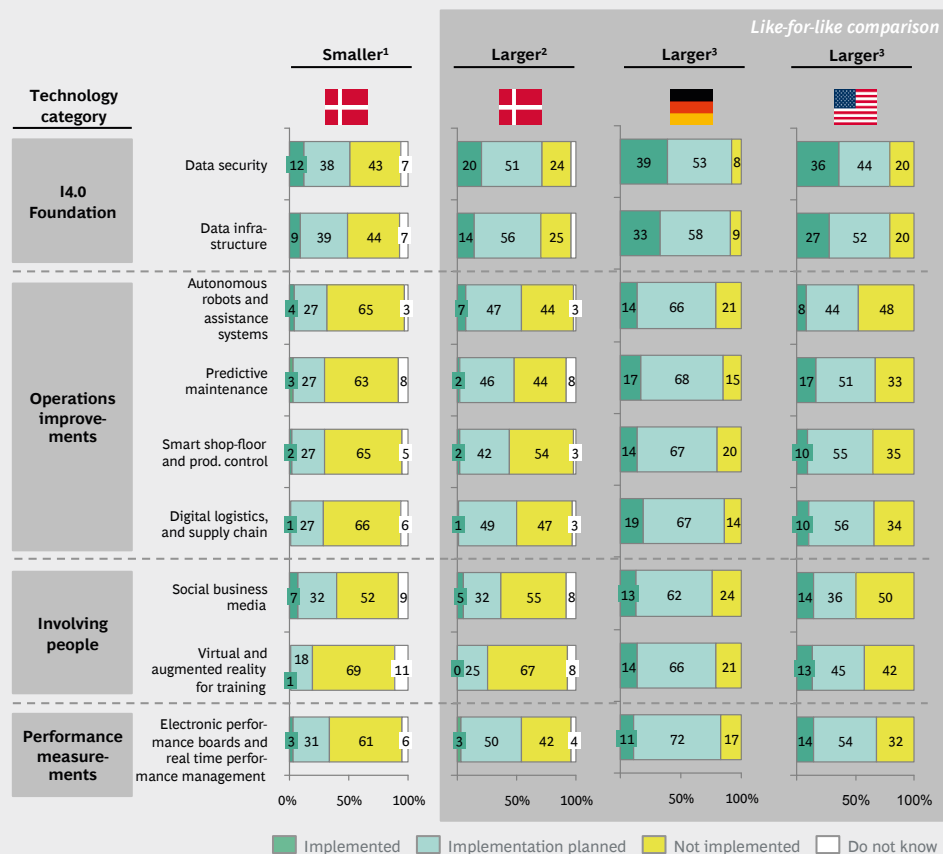
joyed in Germany for many years. This could be changing: During interviews, a Danish robotics consultancy pointed to a recent jump in Industry 4.0-related headlines in Denmark in the past 6 months. With this awareness spreading, perhaps attitudes will follow.

So, taking a step back, we can see some progress in the manufacturing scene. But smaller firms, in particular, are not prepared for the time to come.

Vorsprung durch Technik. Our primary bulwark against Germany is the robotics hub on Funen, spearheaded by the Danish Technological Institute and the University of Southern Denmark in Odense. These specialized hubs drive innovation, shown by the

EXHIBIT 9 | DENMARK IS FAR BEHIND GERMANY IN ADOPTION OF INDUSTRY 4.0 SOLUTIONS

WHICH INDUSTRY 4.0 SOLUTIONS ARE PLANNED OR ALREADY IMPLEMENTED IN YOUR COMPANY?



Source: IFD/BCG online survey; BCG report “Time to accelerate” (May 2016)

Note: Because of rounding, not all percentages add up to 100

¹Micro/small: Revenue less than DKK 75m (n=411)

²Revenue higher than DKK 75m (n=119)

³More than € 50m in revenue (n=221 for Germany, n=215 for USA)

intellectual property rights gathered in this area, which we consider to be a tangible proxy for innovation. As part of our extensive analysis of patent applications, we focused on three Industry 4.0 technologies: Advanced robotics, additive manufacturing, and big data analytics in Denmark and the Nordics. Overall, the Nordics produce only a fraction of the world's patent families, but Nordic growth has exceeded global growth in recent years (see Exhibit 10). Sweden is the main driver behind this development, thanks to innovators such as Arcam, ABB, and Ericsson – with Denmark lagging behind.

In the three technology groups, Denmark has the most patent families for “SMART Robots” (especially when considering that overall there are more patents filed in additive manufacturing than in robotics). For all countries, one or two big players drive the majority of patent families. In Denmark, Universal Robots is the most prolific, driving 88% of patent families in SMART robotics. In Sweden, Arcam has filed 59% of all the patent families on additive manufacturing. And in Finland, 56% of patent families on Big

data and analytics are filed by Nokia. (see Exhibit 11).

This pattern is also apparent in other areas. For instance, we see that large and medium-sized companies are filing more than 2/3 of patent families in the Nordics across advanced robotics, additive manufacturing, and big data analytics. In Denmark and Sweden, the number is above 85%. This is also a trend in the worldwide data set in which a few giants – e.g. Samsung, Microsoft, KUKA – hold the majority of all patent families in the three technologies. Some are produced internally, while many stem from acquisitions of other companies.

