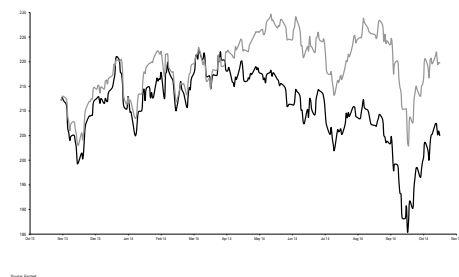


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INDUSTRY 4.0 – Promising (R)Evolution

This report is intended to provide an introduction to the Industry 4.0 concept, its potential, on obstacles and risks. We believe that Industry 4.0 has yet to prove whether it is a revolution or ‘just’ an evolution, the chances arising for the engineering and IT world appear promising. Germany has solid foundations to assume a leading position and we show how a selection of our coverage universe approaches the topic.

- ✓ A possible definition of Industry 4.0 is the **1/technical integration of Cyber Physical Systems (CPS) into production and logistics as well 2/as the industrial use of the Internet of Things**. At the same time Industry 4.0 is not blind with respect to human interaction. Networking is a key element whilst intelligent or smart products, grids, buildings and factories are interconnected in respective structures.
- ✓ The ultimate motivation of Industry 4.0 should be the creation of even more wealth through improving efficiency. Seen from this angle it is not different from former industrial revolutions, **it might emphasize a higher degree of individualisation for consumers at reasonable production cost**. Industry 4.0 enjoys government support aimed to defend leadership positions.
- ✓ Within the sense of an ecosystem, **Industry 4.0 appears to be a perfect bracket embracing buzz-words like M2M, Big data, Cloud, 3D Printing** and providing them additional justification at the same time. Since each of these components are seen growing with high double-digit rates, Industry 4.0 can hardly have less potential per se. Implementation efforts can however not be ignored, but rewards seem big.
- ✓ As regards the potential of Industry 4.0, **PWC sees German core industries’ relevant spending amounting to a strong figure of EUR 40bn p.a. in the next 5 years**. According to Roland Berger, the overall industrial sector should grow, meaning an increase in the overall contribution rate to EU GVA from 15% to 20%.
- ✓ **Industry 4.0 challenges to overcome** or to cope with are in our opinion 1/the need for a high(er) educational level, 2/cannibalisation and change risks, 3/misallocation of resources as no ‘Industry 4.0’ standard’ exists, 4/regulatory hurdles and 5/security and reliability of CPS.

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Introduction into 'Industry 4.0'

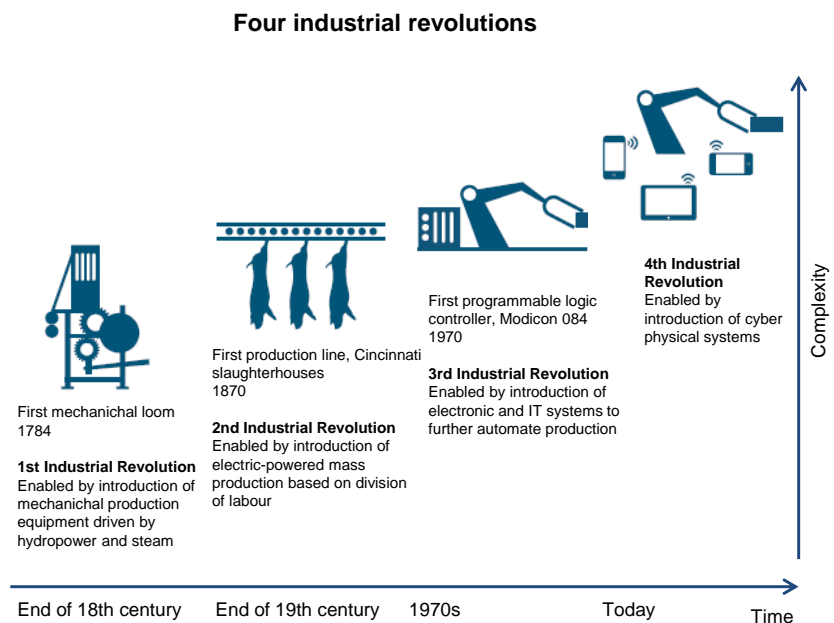
Why '4.0' – the historical context

The term "Industry 4.0" refers to the continuation of historically significant leaps of the industrial development:

The 1st industrial revolution was mainly shaped by the invention of the **steam engine** by Thomas Newcomen in 1712¹. For the first time, the transformation of thermal energy to mechanical work was made possible and led for example to the invention of the first mechanical loom in 1784. The long-term consequence was rapid, exponential economic growth and increasing prosperity.

The 2nd industrial revolution represents the emergence of mass manufacturing through the **division of labour**, supported by electrical energy. Occurring in the 1870s and 1880s, it also meant the beginning of assembly line work and the specialisation of employees on small sub steps of production. A practical example was the first production line installed in a slaughterhouse in Cincinnati in 1870. A dramatic decrease in production cost was made possible and at the same time a great variety of products became widely economically accessible for consumers. On top of that, the electrical light enriched the life of the general population by creating independence from daylight hours.

The 3rd industrial revolution was characterized by the automation of production in the 1960s and early 1970s. Controller devices and **information technology** brought diversification of products and an affordable increase of quality. Primarily, manual steps were replaced by machine work, putting employees increasingly in a supervising and controlling position. Consumers were now able to choose from an even greater variety of things. Computational power grew rapidly and was described by the law of Gordon Moore from 1965 (the number of transistors in a dense integrated circuit was said to double approximately every two years) further boosting productivity.



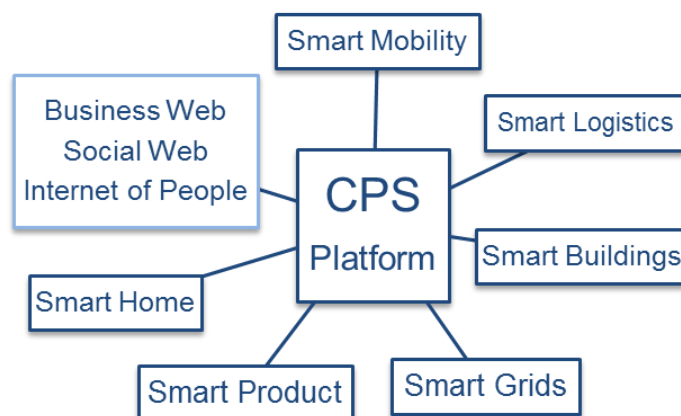
¹ (Matschoss, 1901)

A 4th industrial revolution on the horizon? The 3rd industrial revolution was largely creating effective single-system units. The development of **IT network infrastructures, massively supported through broadband connections**, is now leading to a significant expansion of scope in many aspects which we will examine in this report. This should be the case even in spite of Moore's law probably seeing (physical and economic) limitations when it comes to the further shrinking of microstructure architectures. While for example the advantage of low cost mass production did not enable low cost individualised goods, 'Industry 4.0' appears to promise a respective solution next to further efficiency gains in many areas which we will highlight in this report. What characterized every revolution so far was their resulting in prospering wealth and exponential growth. Will 'Industry 4.0' connect seamlessly to this ultimate motivation of new technologies and who will exploit is potential? What are the obstacles? In any case, it seems that this is the first time that an industrial revolution is announced prior to its occurrence.

What is 'Industry 4.0' and its composition?

The term 'Industry 4.0' was introduced the first time at the Hanover fair in 2011 and has to be seen in conjunction with a German government initiative which focused initially on the next level of efficient factory manufacturing, i.e. on the so-called 'smart factory'. Two elements appear to be important here: 1/So-called Cyber Physical Systems (CPS) and 2/the Internet of Things (IoT). However, the interpretation options of 'Industry 4.0' proliferated and the meaning is now much more wide-spread in our opinion as we will describe later.

Cyber Physical Systems: CPS² are hybrid systems of application based control and a physical object, like for example a production robot or a cooling system. CPS differ from so-called embedded systems as the emphasis tends to be less on the computational elements, and more on the **interconnection between the computational and physical elements**. While originally focused on actual industrial production, CPS can more and more frequently be found in different sectors and in different intelligent systems as there are for example: 1/*Smart grids* are power supply systems with intelligent measurement and steering technology, ranging from generation to consumption monitoring. 2/*Smart homes* allow control of illumination, water and home appliances as well as usage monitoring applications. This extends to intelligent car charging and automobile information technology. 3/*Smart buildings* make it possible to remotely lock and unlock doors or windows and control a variety of appliances.