Interestingly, there are notable regional differences between the Nordics and countries in South-East Asia, especially South Korea. In South Korea, both universities and companies file a considerable amount of patent applications. In the Nordics, it is chiefly companies that drive applications, not universities. This is not to imply that one version is better than the other. From our point of view, the key to success is two-fold: (1) Fostering strong part-

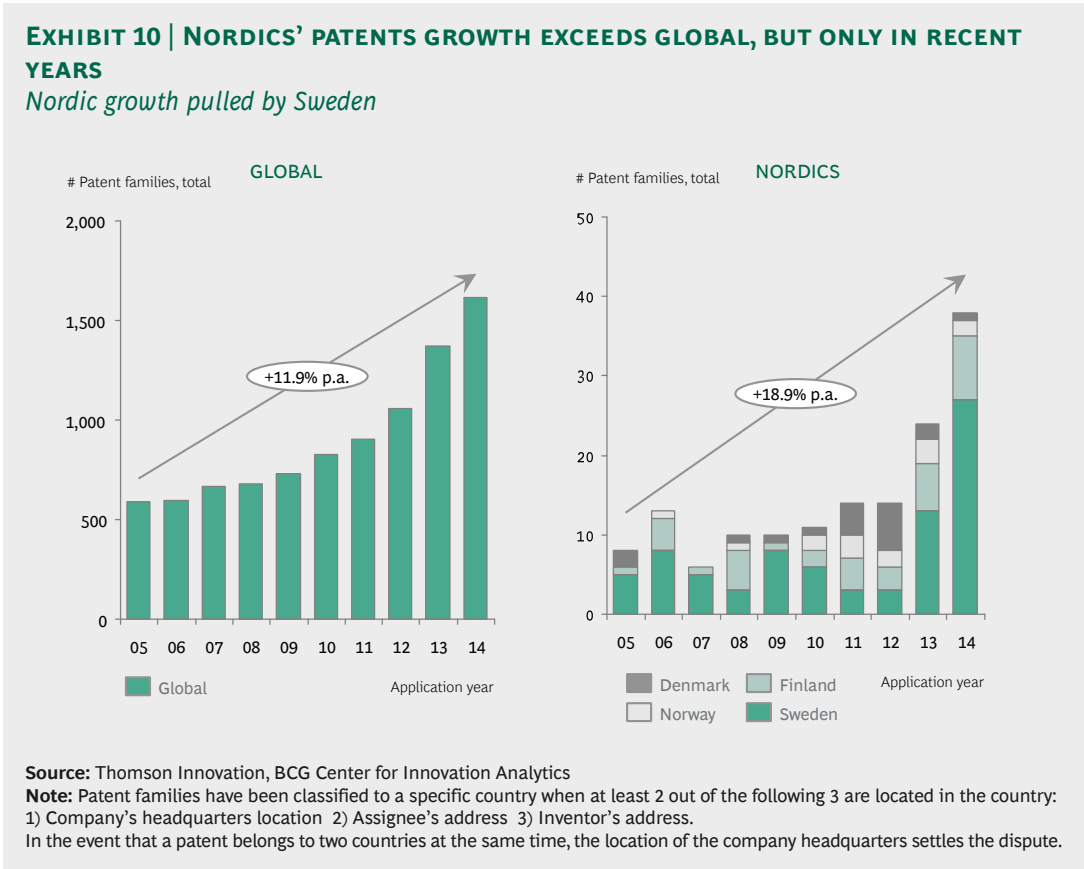
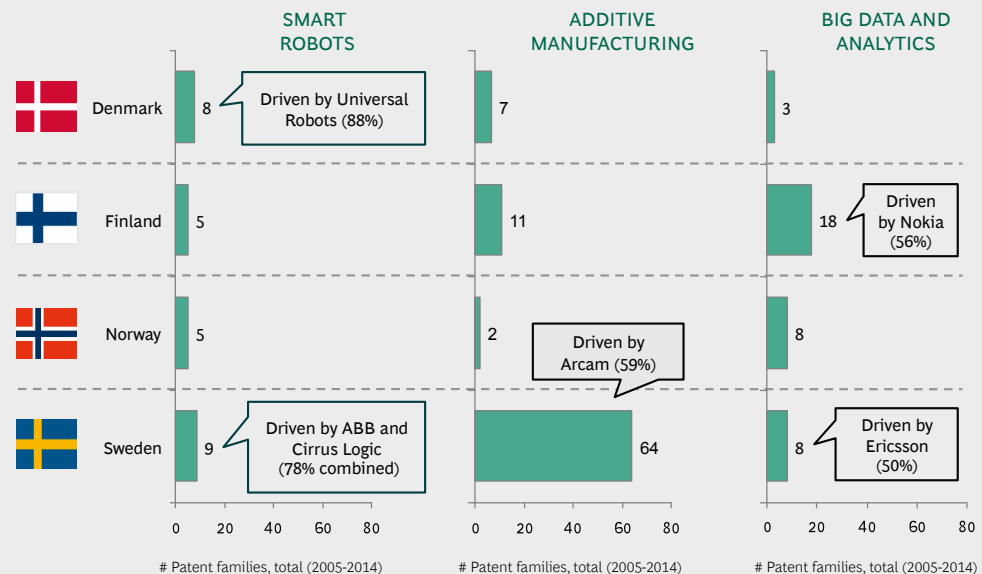


EXHIBIT 11 | ACROSS NORDICS, FEW COMPANIES FILE MAJORITY OF PATENTS Denmark strong in SMART Robots, where Universal Robots account for 88% of patents



Source: Thomson Innovation, BCG Center for Innovation Analytics

Note: Patent families have been classified to a specific country when at least 2 out of the following 3 are located in the country: 1) Company's headquarters location 2) Assignee's address 3) Inventor's address.

In the event that a patent belongs to two countries at the same time, the location of the company headquarters settles the dispute.

nerships between companies and universities in order to develop and implement new technologies and (2) developing intellectual property with the aim of promoting growth and employment – and not to have the papers stashed away in some dusty lab. In Denmark, successful partnerships between companies and universities usually start by settling their views on patent ownership in advance, usually facilitated through institutions like the IFD, MADE, and GTS.

Altogether, one of the key takeaways of our IP analysis is that it pays to cluster together. This is an old insight, stemming from the classical economic insights of Adam Smith and the lessons of Ford's assembly lines: There are great benefits to be gained from specialization.

Overcoming Obstacles

Barriers to entry. In our survey, we asked respondents what needs to be in place in order to motivate them to implement Industry 4.0 solutions. More than 2 out of 3 pointed to the following areas (see Exhibit 12):

KNOWLEDGE AND PRIORITIZATION

- More knowledge about Industry 4.0
- Higher prioritization within the firm
- Access to advice

FUNDING THE JOURNEY

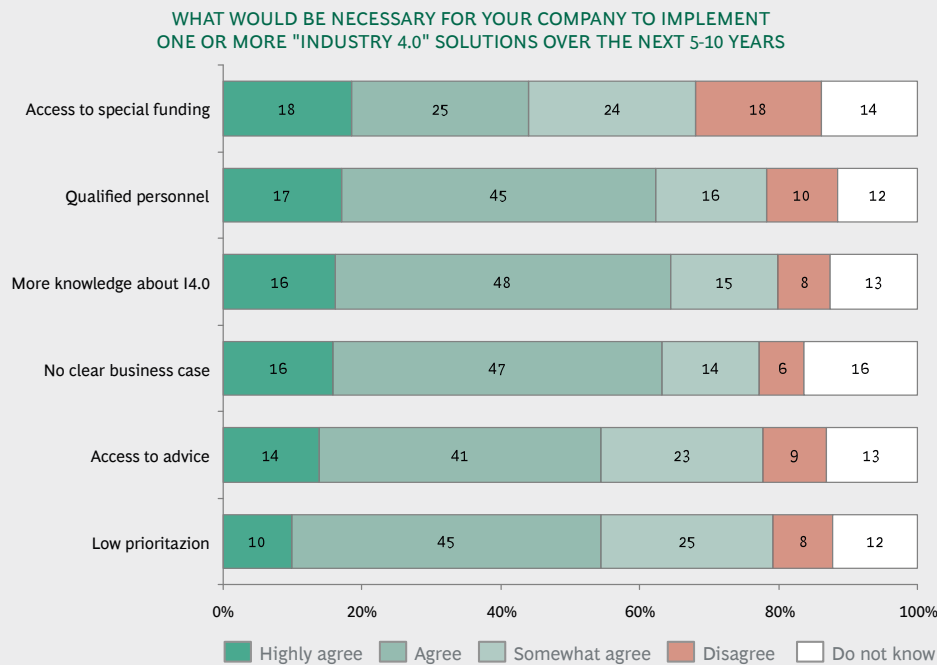
- A clearer business case
- Access to special loans and grants

CAPABILITIES

- Identifying and recruiting qualified labor

Interestingly, our survey also shows that early adopters see more barriers than firms that have yet to adopt any technologies. Having ventured into uncharted territory, firms have a much better understanding of the challenges. They also realize that many technologies are not “off-the-shelf” products, but are still under development. In one particular interview, an industrial goods manufacturer described the initial ambition to upgrade production equipment with Industry 4.0 technology. During the

EXHIBIT 12 | ACCESS TO FUNDING AND QUALIFIED PERSONEL ARE MAIN BARRIERS TO INDUSTRY 4.0 ADOPTION



Source: IFD/BCG online survey

Note: Because of rounding, not all percentages add up to 100

process, however, several unanticipated problems cropped up. This goes to show that we need to soften the barriers if we want to help innovators succeed and not leave them broken on the rack. Many looked favorably on centralized demonstration centers and organized company visits to help them get an overview of the benefits and challenges of each technology before starting out on the journey.

The interviews also labeled funding as a decisive, deal-breaking obstacle. In the survey, 18% strongly agreed that access to special loans and grants would enable the adoption of new technologies. When we benchmark this to German and US data, the Danish number is in line. So it seems that even for the more advanced manufacturing sector, this particular barrier is prevalent.

Traditionally, companies would rely on banks to provide external funding for new projects. Modern technologies, however, are difficult to fit into conventional business cases. We talked to several firms that faced the challenge of putting together a strong business case. Part

of the struggle is putting a figure on the potential cost-savings, which can require expert knowledge to estimate. But it is far trickier to estimate new revenue streams, as well as other add-on effects. A robotics consultancy firm listed flexibility, shorter time-to-market, and rapid prototyping as examples of benefits that are not easily quantified, even when they are clearly genuinely valuable (see Case Study 2).

One Industry 4.0-centered advisory firm has found that SMEs generally tend to handle business cases inadequately, because they are too focused on the short-term and do not have a strategic mindset. At the same time, some of the larger companies had purposely glossed over the traditional requirements for a business case and assigned several millions and expert resources for sandboxing new technologies – a luxury that smaller firms could not hope to afford.

Picking winners. Instead, innovative firms must turn to capital that is friendlier towards risky investments. Government soft funding is often seen as the most risk-friendly source of capital.