Source: Bosch Software Innovations 2012, equinet research

² (AK Industrie BMBF, 2013)

Internet of Things: All these areas are connected via CPS *platforms*, creating the Internet of Things (IoT). In other words, the IoT can be seen as the interconnection of CPS or embedded elements and Internet infrastructures. Usually, the foundation for the IoT is the so-called **machine-to-machine communication (M2M)**, a direct wired or wireless communication of devices of same or similar types which requires certain standards.

'Human factor': The CPS platform connections expand today to the internet of the people, the social web and the business web, expanding the IoT to a **broader human/IoT interaction which could well be done today by mobile devices**. This link provides the input for example for the individualisation of products, collaboration of multiple enterprises in an 'Industry 4.0' cluster and grants access to the human user with respect to the control and the output.

Application example I - The Smart Bottle Factory

The German research unit for artificial intelligence (DFKI) has built up a pilot plant in cooperation with 20 partners to showcase the **intelligent production of soap bottles**. Radio frequency identification (RFID) is used in the form of smart stickers to assign black or white closing caps. A product memory is created. Information technology can be used to evaluate the process. The system is open to the extent that further implementation of CPS components is possible without question.³

Application example II - End-to-End System Engineering

The architecture of value chains tend to be relatively static. It is not possible to directly observe or manipulate the production of a single product from a central place. Although there is information exchanged between the parts with the help of a variety of interfaces between IT support systems, there is no **global controlling system**. CPS can enable such control. The system would need to be based on a single paradigm to keep up with the pace of product development. The results are individual products, since each part of the value chain sets its parameters according to the information about the specific unit from the cloud. The implementation of these steps will most probably occur gradually.⁴

Application example III - Agriculture

Agricultural business has to face several challenges. One is the availability of harvesting machines. Real time monitoring could reduce the risks of availability issues significantly. If a machine is defective, it can quickly be repaired if its status is reported in real time to service providers. Linking machines and people with technology to coordinate the harvesting process can help **optimising quality and quantity**. CPS can collect results and gain artificial experience about the process. The soil can be conserved with the help of improved coordination of farm machinery. Emissions of such can be cut. Prediction and real time data collection can optimise action planning, such as the automatic regulation of the harvesting pace.

³ (Siemens AG, 2013)

⁴ (AK Industrie BMBF, 2013)

Why implementing Industry 4.0?

We believe that the main factors driving these innovations are decreased production cost through efficiency on one side to further improve profitability and wealth. As regards the latter, there should be as well a political interest to support leadership structures. On the other hand, it enables a high customer demand for individuality. Furthermore, we would not rule out a self-enforcing component around 'Industry 4.0' as it appears to have become hype.

Further boosting efficiency and lowering costs: While 'Industry 4.0' should be geared towards lowering the costs for the input factors like labour, energy and working capital resources as well as information access, additional advantages can be seen for example in the greater flexibility with which companies can respond to the market by using data flows for customised production. In other words, the **time-to-market accelerates significantly**.

'Lot size 1': The 3rd industrial revolution could provide lower costs through further mass market production efficiency, but it could not **provide individualisation at reasonable cost**. With 'Industry 4.0' there is a chance that it will be possible for companies to produce highly individualised products at comparable cost of a mass product by linking up all parts of the production process with CPS platforms.

Defending Dominance: Every industrial revolution described before has been sparked in Western markets. As the chart on p.3 shows, the complexity that came along with the applications of each industrial revolution has increased with the next level. So far, Western nations have managed to conserve a leading R&D position, but the 3rd revolution coincided or even fuelled Emerging Market, in particular Asian, societies coming up. **We speculate that there is a political interest of the Western world to defend the leading know-how position by mastering the complexity of 'Industry 4.0' and thus, staying ahead of the curve from a global perspective.** We can say here that the latter brings huge challenges to the societies that want to compete in this field with respect to long-term educational levels.

Last but not least - Paranoia: According to a KPMG survey, **about 50% of companies fear that their IT systems will be outdated and uncompetitive in 1-2 years**. This included 460 industrial companies out of which 30 are located in Germany. A minority of 40% of German companies is concerned that their business model will be outdated soon due to the expected changes. 77% of German companies plan to use disruptive innovations in their business strategy in the next 2 years, compared to only 36% worldwide. As the term 'Industry 4.0' gets more widespread in the heads of decision makers, it could become some sort of a self-fulfilling prophecy.

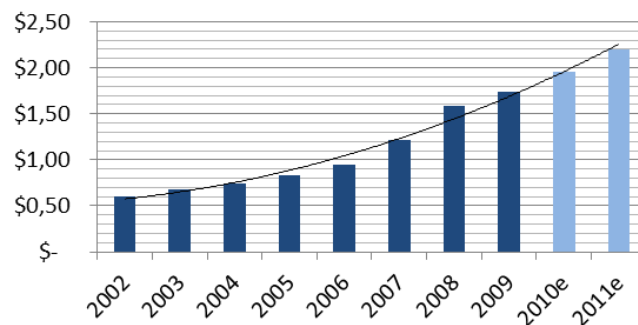
Tackling costs and efficiency improvements

Low labour cost advantages fading

Considering that there is a great divergence in manufacturing labour cost worldwide, there are enormous competitive advantages for countries with low wages. For example China has profited from this for a long time. But with regard to rising labour costs, it needs to find **other channels to competitiveness**. Flexibility and efficiency through intelligent production is a very likely approach which is why China is spending EUR 1.2tn via subsidies, tax breaks and other financial incentives in a five year plan until 2015.⁵

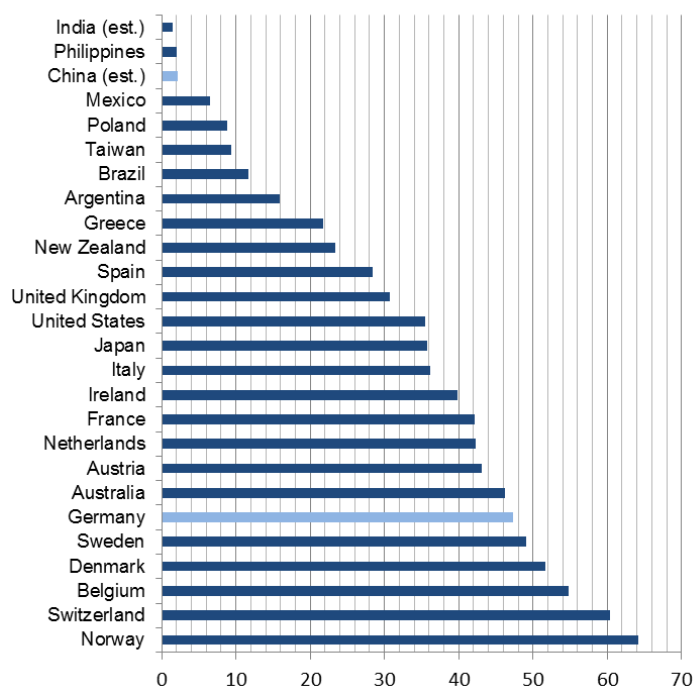
⁵ (AK Industrie BMBF, 2013)

Hourly Chinese Manufacturing Labour Cost



Source: US Bureau of Labour Statistics, equinet research

Hourly Manufacturing Labor Cost 2011 in USD



Source: US Bureau of Labour Statistics, equinet research

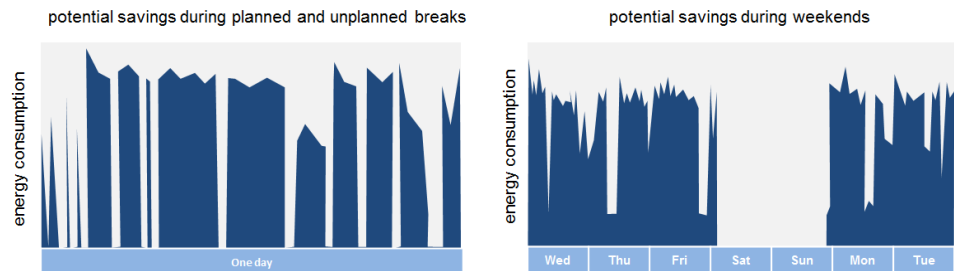
Production chain structure challenges

A controversially discussed trend is vertical integration of parts of the production chain. On one hand, companies can make use of the synergies created by the smart factory. On the other hand, experts predict the **emergence of small companies** that focus on core competencies and are able to participate as way points with little or no capital, merely built on collaboration. The German sports manufacturer Adidas is considering mini-manufactories that can operate decentralized and dynamically, to produce highly individualised and deliver in very short time spans. So even though it is clear in which direction the production style is going, it is not clear what structure corporations will adapt.