CASE STUDY 2 – BACK TO BUSINESS ELTRONIC

For Eltronic, an advisory firm and system integrator for industrial companies, Industry 4.0 is a game changer. They mainly service many larger clients, but are also keen to help smaller companies get a share of the spoils.

Ask the Expert

For most companies, any large-scale initiative is supported by a business case that lays out the expected costs, revenues, and uncertainty involved. This provides the backbone of a funding application, both for internal and external sources. But especially for smaller companies, the uncertainty takes the upper hand.

For most applications, it is straightforward to estimate the cost savings. Part of Industry 4.0's appeal, however, is the potential to generate new revenue streams.

But this is not a simple exercise and there are only few precedents. There is no conventional way to estimate revenue gains of e.g. more flexible production or higher degree of customization.

To overcome this, Eltronic is working on developing a methodology around building business cases to determine the potential benefits of introducing Industry 4.0 technologies in their customers' production systems. In connection to this Eltronic has applied for a Ph.D. at the Innovation Fund's "Industrial PhD" scheme, where both Eltronic and the Fund chip in.

Already today, Eltronic helps their customers build watertight business cases in slippery terrain. In the future, they hope to set the standard for how it is done for the fourth industrial revolution.

It is patient, stable, and meant for the long-term. As an example, Innovation Fund Denmark routinely injects cash into innovative, early-stage projects that struggle to produce conventional business cases. Any idea that has the potential to impact positively on Danish growth and employment is taken seriously.

Globally, government funding takes a central role, even in nations that are generally perceived as 'non-government driven', like the US. In terms of direct government funding, as well as indirect government support through R&D tax incentives, Denmark ranks 22nd behind countries like Sweden, Norway, and the US. For example, where Denmark spends 0.12% of GDP, the US spends 0.27% of GDP – more than twice as much. Moreover, the US spends 75% of government funding directly on businesses. In Denmark, this number is 50%. Indirect funding is made up of various tax incentives and usually only kicks in when there is a profit. Direct funding, on the other hand, can be as simple as a cash transfer. The purpose is to jump-start innovative, yet cash-strapped, businesses and bring them back on a positive trajectory.

During our interviews, the vast majority of smaller firms identified potential in optimizing the many public funding schemes. One manufacturer called it a "jungle" to navigate. Many complained that funding opportunities were scattered across many sources and that the grant sizes were too small – it would take many successful applications to fund an Industry 4.0 project, which is typically capital-intensive. All would prefer to spend less time writing applications and more time coming to terms with new technology. Some suggested new financing solutions, such as co-financing, soft loans and an external consultant that can assist in writing strong applications.

This is our starting position. In the next section, we will look at specific recommendations to accelerate Denmark's progress. While we should learn from Germany, we should not fall into the opposite error and copy them blindly: What works in Hanover may not work in Herning.

ACCELERATING DENMARK

STANDING IDLY BY AS THE platform burns should not be in the cards for a country at the frontier of science and technology. Industry 4.0, taken seriously, promises growth, jobs, and a fighting chance in the international arena. In this section, we propose a comprehensive set of recommendations for the next 10 years that seeks to boost our industrial competitiveness. Some recommendations address issues that need to be tackled immediately. Others take a longer view and look at structural changes that require careful planning. Taken together, they provide a sound starting point for any discussion of a national strategy.

Several countries have already set sail: China aims to build 40 manufacturing innovation centers by 2025 as part of the recent “Made in China 2025” plan that seeks to move China away from low-end manufacturing. Recently, the Obama administration set up its ninth manufacturing hub, the Smart Manufacturing Innovation Institute with \$140M in public-private funding, and has pledged to invest \$800M in five additional hubs. With its booming startup culture, Finland has published a 2020 vision, which is to become the “Silicon Valley of the Industrial Internet”. And Germany, as we know, is leading the race with its network of innovation-centered public institutions and a dedicated Industry 4.0 strategy.

On the shoulders of giants. Yet, we do not start at rock bottom. The Manufacturing Academy of Denmark (MADE) is working to bring cutting-edge technology from universities to factory shop floors. The GTS-network (Advanced Technology Group), a web of independent Danish research and technology organizations, offers knowledge and counseling to ambitious firms. And more recently, the government has brought together a panel of experts on Industry 4.0 to produce guidance for policy-makers (*»Produktionspanel 4.0«*).

In 2015, the previous *Produktionspanel* presented a vision for Danish manufacturing that sought to secure competitiveness and reverse declining employment. This vision focused on building a solid framework, training capable employees, and maintaining a high investment level. This report builds on this vision. As such, our recommendations will be grouped into three buckets (see Exhibit 13):

1. Strengthening Denmark’s Industry 4.0 *ecosystem* by building awareness and partnerships
2. Conducting strategic and tactical *workforce planning* and capability building
3. Increasing the availability of *financing* earmarked to Industry 4.0

EXHIBIT 13 | NINE STRATEGY INITIATIVES TO ACCELERATE INDUSTRY 4.0 IN DENMARK BY 2025



Source: BCG Analysis

Within each recommendation, we have identified three specific initiatives that are required for Denmark to accelerate in the Industry 4.0 race.

Our recommendations stem from (1) interviews with companies, technology organizations (GTS) and universities, (2) an extensive literature review, (3) interviews with Industry 4.0 experts, (4) our survey results, (5) various external data sources, and (6) discussions with our stakeholders, including the Confederation of Danish Industry (DI), Manufacturing Academy of Denmark (MADE), the Danish Technological Institute, the Danish Metalworkers’ Union, the Danish Advanced Manufacturing Research Center (DAMRC), the Ministry of Business and Growth, and the Danish Agency for Science, Technology, and Innovation.

Building an Ecosystem

Better together. One of our chief recommendations center on the ecosystem made up of

government, universities, technology organizations, and manufacturers. To this end, we recommend a systematic approach towards *building Industry 4.0 awareness* and *forming partnerships*.

Building awareness of Industry 4.0. Many firms know that times are changing, but are unaware of the options available to them. So the first step is to set up new centralized demonstration centers, while also reinforcing existing institutions that offer similar services. The demo centers should showcase Industry 4.0 technologies that are new, yet ready for implementation, for example top-of-the-line metal 3D-printers. This allows manufacturers to see first-hand how the technologies work and understand how they could be implemented. It is equally important to build the demo centers around a long-term strategy so they don’t open and close, or run out of funding, but stay open and keep stakeholders continuously informed of the newest technology.

One particular inspiration for demo centers is the public-private *Catapult* program in the UK, where the government and business community each supply part of the funding. In Germany, manufacturers travel to one of the *Fraunhofer Society's* demonstration centers, where cutting-edge technologies are on display. Our centers should be complementary to the German ones, in the sense that we focus on technologies that are relevant for Danish manufacturers, whereas *Fraunhofer* will maintain a more general exhibition. As for Denmark, we believe that knowledge institutions and the business community at large are well-suited to run the demo centers jointly.

Demonstration centers should go hand-in-hand with a task force of trained Industry 4.0 consultants – fully or partly funded by external resources. This can be offered by demonstration centers or technology consultancies. The task force diagnoses the manufacturer's factory for potential Industry 4.0 applications, estimates the associated productivity gains and upfront investments needed, and assists with the design and implementation roadmap of the solution (see Case Study 3). The purpose is to accelerate the adoption of Industry 4.0, especially among SMEs that cannot afford to employ specialists. This setup allows them to shortcut the process: Bringing in knowledge without facing a prohibitive

cost barrier. At the same time, the point is to encourage a sub-industry of Industry 4.0 knowledge providers.

Enabling partnerships between companies. Industry 4.0 is still hot off the press. New innovations happen every day, in every corner of the world. Yet, unlike standardized automation solutions, they cannot be used off-the-shelf. Industry 4.0 is in its infancy, so every implementation requires tweaks and customizations in order to address a company's specific pain points. Against the background of this complexity, manufacturers should seek to form partnerships – in some cases even with their competitors.

For this to happen, we need a set of key mechanisms that helps to match like-minded companies with each other. This could involve matching companies with similar needs to a single supplier, integrating a manufacturer with a supplier, or finding a band of companies that would like to co-finance or co-develop an Industry 4.0 project. Denmark is especially well-suited to horizontal partnerships, because few manufacturers are in direct competition. But it is not enough to simply match them. There has to be an institution that stays on to facilitate the partnerships afterwards. Both MADE and the GTS-network are uniquely qualified to accomplish this. They should bring the partners

CASE STUDY 3 – KNOWLEDGE FOR HIRE TECHNICON

Technicon, a small advisory engineering firm, deals in hardware as well as in bits and bytes. They are specialists in collaborative robots and, more broadly, “flexible automation” solutions. Firms seek them out to learn about the newest technologies and to get assistance in implementing them.

Industry 4.0, gift-wrapped

Technicon, and other consultancies, provide turnkey solutions. The consultants usually advise clients during every step of the value chain: From analyzing the factory floor and providing suggestions for improvements, to designing, building, and

installing the solution. The solutions go beyond “just installing robots”. Typically, the setup involves an array of sensors and actuators, as well as cobots that communicate with each other, while providing data that can be analyzed to produce fresh insights.

Currently, firms lack this specialist knowledge. At the same time, qualified labor is growing scarcer. Even when available, it may be prohibitively expensive to employ a specialist full-time. This case shows that a lack of skilled manpower won't be an issue if there is a market for renting it.

together in order to build trust, create a framework for collaboration, and match expectations.

In Germany, *Plattform Industrie 4.0* serves as the facilitator. They have drawn a map of Germany, which charts the implementation of Industry 4.0 technologies. The map includes detailed examples of German companies that cooperate on specific topics and exchange best practices with each other. This sort of approach is especially relevant for the German *Mittelstand* and could be highly relevant for Danish mid-sized companies as well. In Denmark, MADE and the GTS-network are the key players. Already, MADE hosts conferences, company visits, and other sessions on Industry 4.0 themes, seeking to bring together manufacturers for knowledge sharing and inspiration. Their efforts could be amplified by continuously mapping the progress and taking a more active stance in facilitating partnerships.

Facilitating knowledge partnerships. Danish universities work at the frontier of science and technology; manufacturers do not. However advanced and knowledgeable our universities are, it is worth little until the technology is implemented on the shop floor. A fully self-sustaining ecosystem requires seamless cooperation everywhere in between research labs and factory floors. This is worth taking seriously. According to a study by Universities Denmark, companies that work directly with universities experience higher productivity growth. The first step is to make manufacturers aware of the possibilities for cooperation with knowledge institutions. This means emphasizing the role of the GTS-network of research and technology organizations and their role in linking universities and manufacturers together.