Energy Efficiency at a Vehicle Body Assembly Line

A laser welding production line consumes 12% of total energy during production breaks, weekends and shifts without production. The line remains powered up to continue production right at the beginning of the week. 90% of power consumption during breaks is caused by robots, extractors, laser sources and their cooling systems. Due to new

technology, robots will be powered down in short breaks and enter a Wake-On-LAN mode during longer breaks, since they can use information from preceding systems of the production line. Extractors could use speed-controlled motors that are adjustable to meet requirements at any time. The laser sources would have to be reengineered from the bottom. **Energy consumption could be lowered by 12%.⁶**



Source: Siemens 2013, equinet research

Individualisation Example – Custom Car Order

The areas of customization are diverse: design, configuration, planning, production and logistics. **Last minute requests even during production** could avoid a mistake caused in the order or modify the product in the interest of the customer. A high degree of flexibility is necessary, but the potential economic gain is huge. Premiums for short term delivery and individualisation have proven to be large enough to justify this development. With the right technology, it will make production itself even cheaper. With intelligently connected production lines it will become possible to send a car to different workstations where production information is already present. Custom seats and windows have already been produced at time of order and are put into the vehicle with the help of IDs. All of this will be possible at a small price premium.

Static vs. dynamic, flexible production



Source: equinet research

Government Support Examples

Germany

Germany has conquered a top position in the manufacturing equipment sector. The conditions for the implementation of networked manufacturing are excellent due to strong research, IT competence and technical know-how. While China is facing rising labour costs, Germany has the chance to remain self-assertive in the industrial sector. But progress will be necessary to maintain a strong position in the long-term. Mainly, there are two channels Germany needs to take advantage of: First: The integration of IT and communication technology into the traditional high-tech strategy. Second: the creation and support of a CPS market. The **working group initiated by the Germany ministry for research and education** gives the following features as guides: *Horizontal integration* through value networks, *end-to-end digital integration* of engineering across

⁶ (AK Industrie BMBF, 2013)

the entire value chain as well as *vertical integration* and networked manufacturing systems.⁷ This means creating reference architecture for companies to enable the flow of data between different companies.

The growing complexity of the systems installed makes explanatory models and appropriate planning necessary. The broadband industry will be another step: Reliable and fast communication networks need to be created and maintained. Data connections also need to be protected and secured. Due to the change in working conditions, further education in the short term and the right educational approach in the long term will be crucial. The **German government has setup a broadband initiative** to support the roll-out of 50Mbit/s connection in households. 50% penetration was achieved in 2012 and 75% was planned for 2014. We have the impression that this target was replaced by 100% in 2018⁸.

United States

The United States have also launched an innovation program with 40 partners for the transition to the next industrial stage: the Smart Manufacturing Leadership Coalition (SMLC). Its main purpose is to provide collaborative R&D, implementation and advocacy teams to manufacturing stakeholders to develop approaches, standards, platforms and shared infrastructure. It is a non-profit organisation to overcome the barriers of smart manufacturing (SM) systems with the help of an agenda to build scaled, shared infrastructure. The approach is to develop a modern industrial infrastructure. SMLC also plans to build the business, interoperability and technology models as well as demonstrations.

⁷ (AK Industrie BMBF, 2013)

⁸ (TüV Rheinland-Studie for BMWi, 2013)

Looking briefly at complementary technology

It appears that 'Industry 4.0' is sometimes regarded as a buzz-word or a hype phenomenon. One interesting aspect is that actually Industry 4.0 helps to provide factual justification for a row of other buzz-words like M2M, Cloud, Big data, etc. and their practical applications. We will highlight in the following that there are significant intersections between those topics.

M2M Communication

Machine to Machine (M2M) is a broad label **referring to any technology enabling networked devices to exchange information and perform actions without the (manual) assistance of humans**. It is often used for remote monitoring. An example is product restocking: a vending machine can message the distributor as a particular item is running low. It plays a significant role in warehouse management, remote control, robotics, traffic control, supply chain management, fleet management, logistics and telemedicine. The communication architecture and infrastructure required in future M2M communication will be introduced hereafter.

The focus will strongly lie on the emergence of sensors and RFID, but also Wi-fi and cellular communication as well as autonomic computing, a self-managing computing model regulated without conscious input from the individual. Telemetry has been in use since the early part of the last century for production, but also scientific data gathering, first in the form of telephone lines and later in the form of radio waves. Not the monitoring and data collection, but **the autonomous decision making ability of machines in production is also referred to as 'smart manufacturing'**. Since there currently is no standardized connected device platform and M2M systems are built task-specific, Industry 4.0 could lead to great changes.

Internet Address Space Limitations

At the time of writing, Cisco counts close to 13 billion people, processes, data and things connected to the internet. For 2020, they give a 50 billion estimate. The greatest increase is expected at the end of the decade due to decreasing connectivity costs⁹. The increasing number of devices connected to the world net will require a new protocol in the near future. The technology being widely used is Internet Protocol version 4 (IPv4) that offers 2^{32} (=4.294.967.296) addresses from which about 3.7 billion can be used to contact computers and devices directly. In the early days of the internet, this was sufficient, but at this time, **not many addresses remain to be allocated. IPv6 in the format will expand the address room to 2^{128}** , about 340 undecillionths of addresses. The protocols are not interoperable, but there are transition mechanisms to enable communication between IPv4 and IPv6 hosts, so the transition is already taking place.

IPv4 format: 172.16.254.1

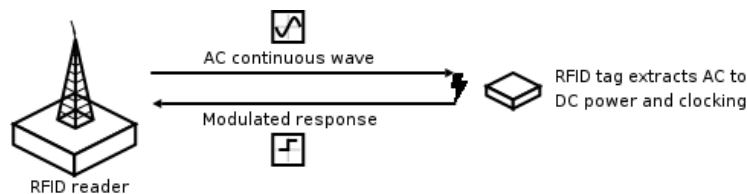
IPv6 format: 2001:0db8:85a3:08d3:1319:8a2e:0370:7344

Source: equinet research

⁹ (CISCO, 2013)

RFID

Another key technology bringing industrial change is the introduction of radio frequency identification (RFID) to a whole range of products, ranging from production utilities and raw products to household equipment. **Ways of application are the assignment of machine tasks to specific products** as in our bottle factory example. This can also be applied to create unique products. Possibilities reach even further. Kodak has filed a patent for the integration of RFID chips into medication. The benefit would be the monitoring of medication intake, but it makes patients literally transparent to RFID scanners. There have also been cases where companies have secretly integrated RFID into ID cards, like the wholesale company METRO for their membership cards and Deutsche Bahn into the all-inclusive Bahn Card 100.



Source: Rob Blanco, 2007

Sensor-Driven Computing and Analytics

Sensors will turn simple perception into helpful insights. With the help of sensors, temperature, pressure, motion, voltage, chemistry and usage can be measured. As sensors become cheaper, smaller and more sophisticated, integration becomes increasingly dependent on the compatibility with the existing data infrastructure. Sensors can help reduce cost and increase efficiency by monitoring energy consumption and frictions of any kinds in the manufacturing process. **Analytics of sensor data will become standard for industrial businesses as it turns data from sensors and other sources into actionable insights without the need for human interaction.** This can even help anticipate events in the future and prevent failure. The key in this process is that 'smart machines' will be able to autonomously execute correction measures and notify a human worker who can review the adjustments. This may ultimately prevent unscheduled interruptions.

3D Printing

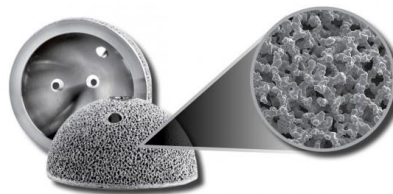
3D printers build things layer by layer from a particular material instead of cutting, drilling or machining. The process is also called additive manufacturing. For variations, **only a slight software tweak is necessary, without retooling of machines.** 3D printing is already used for prototype parts, mock-ups, gadgets and craft items, but also more and more for small series production. Even though it will most likely not replace mass production as known today due from a unit cost perspective, the world's biggest manufacturers such as Airbus, Boeing, GE, Ford and Siemens are starting to use it today. Industry 4.0 is embracing 3D Printing in particular as the 'lot size 1' aspect has become reality.

The 3D printing market already grew about 29% in 2012 according to Wohlers Associates¹⁰ Most products are in fact highly individual components. But at BMW, assembly line workers can print custom tools to hold and position parts and replace broken parts quickly by printed stand-ins. So, **additive manufacturing does indeed influence conventional manufacturing**, since there are visible hybridising effects. The

¹⁰ (The Economist, 2013)

number of materials used is increasing (e.g. in plastics and metal) and products can be printed that would have to be assembled with many components otherwise. An area where it is highly present is the health care sector for unique products such as hearing aids or plastic braces for straightening teeth. A typical F-18 fighter jet contains about 90 3D-printed parts and for the F-35, about 900 parts could be 3D-printed. Furthermore, 3D printing reduces the cost of resources and shortens logistic chains. Beyond that, the beauty is that complexity of the products manufactured is not a criterion anymore. Thus, through 3D printing, objects with excavations or undercuts can be manufactured in one process which is not possible with conventional technology. For example, this fosters light-weight applications and products. 3D printing is made more widely accessible through service providers where single parts or objects can be ordered.

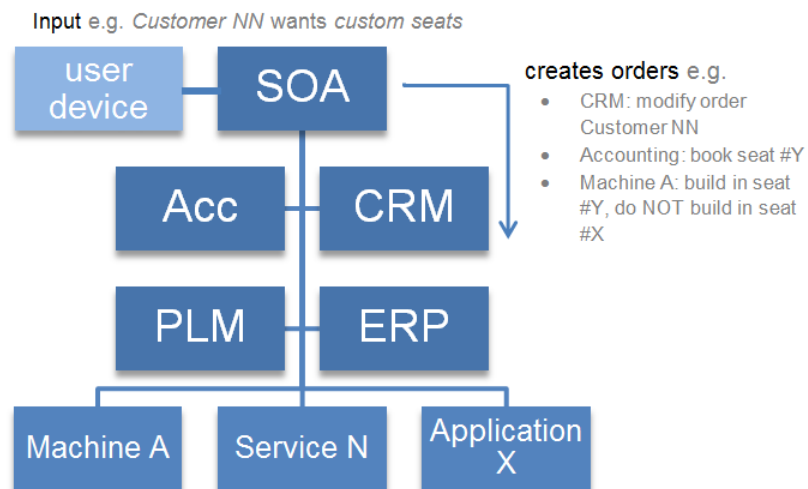
3D printed femoral head



Source: SLM Solutions

Data architecture

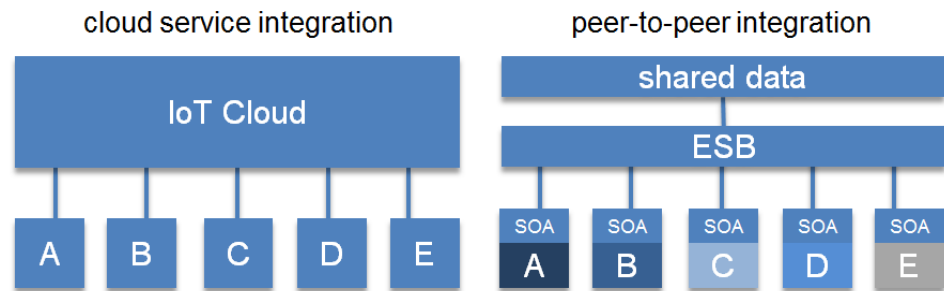
It is crucial for the technological advance to find a **common data structure for the communication of machines**, devices, internet of things and social internet. It has to guarantee reliability, openness and security at the same time. The element that connects all factors is a service platform that works as infrastructure. A plausible model is service oriented architecture (SOA). All actions in a company are categorised and grouped to more or less complex services. The service platform receives and gives orders to the user and does the same to each component analogously.



Source: equinet research

Cloud service or peer-to-peer: For the integration of the machines, applications and services there are different options. All components can either directly be connected to a controlling cloud (that would mean they would all have to speak the same language) or they could be connected via an enterprise service bus (ESB) that can translate

commands from the cloud to all parts respectively. With growing complexity of the web, the cloud solution could become more efficient but requires a common standard.



Source: IBM, 2014

Cloud Computing

As it is argued by the Karlsruhe Institute of technology, outsourcing company data and service into external clouds will come with a major trade-off between three incompatible measures: availability, performance (latency, throughput) and security & privacy. Resources to be outsourced include infrastructure as a service (IaaS), development and runtime platforms as a service (PaaS) and software and business applications as a service (SaaS). In the optimal case, **clients do not own the resources**, which are continuously and solely accessible to clients.

Clouds can provide improvement in organizational efficiency, cost reduction and faster time-to-market.¹¹ They could also decrease overall IT spending. Low-cost access to data centres could also reduce market entry barriers in many sectors and enable new business models. It could help improve scalability, availability and other non-functional properties of application architectures. **The basis for cloud technology is virtualization** which can work in different ways: System virtualization allows the installation of system software in a virtual environment. Storage virtualization creates virtual storage drives that have access to several, possibly heterogeneous drives. Lastly, application virtualization enables the installation of applications designed for different operating systems on one single system.

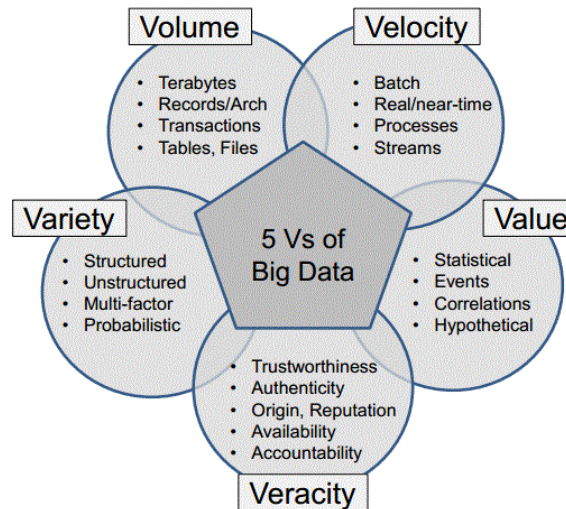
The greatest issue arising with cloud computing is data security. Companies tend to prefer an intern storage solution, when facing the build-or-buy decision, since giving up control over their data is not an option for many companies. With data from manufacturing machines and controlling devices, the need for security even increases. Encrypting the data before the upload makes conventional meaningful operations on the server impossible and requires homomorphic encryption methods. Costs for development and operations of such exceed those of the installation of an intern system by far. Conclusively, trust will remain the main factor for the decision in favour of a cloud solution.

Big data – More than just storage

Industry 4.0 and its components come with a vast number of dataset and files. Staying in the example of the producing industry, starting from the data input from the customer and further going to the manufacturing data the sensors and tools collect autonomously, while the final end-product also collects data feedback, it becomes clear that **classical data collection, monitoring and storage systems face major challenges**. Hence, the IT and services industries have created the buzz-word 'big data' which is however more than just processing and storing lots of files. There has to be 'big use' as well and expressed in other words, **reasonable big data architectures have to contain the '5 V's'**: Volume, Velocity, Variety, Veracity and Value.

¹¹ (Karlsruhe Institute of Technology, 2010)

The 5 V's of Big Data



Source: Softwareinsider.com, Bitkom, Fraunhofer, equinet Research

While 'Volume' should be largely self-explaining (simply the number of files and Terabytes, etc.) and should be seen the starting point for the term 'big data', 'Velocity' is important. Big data systems are constantly producing data files which requires broadband connection to transmit. As this data should create value at the end for example for in time forecasting, **big data needs to be more or less real-time capable**. Furthermore, the 'Variety' aspect stands for unstructured, semi-structured or structured data input which a big data system has to master. In any case, however, this data has to be authentic and trustworthy ('Veracity'). Otherwise, the ultimate purpose of analytics, i.e. the recognition of patterns, meanings to provide forecasting and projections, was at risk. Therefore, it has to result in statistical 'Value', i.e. a mathematical value with which the user can create 'Value' for its business model.