It also suggests that universities could benefit from specializing in certain niches within Industry 4.0 and work to be result-oriented in their research, as a recent report from the Confederation of Danish Industry recommends. At the same time, they should seek to work more closely with the business community. A good example is the University of Southern Denmark that works closely with the robotics hub in Odense. We can also emu-

late Germany, where universities regularly drive external research projects in cooperation with companies. It is a common practice and has been applied with a specific focus towards Industry 4.0.

In addition, we recommend clear guidelines for patent ownership rules in order to promote frictionless collaboration between universities and companies, in which relationships do not turn sour towards the end. As our patent analysis has shown, there is plenty of room to build up more intellectual property in Denmark.

A tightly-knit ecosystem is more than just a catalyst for change. To achieve any ambitions of higher Industry 4.0 adoption rates, the ecosystem is a strictly necessary prerequisite. In the short term, fostering partnerships between manufacturers and knowledge institutions must be a strategic priority.

Planning the Workforce

The times they are a-changin'. When the steam engine replaced much of the work previously done by hand, the demand for textile weavers vanished. A similar event is taking place now. By 2025, some jobs that are at the fringe today will be mainstream. Others will be obsolete. Already now, the government must take a long-term view and structure the education system accordingly. Or it could respond with inaction and oversee our descent into a nation of jobless textile weavers.

In the following section, we identify three key recommendations for the nation's workforce planning.

Determining the demand-supply gap. As a first step, our recommendation is to map out the specific competencies that will be required in science, technology and engineering over the next 10 years due to Industry 4.0 – from specialists to unskilled workers. In particular, we should expect an increase in demand for industrial data scientists, robot coordinators, industrial engineers and simulation experts, supply chain coordinators, digitally assisted field-service engineers, data-modeling specialists, and 3D-computer-aided design and

modeling specialists, to name a few. As a next step, we need to gauge the size of the gap. For this, we recommend a detailed forecast of the future workforce, in order to get an estimate of the gap between supply and demand across the various competencies that will be needed. Yet this should not be a one-off event, but a continuous process, since the required skills will change over time.

Closing the demand-supply gap. With a better understanding, we should aim to close the gap before it is too late. In addition to specific job areas, we should aim to educate both generalists and specialists, emphasizing depth of knowledge as well as broad, multidisciplinary skills in higher education and vocational training.

To do this, we have to focus on building the right kind of capabilities, increase the number of newly educated people, add to the supply of fully-trained workers, and rethink traditional work models.

On the first point, we need to build a workforce that meets future demand. There should be an emphasis on developing world-leading expertise by head-hunting top scientists and engineers from foreign universities. Danish universities should follow suit by specializing in specific domains in order to gain world-class knowledge.

But the workforce should also shift away from its current mix and towards the engineering sciences. The Confederation of Danish Industry, the Danish Metalworkers' Union, and the Danish Society of Engineers all recommend promoting the engineering sciences (as opposed to, for example, the social sciences), especially in terms of public funding. Denmark is currently at the bottom of the OECD rankings, with only 13% of the public research budget going to engineering science in stark contrast to Germany's 22%. As a follow-up, we also recommend that IT takes part in non-technical disciplines, such as business-related courses, to build a better understanding of the versatility of technology. We should also make an effort to identify new interdisciplinary fields and award them their own degrees.

On the second point, we need to dramatically increase the supply of students with a technical background. The most critical challenge is the dwindling supply of IT specialists. We recommend that universities, companies, industry associations, and governments encourage students to pursue IT-related degrees. We should work to improve awareness of technical degrees by actively promoting them as potential career paths in secondary school. In a similar vein, we should promote vocational colleges and rid ourselves of the fiction that a master's degree is necessary in order to enter the workforce. Finally, to boost the number of engineering students, we need to strive for a better gender balance among the technical disciplines.

As for the third point, part of the strategy must also include attracting talented, foreign workers. The focus should be on making it attractive to work in Denmark through various incentive schemes, tax breaks, and general infrastructure for expats, while bearing in mind that the global competition for talent is tough.

Finally, it is also time to rethink the traditional work model, in which one employee belongs to one company. Instead, multiple companies may share one specialist, splitting the costs between them. This will increase the number of companies with access to specialist knowledge and lead to a decline in the demand for technical employees.

Continuously upgrading the workforce. We should dispel the myth that an old dog cannot be taught new tricks. Instead, we need a brand new format for further education that emphasizes ongoing retraining of the existing workforce. Above all, universities must take advantage of alternative learning platforms, such as online learning, open universities, and mobile apps. To this end, universities could offer high quality "Massive Open Online Courses" (MOOCs) and also offer part-time upgrade courses, e.g. for engineers who wish to take on a new specialization. Finally, vocational colleges should add Industry 4.0-related topics to their curricula and, like the universities, offer relevant upgrade courses for the current workforce.

Increasing Funding

A penny for your thoughts. We have spoken with several ambitious companies hamstrung by empty coffers and cautious bankers (see Case Study 4). As it turns out, bank funding does not mix well with advanced manufacturing techniques. With unconventional business cases and uncharted territory, bankers who worry excessively about risk tend to steer clear of these projects.

special loans. The first is a class of government loans with favorable interest rates. The second method is to increase the supply of private bank loans where the potential downside for the bank has been cushioned by the government. This will help decrease bankers' risk aversion towards Industry 4.0 and increase the amount of funding available. Finally, we should strengthen the opportunity to grow via venture capital funding.