Innovative potential from Big Data application

Improved storage capabilities

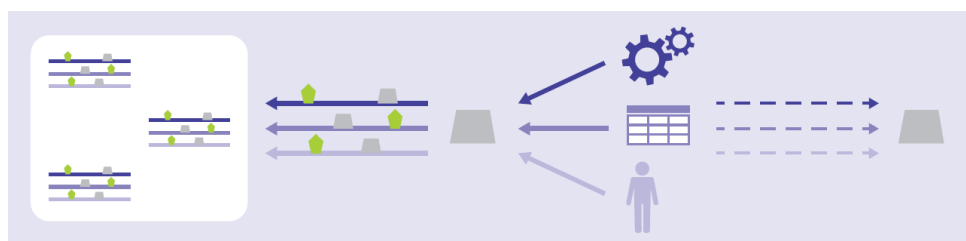
- Raw data does not have to be deleted
- Expanded history

Complex event recognition

- Expanded monitoring
- Faster recognition
- Exploit informational edge

Predictive analysis

- Forecasts
- Simulation



Improved efficiency through:

Exploiting potentials	<ul style="list-style-type: none"> • Product improvements • Employee acquisition • Personalized product recommendations • Market monitoring to improve sales potential 	<ul style="list-style-type: none"> • Pre-emptive maintenance
Minimize risks	<ul style="list-style-type: none"> • Farseeing control • Early cancellation warnings • Detection of attacks • Fraud detection 	<ul style="list-style-type: none"> • Sales forecast • Financial risk planning

Source: Fraunhofer IAIS 2012, equinet Research

Practically speaking, big data systems are capable of quick recognition and analysis of huge data sets and underlying patterns. Thanks to low pricing for storage, data collected can build a much better historical basis as no files need to be deleted anymore. The lower half of the chart on the previous page shows how user groups use the new ways of monitoring, forecast of exploration. The green elements in this chart above are use cases for big data analysis that have not yet been recognized as such, but as the data is existing and was collected, they might be relevant for future analysis. Direct applications are pre-emptive maintenance of equipment or improved sales forecasting to mention only few. Beyond that, big data systems can reduce risks, e.g. in fraud detection patterns for financial institutions. In any case, **the goal of big data is to improve market and event response time and increase flexibility to find rapid solutions to upcoming problems.**

Brief economic assessment of Industry 4.0

We believe that Industry 4.0 is still in its infancy. As we have highlighted, the adoption of Industry 4.0 can result in a comparative advantage in energy, capital and personnel costs. Moving early into this new field might mean the creation of an competitive edge and potentially higher margins for enterprises. At the same time, and in particular as standards have yet to be developed, the risk of misallocation of resources is high. In this paragraph we will highlight shortly the potential of Industry 4.0 as well as costs, obstacles and risks.

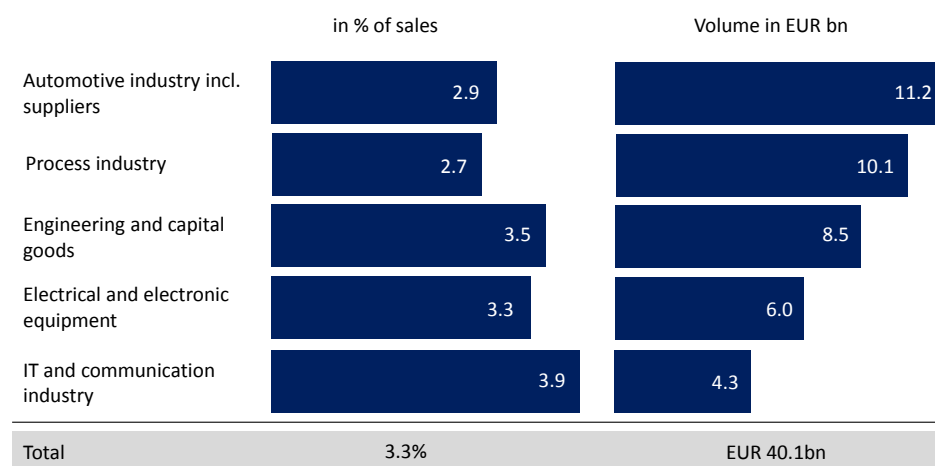
The economic potential

Consulting house PWC has done an intense research on the Industry 4.0 landscape in Germany. One of the outcomes was that **German industrial companies plan to invest about 3.3% of their annual revenues into Industry 4.0 products in the next 5 years.** This would equal a total amount of EUR 40bn p.a. PWC's survey comprised 235 companies from the engineering, automotive supply, electrical equipment, IT and processing (e.g. chemical, pharma and steel industries) sectors, among them Siemens, Bosch, Kuka, Festo and Wittenstein.

For the automotive industry alone, EUR 11bn out of the aforementioned EUR 40bn will be invested while the process industry is expected to spend EUR 10bn. Next to efficiency gains (e.g. reduction of capital costs when automation increases), the investing companies expect to increase revenues. **According to PWC, an additional sales contribution was said to be EUR 30bn in the next years** that shall be generated with 'Industry 4.0' solutions in Germany. Despite the annual spending being higher, the reward is nevertheless positive as enterprises expect to lower their production costs.

PWC researched that two thirds of the companies in the survey were already working on digitalisation and network infrastructures to optimize the production value chain, **20% of all the enterprises in question could be characterized as highly involved with 'Industry 4.0'.** PWC predicts that this ratio should increase to 80% in 5 years from now.

Annual capex for Industry 4.0 Solutions until 2020

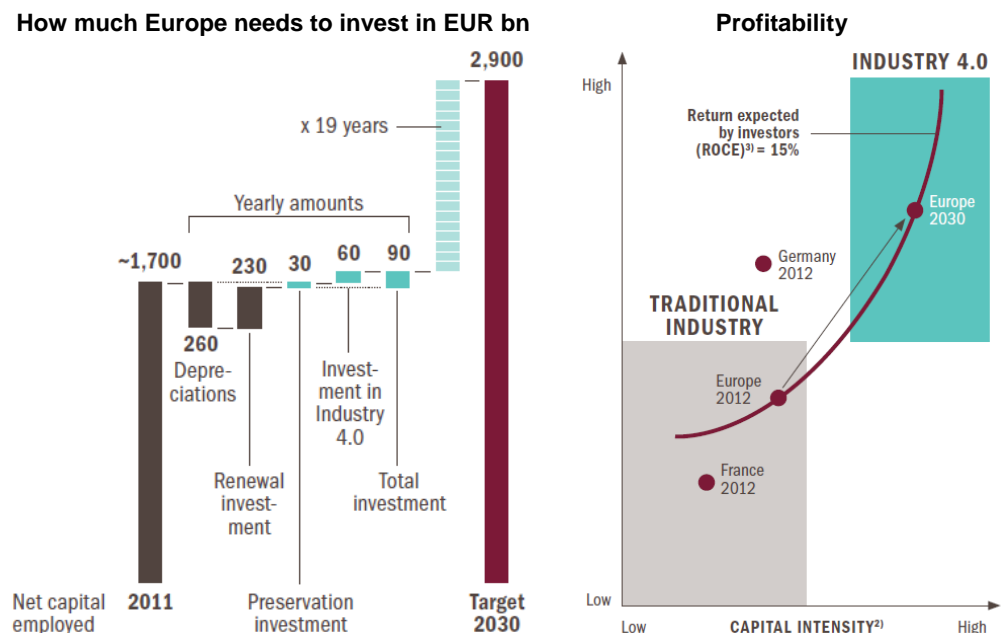


Source: PWC 2014, equinet Research

An additional hint on the Industry 4.0 prospects might be provided by growth rate predictions of complementary technology elements, e.g. big data and cloud: **IDC predicts that the world market for big data will reach USD 16bn in 2014, growing 6 times faster than the overall IT market.** IDC includes in this figure Infrastructure (servers, storage, etc., the largest and fastest growing segment at 45% of the market), services (29%) and software (24%). In 2016, IDC projects the market volume to reach about USD 24bn. Furthermore, IDC predicts that cloud infrastructure will be the fastest-growing sub-segment of the big data market, with a 2013-2017 CAGR of close to 50%.

Beyond the considerations above, the potential of Industry 4.0 can also be seen from another angle: The EU Commission strives to increase Europe's manufacturing share of GDP from 15 to 20%. This should be achieved by increasing the profitability of the industry and rendering Europe as a manufacturing base more attractive. **The incremental 5% in GDP share increase would equal EUR 500bn value creation and about 6 million new jobs** c.p. assuming the sustainability of current GDP growth and inflation. According to Roland Berger¹², the Industry 4.0 concept should be well suited as a prerequisite to achieve the targets:

In terms of sector profitability, Roland Berger assumes that investors expect a 15% ROCE for the European manufacturing industry with Germany leading, i.e. exhibiting an even higher ROCE. Through the efficiency of Industry 4.0, this level can be increased significantly seen in the right chart below. However, this benefit does not come for free. The overall investment need measured since 2011 is an annual EUR 230bn for renewal, EUR 30bn for preservation and EUR 60bn in new Industry 4.0 concepts, equalling in a change of net employed capital from EUR 1.7tn to EUR 2.9tn until 2030. Consequently, **European companies have to invest EUR 90bn p.a. to achieve the EU goal.**



1) EBIT as % of value added; margin: Low = below 5%, High = above 20%. 2) Capital employed/value added; margin: Low = below 0.5, High = above 1.3. 3) ROCE = profitability x capital intensity.

Sources: Roland Berger Strategy Consultants, equinet

research

Several types of costs can occur when investing into Industry 4.0. These are the **costs of training and education which will most likely be significantly higher than before**, the cost of implementation (which also requires skilled workforce) and maintenance costs that can hardly be predicted. Industry 4.0 research should be capital-intensive.

¹² (Roland Berger Strategy Consultants, March 2014)

Patents and licenses can be a government tool to push the development and protect frontrunners, but lawmakers have so far not developed new ways of approaching these changes which brings us to obstacles and risks.

Obstacles and Risks

Security Risks and Safety Issues

With more and more machines and devices connected to a network, the overall system security is at risk. If security mechanisms are not always up to date, there is the **danger of invaders taking over a whole factory** or even larger structures without physical presence. This can go as far as control over every machine and device, but also CPS connected to doors, windows in smart buildings and others. Large amounts of data are at risk of being stolen and used by competitors. Self-driving cars could be manipulated and RFID chips could be duplicated to simulate a key without the owner noticing.

Within this respect, one interesting case from 2010 was the **'Stuxnet' virus** that was able to intrude Siemens industrial Simatic software in Iranian plants. There have been unexplainable disturbances in Iranian Uranium enrichment plants that have been linked to the appearance of the virus. It was not only able to decide to just spread or take action depending on the plant properties, but could also update and modify itself without enduring internet connection. Connections between the internally used 'Myrtus' code name and the Hebraic 'Esther' evoked conspiracies of Israel having ordered the programming, but a US armed forces officer was also suspected. Further virus developing is not only probable, but has already been discovered.¹³

Cannibalisation and Change

Cannibalisation is often referred to as an unpleasant term. In fact it needs to be considered whether it is a necessary change under dramatically changing circumstances. Especially in the technological sector (which is expending towards the industrial sector) circumstances are, in fact, changing rapidly. Hardware and software providers will see change in demand of their product portfolio. If new solutions are not implemented, they will not see cannibalisation, but a trend towards insignificance. With the aim of providing whole end-to-end solutions and achieving customer loyalty, corporations should be brave and make necessary changes in their strategy. This applies for information technology, such as CRM, PLM and ERM but also machine and logic controller developers that operate in areas where disruptive innovation is slower as e.g. in software. It is very probable that if technological improvement towards Industry 4.0 is avoided by one competitor, it is accomplished by another. Proof of shifting competences is given by **IBM and HP that are now competing with firms as Siemens or ABB in their established home segments**. A way to compensate companies' losses from cannibalisation is additional service and aftermarket business. This could complete the combined solutions that will be in focus at a later point.

Lack of standards and regulatory hurdles

As we have already alluded to, there seems to be an astonishing number of companies agreeing that the next step in the revolution is highly important, few manufacturers have taken steps to adopt embrace it fully yet; hesitant policymakers are one of the reasons.¹⁴ There are a number of legal uncertainties yet to be resolved. **Freedom of trade and freedom of information across borders has to be guaranteed for companies to access CPS globally**. Security standards need to be established bilaterally. But governments cannot push the shift by themselves; they need the support of stakeholders in various areas such as industry, education, research and others.

¹³ (Spiegel Online, 2010)

¹⁴ (Economist Intelligence Unit, 2014)

Interim conclusion

Applying companies

As the PWC report has already highlighted, the sectors that will potentially profit most at first glance from the application of Industry 4.0 are mechanical and electrical engineering, automotive and parts, ICT, chemicals, but also farming and forestry. Service providers can benefit through increasing maintenance and support requirements. Even though there are upfront investment costs, early adopters might enjoy real competitive advantages and outperform companies sticking with the traditional industry. Research pace and the right timing will be crucial for success for every company trying to enter Industry 4.0 while **companies ignoring or avoiding it will most certainly be unable to stand the competition in most sectors.**

Industry 4.0 enablers

Obviously, Industry 4.0 will also create a big market for suppliers of automation technology, software, implementation services as well as consulting, maintenance and hardware producers. The latter might benefit from more component business, i.e. communication ICs, decentralised processing power and last, but not least sensor technology. This creates also opportunities for embedded system vendors, however, the ultimate challenge appears to have the right software and process know-how on board as hardware bears the risk of being commoditized. Manufacturing might at the end become a pure service itself. As data exchange between companies in supply chains increase most likely tremendously and thus, also the number of interfaces. The complex systems become more and more vulnerable. Consequently, **the sweet spot of Industry 4.0 might be the security aspect one day.**

Labour markets

Through the further increasing automation that comes along with Industry 4.0, the trend of the replacement of less demanding human labour by machines will continue, if not increase. However, even more engineers and IT-personnel will be needed for implementation and maintenance and the overall sector could grow in the long term, creating even more jobs for these professions. In an experts forecast it is stated that although networked manufacturing will drive productivity, **it is not likely that the overall employment level will be affected.** There will possibly be a decrease in workers for the same production volume, but potentially an increase of the market volume. Historically, productivity growth has had positive effects on economic development and job creation.

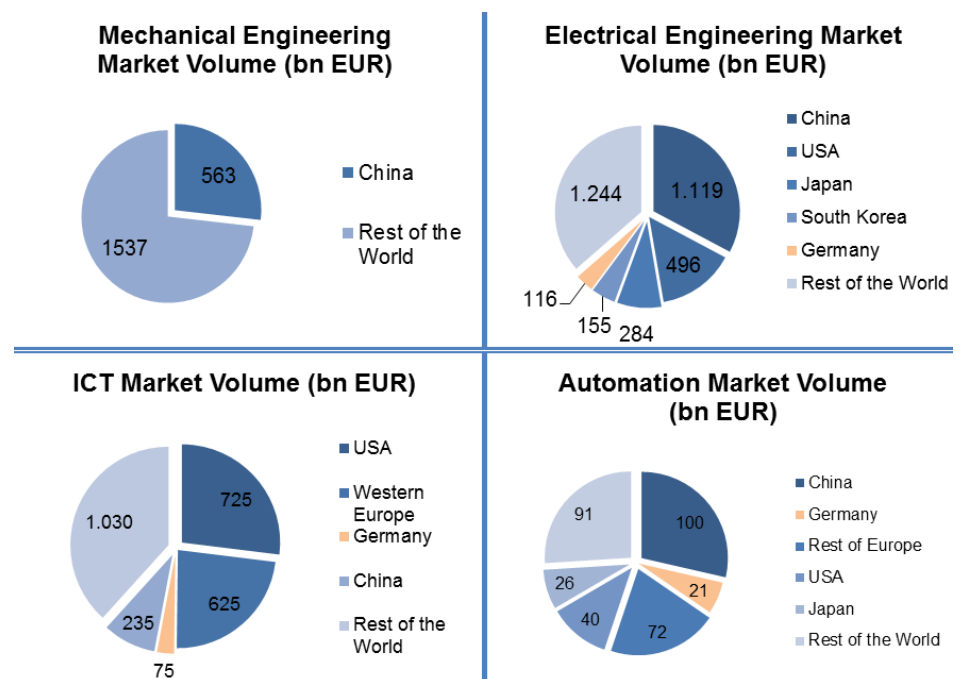
Market Status Quo and Industry Exposure

Before we enter into a more concrete discussion about the approaches specific companies have taken to address Industry 4.0, we would like to present the current domestic market situation and dimension as well as the industry exposure to highlight the potential the new industrial revolution might have here.

Putting Germany into perspective

The financial crisis has put considerable pressure on Germany's machinery and plant manufacturers. The decrease in sales has been in line with the overall EU sector market decline. **As early as 2009, the industry had started recovering.** One or two years earlier, China has passed the US and German markets in 2007 and 2008 in volume respectively and is catching up to the EU overall volume. The German demand was forecast to reach two percent growth in 2013.¹⁵

The German Engineering Federation (VDMA) states that **the majority of German mechanical engineering firms "still see themselves as among the world's leaders** and regard their main competitors as domestic ones, followed only distantly by competitors from the US and Italy."¹⁶ Overall, China has the strongest positions in electrical engineering, automation and mechanical engineering while in ICT it is clearly dominated by western countries. This is in part due to the benefits of cheap labour in China and superior technological know-how and implementation in the United States and Europe.