CASE STUDY 4 – A NEED FOR RISK CAPITAL THÜRMER TOOLS

For Thürmer Tools, the future is 3D-printed. In 2013, the family-owned manufacturer of thread cutting tools partnered with the Danish Technical University (DTU) to get involved with 3D printing, a technology that has already revolutionized plastic manufacturing. When it comes to metal printing, however, it is still in its infancy.

The Spotify for Tools

The ambition is to produce highly customized tools at the click of a button. For now, the virtual simulations are promising, but the output is too brittle. Moreover, Thürmer Tools has yet to buy a 3D printer of their

own, which typically comes with a price tag of DKK 8M – a steep price for a small firm. Sourcing the funding has proved tricky. “No one wants to finance production in Denmark”, Erick Thürmer explains. Banks, in particular, shy away from it. “It is seen as bad business judgment”.

For the time being, Thürmer Tools continues to apply to various funds and EU programs for funding, while putting aside funds from their healthy core business. But to stay at the frontier, they need to be among the first movers. Their grit won't stop them, but their empty coffers might.

Increasing the pool of government-funded risk capital. We recommend a significant increase in the amount of direct government-provided risk capital reserved for the development of experimental Industry 4.0 technologies – both through grants and other kinds of soft financing. This type of funding has to gloss over the concerns that prevent projects from obtaining traditional financing. In addition, the purpose should be to foster innovation at large. So by design, it should be especially tolerant and patient towards risky business cases and seek diversification by spreading investments across many smaller projects. Finally, in their 2015 report »Gode Job«, the former *Produktionspanel* argued for better incentives for companies to invest in Industry 4.0 technology on their own accord, e.g. through special tax breaks.

Facilitating access to special loans. In addition, we recommend implementing two types of

Providing funding to the Industry 4.0 ecosystem. Finally, policy-makers would be acting incompletely without providing universities and research organizations, such as the GTS-network, and industry associations, such as MADE, with the necessary funds to continue pushing the frontier. These institutions should not have to scramble for funds, but should be able to plan for the long-term. The funding plan should match the same time horizon. For this reason, we recommend including MADE as an integral part of the broader vision for Denmark's manufacturing sector.

If policy-makers were to take these recommendations to heart – building a coordinated ecosystem, reforming the education system, and providing the necessary funding for it – then Denmark would be well prepared to win the Industry 4.0 race.

Recommendations for Manufacturers

The task of migrating successfully to a new industrial era does not fall on governments and knowledge institutions alone. If manufacturers wish to future-proof their businesses, the ball is in their court: Hoist the sails or sink.

STRATEGY

In the same manner that we proposed a national strategy for Denmark, this section will offer immediate actions for manufacturers to consider based on BCG case experience.

Seek, and ye shall find. First of all, we recommend that small and medium-sized manufacturers embrace a curious and adventurous mindset. Seek inspiration through demonstration centers, knowledge networks, and factory visits – both domestically and abroad. Reach out to the GTS-network, MADE, and relevant industry associations to get in touch with like-minded people.

At the same time, bear in mind that a successful Industry 4.0 implementation must be driven by a set of clearly identified pain points, rather than investing in new technologies simply for the sake of it. It is also important to understand that Industry 4.0 is rarely about single technologies, but rather about ‘use cases’ that combine several technologies in a meaningful way. The particular business needs in question drives which combination of technologies adds value.

More speed, less haste. When implementing the use case, do not hurry the process. Instead, introduce it slowly through a pilot program. It is ultimately quicker if the implementation is successful on the first try, than if rushed through with errors. Make sure to carefully monitor the impact and any issues that crop up. If successful, roll out the initiative on a broader scale.

ORGANIZATION AND COMPETENCIES

We recommend that Industry 4.0 change should be driven by executive management commitment and alignment. In order to facilitate this, it is necessary to align management opinions and have them commit to the importance of building internal Industry 4.0 expertise.

To this end, key people inside the organization should be identified, who are capable of driving the effort forward. Ideally, they should be willing to adapt, interested in Industry 4.0, and come with a technological skill set. During one interview, the owner of a small Industry 4.0 tech producer mentioned that almost all SMEs in Germany have a CTO (Chief Technology Officer) in their C-suite: A single person dedicated to staying up-to-date with the firm’s technological situation. This is rarely the case in Denmark, but is sorely needed.

Finally, we recommend seeking partnerships with industry associations, knowledge networks, and universities to leverage external sources of talent and expertise.

FINANCING

In our view, it is important to build a business case that focuses on potential top-line gains, derived directly from Industry 4.0 use cases, in addition to traditional cost savings and efficiency gains. When estimating costs, seek expert guidance on both the implementation costs and the required investments. We recommend seeking external risk capital from funds with a long-term perspective on Industry 4.0, e.g. through the Innovation Fund Denmark and the Danish Industry Foundation.

Live long and prosper. On a final note: Don’t bite off more than you can chew. The Industry 4.0 journey may seem overwhelming, but will be less intimidating once you go beyond the buzz and come to terms with the technologies on your own.

BEYOND MANUFACTURING

DENMARK CANNOT RELY ON the manufacturing sector alone. At just 10% of employment and 14% of GVA, there is reason to look elsewhere. In stark contrast, the service sector accounts for 76% of GVA and 78% of employment – a towering figure in the Danish economy. In addition, most service industries lag behind the manufacturing sector in productivity. In particular, the public sector is both labor-intensive and relatively unproductive. Fortunately, many of the same technologies used in Industry 4.0 can help revitalize productivity in services as well.