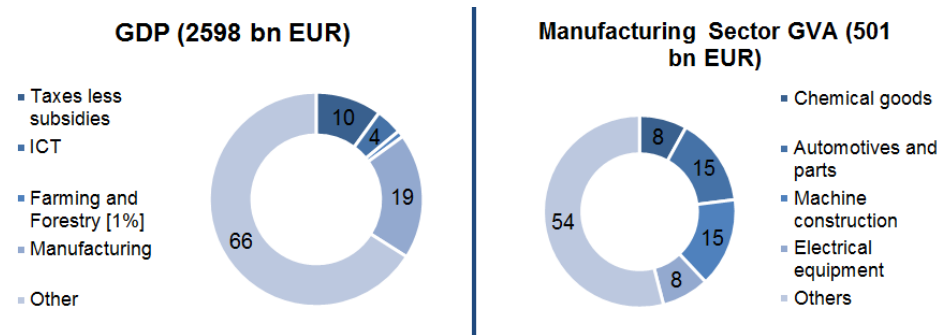
2011 Numbers, Source: (AK Industrie BMBF, 2013), equinet research

¹⁵ (AK Industrie BMBF, 2013)

¹⁶ (AK Industrie BMBF, 2013)

Sector Exposure in German manufacturing

We are now looking at the German manufacturing sector to get a rough idea of its composition and to assess the impact on the economy and on the sectors the implementation of Industry 4.0 might have. **The total GDP came to c. EUR 2.6tn while the manufacturing sector's GVA took a 19.3% stake** of this amount (figures based on 2013), i.e. comprised EUR 501bn with the automotive and engineering areas taking together 30% to this volume, highlighting the dominance of these fields again.



2013 data for Germany, Source: German Federal Statistical Office, equinet research

Mechanical Engineering and Plant Construction

The field of mechanical engineering and plant construction is the place where Industry 4.0 would most naturally be expected, as it is the further development of existing concepts and methods. In that aspect, it can be referred to as evolution rather than revolution. Sales in the sector are around EUR 177bn. At the same time, the market is highly concentrated: More than half of the revenue is generated by 1.4% of the number of companies. The sector accounts for 15.3% of manufacturing sector gross value added (MSGVA) and 3.3% of overall gross value added (GVA). **The expected increase in productivity is significant, i.e. +30% by the year 2025 (about 2.2% compounded annually).**

Automotive and Parts

One of the most important German sectors is the production of cars, trucks and spare parts. Future developments could have a great impact. The driving experience itself can be made safer and more enjoyable, the vehicle can be customized in different ways and spare parts or accessories can be ordered and delivered in short time. **Revenue in this sector is EUR 317bn and is also highly concentrated:** 95% of revenue is created by 3.8% of the number of companies. Automotive and parts account for 14.8% of MSGVA and 3.2% of GVA. Until 2025, up to 20% growth is expected.

Electrical Engineering

The product variety in electrical engineering is huge: it includes electrical and optical devices, machine technology, electrical devices and machines, radio, television, other communication devices, office devices and computers. One decisive point will be whether sensors and *radio frequency identification* (RFID) will soon become very affordable and subsequently spread rapidly. This could establish new possibilities and enhance consumer safety and comfort. The sector revenue is EUR 163.8bn and the market is not very concentrated and marked by many small companies. It makes up 8.4% of MSGVA and 1.73% of GDP. Until 2025, a 30% increase seems likely.

Chemical Industry

One of the most automated industries is the chemical industry. It has already pushed steps towards Industry 4.0. The digital networking capacities and the quality of process and products have yet to be improved. Therein lays the potential for betterment in production of soap, detergents, adhesives, plastic and others. For example, **the process improvement could be made possible through real time supervision of delivery data to minimize the storage capacities.** Revenue is EUR 136bn and 4.3% of companies account for 82.8% of it. The sector reserves 8% of MSGVA and 1.7% of GVA. Expected growth until 2025 is also at 30%.¹⁷

ICT

The challenge to be taken in ICT is not to build up new facilities from the ground, but to enhance existing systems at low costs. New structures that are going to be important for ICT are cloud computing and the handling of big data as we have highlighted before. Here, however, US firms appear to be leading. Nevertheless, **four out of five new inventions of the German economy are based on the ICT sector.** Revenue in this sector is EUR 282bn. It accounts for 4.3% of GDP with an expected increase of merely 15% until 2025.

¹⁷ (BITKOM, 2014)

Summary and Outlook

The ultimate motivation of Industry 4.0 should be the creation of even more wealth through improving efficiency. Seen from this angle it is not different from former industrial revolutions, **it might emphasize a higher degree of individualisation for consumers at reasonable production cost**. A key enabler was and is broadband networking, the latter derived from the womb of principal benefits of the IT introduction, the 3rd industrial revolution.

We believe that the process of the industrial transformation from rather traditional approaches to Industry 4.0 will in some sectors be a more gradual process while in areas it will change production and processes more rapidly and **it has yet to be seen if Industry 4.0 is rather an evolution or a real revolution**.

However, coming back to the basic use case of smart manufacturing, the idea of fully controllable end-to-end designed production is still a promising vision and Germany has good chances to assume a leading role due to its knowledge base and the strong engineering foothold. However, **the country has yet to prove being a trend-setter here**, although political will and support is existing. Having said this, a common standard has yet to be defined and is one of the obstacles for rapid adoption of Industry 4.0 and implementing it is not at all plug-and-play to date. We speculate however, that Industry 4.0 has the potential to bring back manufacturing from Asia to the Western World.

Many projects are in a starting phase and are far from being economically reasonable to date. But as technology develops and frameworks are being built, Industry 4.0 scenarios as shown in this report could soon be implemented. Clearly, it will first of all affect the industrial sector, but also have great impact on consumers and the overall economy. Probably, **it will bring social change that has again repercussions on the economy**, but analysis of these phenomena would be too far-reaching for this report.

Unsurprisingly, benefitting industries are the automotive, engineering and process sectors at first glance in using and implementing Industry 4.0, but also the enablers in IT. Here, sensor and monitoring as well as communication hardware looks promising, but even more so specialized software and security vendors. In any case, **Industry 4.0 should require a higher degree of collaboration between the involved enterprises** and it will be interesting to see which ecosystems might develop.

Within the sense of an ecosystem, **Industry 4.0 appears to be a perfect bracket embracing buzz-words like Big data, cloud, M2M Communication** and providing them additional justification at the same time. While each of these components are seen growing with high double-digit rates, Industry 4.0 can hardly have less potential per se. Implementation efforts can however not be ignored, but rewards seem to be big.

What is common with respect to the companies we have addressed is that **Industry 4.0 has already become a strategic management topic**. All companies have stressed the potentials rather than the risks while a negative influence on the existing product portfolio appears not to be a danger for them. We cannot rule out a certain bias, but a consequently smooth transition of offerings provides evidence for Industry 4.0 being an evolution rather than a revolution.

Appendix

Questionnaire sent to companies

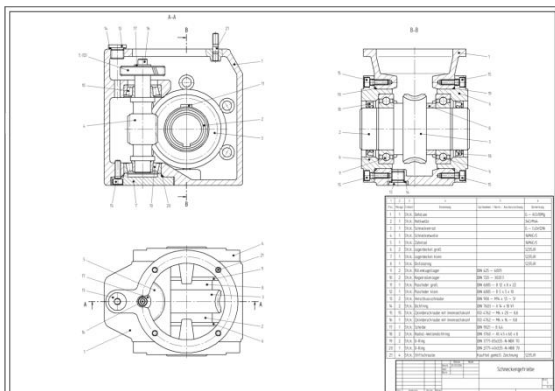
1. The term 'Industry 4.0' is associated with a row of buzz-words like Internet of Things, cloud computing or big data. Would you please be so kind to provide a brief definition according to your understanding of the term? Which complementary technologies are you already using?
2. If you took the option to label some of your products 'Industry 4.0 Ready' which revenue contribution (e.g. < 5%, 5-10% or > 10%) could already be allocated to these products? Do you expect an above proportionate growth for these products in the coming years?
3. Which Industry 4.0 products are in the development phase?
4. Do you believe that parts of your existing product portfolio is endangered through Industry 4.0?
5. In which areas do you see a need to strengthen R&D (software / hardware etc.)?
6. Do you feel the need to transform the company towards becoming more a solutions vendor in Industry 4.0?
7. Do you believe that processes within your organisation (internal and external, i.e. supply chain or the customer side) are influenced in any way through 'Industry 4.0'?
8. Do you believe that your competitive situation will change?
9. Do you feel the need to collaborate on a broader scale with other companies due to Industry 4.0?
10. How important do you rate the development of an 'Industry 4.0 Standard' (e.g. same interfaces, protocols, processes, etc.) and would you be a contributing party?
11. Is there a particular employee base dedicated to Industry 4.0?
12. Do you believe that Germany could assume world-wide leadership in Industry 4.0? What are the prerequisites.

Source: equinet research

Graphical Glossary

CAD (Computer-Aided Design)

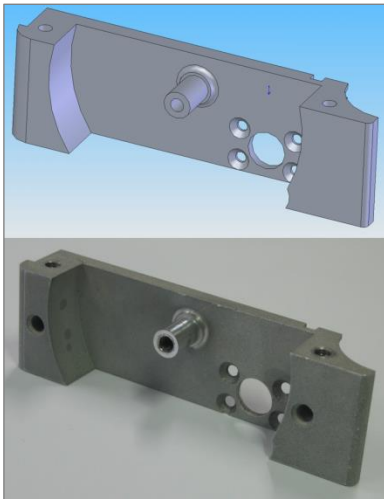
Use of computer systems to assist in the creation, modification, analysis, or optimisation of a design.



CC: Torsten Hartmann

CAM (Computer-Aided Manufacturing)

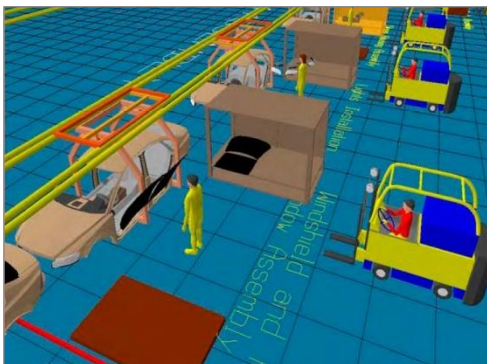
Use of computer software to control machine tools and related machinery in the manufacturing of work pieces.



CC: public domain

CIM (Computer-Integrated Manufacturing)

Manufacturing approach using computers to control the entire production process.



CC: public domain

Cloud

Quasi-virtual storage of application data, services and computing capacity that can be accessed from multiple devices.

CNC (Computerized Numerical Control)

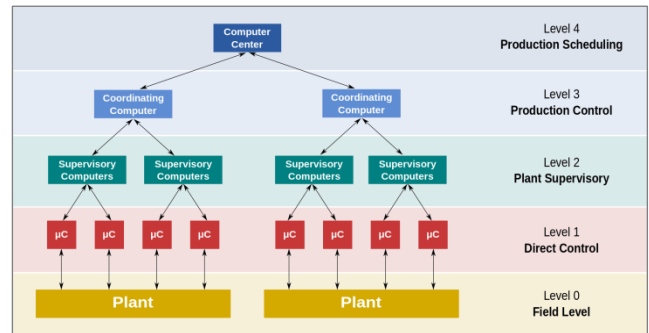
Automation of machine tools by precisely programmed commands encoded on a storage medium.

CPS (Cyber Physical Systems)

Hybrid system of physical object and interface to intelligent system

DCS (Distributed Control System)

Steering of process plant and industrial process wherein control elements and intelligence are distributed throughout the system.



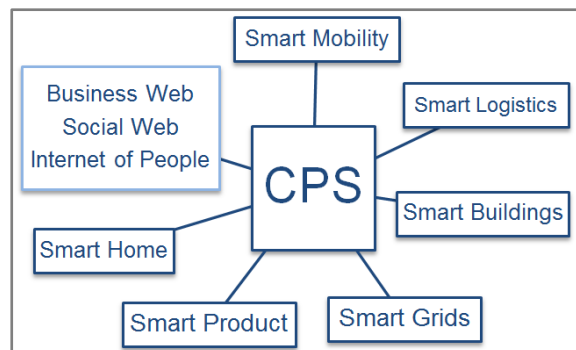
CC: Daniele Pugliesi

HMI (Human-Machine Interface)

Part of machine that handles human-machine interaction, such as membrane switches, rubber keypads and touchscreens.

IOE (Internet of Everything)

Generic term for all networks combined, including but not limited to IOT, human internet, business web and social web.



C: equinet research

IOT (Internet of Things)

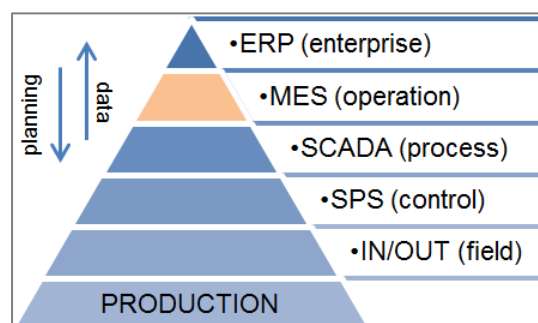
Generic term for data network of physical things connected to the cyberspace.

Metrology

Science of measurement, including all theoretical and practical aspects.

MES (Manufacturing Execution System)

Computerized systems used in manufacturing, showing current conditions and suggesting efficiency measures.



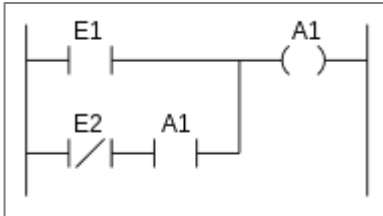
C: equinet research

PAC (Programmable Automation Controller)

Small, local control system in modern programming language such as C or C++, with I/O, processor and software, but usually without human interface.

PLC (Programmable Logic Controller)

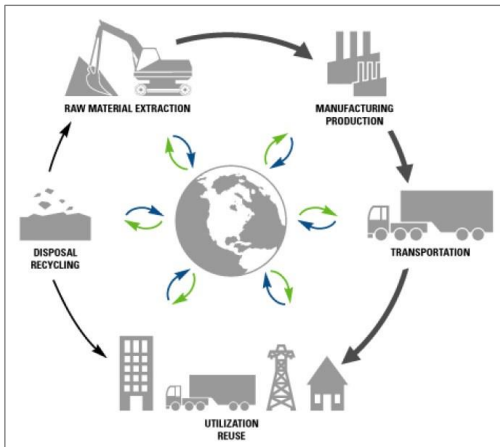
Control system programmed in a graphical representation of coils and contacts called Ladder Logic.



CC: public domain

PLM (Product Lifecycle Management)

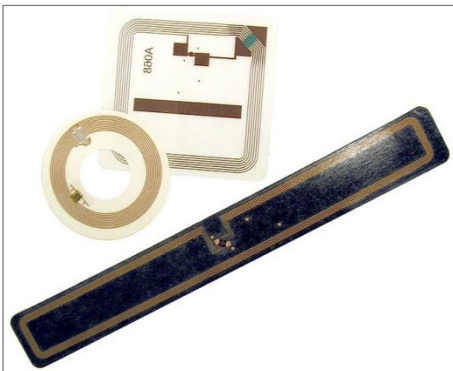
Process of managing the entire lifecycle of a product from inception, through engineering design and manufacture to service and disposal.



CC: public domain

RFID (Radio Frequency Identification)

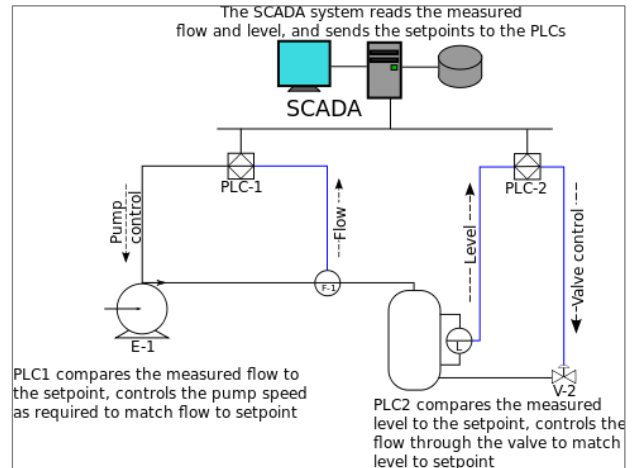
The wireless non-contact use of radio frequency electromagnetic fields to transfer data, for the purpose of automatically identifying and tracking tags attached to objects like cards or keys, but also clothes, medication or raw products.



CC: Markus Manske

SCADA (Supervisory Control and Data Acquisition)

System operating with coded signals over communication channels so as to provide control of remote equipment, but also data acquisition in the form of status request or recording functions.



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Sensor

Technical component able to qualitatively or metrically collect physical or chemical characteristics or states.



CC: open

Smart X

Objects or services connected to the Internet of Everything

SMLC (Smart Manufacturing Leadership Coalition)

United States industry reform initiative

TIA (Totally Integrated Automation)

Interaction of extensive single components, tools and services to achieve an automation solution.

Ubiquitous Computing

Permanently active computational activity above the complexity of personal computing.

Value Chain

Process model as sequence of actions or processes of a product from development until marketing and services.

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