At your service. Service companies have more catching up to do than their industrial colleagues. Advances in software and hardware promise proactive and customized multi-channel support – popularly known as Service 4.0. In particular, this will happen through faster time-to-market from initial idea to final service offering, higher productivity through automation of process steps, and better quality by proactively solving problems before they even happen (See *Tapping into the Transformative Power of Service 4.0*, BCG Perspective, September 2016).

The point is to eliminate “waste” in the broadest sense: Reducing waiting time, utilizing skills better, and avoiding unnecessary use of expensive systems (See Exhibit 14).

This applies to all service industries from Energy, Telco, and Banking to Insurance, Government, and Health Care. Several technologies that are making an appearance are also making their way into the service world, notably Big Data and analytics, augmented reality, the cloud, and automation through robotics.

Big Data and Analytics. Where manufacturers use data-driven analytics in order to predict and prevent production line failures, service providers can use big data and predictive analytics to better understand customer behavior and identify opportunities for proactive engagement.

Augmented reality. The power of augmented reality technology for providing workers with real-time information is relevant for both manufacturing and services. For example, utility providers provide technicians with step-by-step repair guides using augmented reality.

The Cloud. Support functions can increase the performance and speed of calculations by deploying enterprise cloud solutions for comprehensive data integration, real-time processing, and analytics.

Robotic process & automation. As a result, most routine processes still require human intervention, which leads to errors and reduces speed and efficiency. An automation capabili-

EXHIBIT 14 | SERVICE INDUSTRIES EXPERIENCE HIGH LEVELS OF WASTE

Sources of waste	Energy	Telco	Banking	Insurance	Government	Health care
Overprocessing	Unnecessary use of expensive systems and resources (for example, unneeded system complexity)					
Overproduction	Excessive service and output levels, which have an insufficient link to customer value					
Transport	Too many unnecessary physical activities and processes (for example, multiple data entries)					
Motion	Manual work that can be automated or eliminated (for example, data lookups or validations)					
Inventory	Large stockpiles of physical goods (for example, Telco devices) or a backlog of troubleshooting tickets					
Defects and Rework	Quality problems that hinder downstream processes or necessitate rework					
Waiting	Inefficiencies that result from waiting for resources or slow processing					
Improper utilization of Skills	Use of overqualified employees for simple tasks or underqualified employees for complex tasks					

Source: BCG Analysis

ty known as software robots can replicate human tasks, such as data entry and account handling, and thereby eliminate errors.

Smart Government. There is ample opportunity for government agencies to benefit from Service 4.0. In 2013, the UK Cabinet Office found that digital public-sector transactions are 50 times cheaper than face-to-face interactions. Yet cloud services, big data, bots, and the Internet of Things promise to transform the public sector across all agencies and ar-

eas. By working in the cloud, cost-conscious governments need not upgrade hardware and software. Big data and the Internet of Things are prerequisites for a smart public sector. Bots assist citizens with routine questions without the need for human intervention. This takes serious effort, e.g. in terms of data sharing between government agencies, but the reward is a streamlined public sector that delivers added value to its citizens.

APPENDIX: METHODOLOGY

The methods and assumptions used throughout the report are outlined in this chapter.

Patent analysis

We look at the flow of patents for two reasons. First, it acts as a proxy for innovation. Secondly, a build-up of intellectual property rights can be seen as a competitive advantage for a country.

Patent families. When an invention is patented, the inventor often files for protection in other countries as well. For this reason, a single invention may be associated with multiple patents. To overcome this, we look at patent families, which group a set of common patents into one. Using patent families gives us a much clearer measure of innovation.

For our analysis, we focused on three Industry 4.0 technologies:

- Advanced robots
- Additive manufacturing
- Big data and analytics

These focus areas stem from our survey, interviews, advice from experts, and were made in collaboration with IFD and MADE.

Database. Specific patents were found in the Derwent World Patents Index (DWPI), a

database that contains patent applications from more than 40 patent-issuing authorities. Working closely with the BCG Center for Innovation Analytics, we located relevant patents in the DWPI database using the following key words and their combinations:

Advanced robotics. Intelligent, artificial intelligence, collaborative, integrated sensor, autonomous, cooperative, machine learning, machine vision, machine to machine, machine to machine and communication, learning system, self adapting, reinforcement learning, self learning, rapid and learning, mobility, modular, manipulator, robot.

Additive manufacturing. Additive, manufacturing, 3D, 3 D, three dimensional, product, design, object, body, bodies, article, layer wise, layer-wise, layer, printing, production, powder bed, system, fusion, selective laser melt, electron beam melting, direct, energy deposit, laser clad, laser, net shape, direct, light fabrication, sheet lamination, laminated object, binder jet, wire feed.

Big data and analytics. Data, analytic, computer human, artificial intelligence, machine learning, real time and decision making, software and (data, model, data driven service, optimization, decision making, CRM, ERP, enterprise resource, customer relationship management, SCM, supply chain management, MES, manufacturing, machine data), sensor

and (predictive maintenance, embedded system, integrated system, cyber physical).

We narrowed down the search to include only those applications filled between 2005 and 2014. In total, our analysis found ~ 1,700 patent families related to Smart Robots, ~ 3,700 patent families related to Big data & Analytics and ~ 3,700 patent families related to Additive Manufacturing.

Classification. For the Nordic countries, we classified each patent family as belonging to a specific country when two out of the following three aspects were located in that country: (1) The company's headquarters, (2) the assignee's address, and (3) the inventor's address. In the event that a patent belongs to two countries at the same time, the location of the company's headquarters settles the dispute.

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