WORKING PAPER

Industrial internet of things: Digitisation, value networks and changes in work

Impact of game-changing technologies in European manufacturing

Future of Manufacturing in Europe

Authors: Chiel Scholten (Technopolis Group)

Research manager: Enrique Fernández-Macías

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European Foundation for the Improvement of Living and Working Conditions

Telephone: (+353 1) 204 31 00

Email: information@eurofound.europa.eu

Web: www.eurofound.europa.eu

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Contact details

Donald Storrie (Project Manager) Donald.Storrie@eurofound.europa.eu

Alessandra Massaro (Project Administrator) Alessandra.Massaro@eurofound.europa.eu

Contents

Executive summary

The Industrial internet of things (IIoT) is a concept that refers to the integration of complex physical machinery with networked sensors and software in industry. The internet serves as the channel through which information flows and through which objects in a factory (and between factories) are connected. It is a subsection of the broader concepts of Internet of Things and Industry 4.0. IIoT factories becoming **smart factories** can be considered game changing. IIoT is one of five of such game changing technologies that have been studied for Eurofound in a series of reports on the impact of game changing technologies on production processes and work in the manufacturing industry.

Characteristics and adoption of the technology

Three main aspects make IIoT game-changing: (1) the autonomous exchange of large amounts of information between machines and between machines and components or products; (2) flexibility of processes and customisation of products; and (3) connectivity between factories, customers and business partners. These aspects influence value chains, business models, production processes and work in manufacturing industries. The autonomous exchange of information and the connectivity have led to new paradigms in business, most notably **servitisation**. This has changed business models in manufacturing by developing (data-driven) services connected to products, such as predictive maintenance. The flexibility of processes and **customisation** will enable companies to produce unique products designed with or by customers. Producing unique products, flexibly and fast, requires a much more local and distributed production system and different forms of digital cooperation with customers and value chain partners.

Investments in IIoT by manufacturing companies are **driven** by financial/economic, social and environmental incentives. IIoT is considered important for future competitiveness in Europe: customised products should counter competition from mass production in low-wage economies. It is expected to improve productivity and reduce costs, while increasing sales and improving quality. The social drivers of IIoT are related to better safety and working conditions of employees and improved customer experience through early involvement in production processes. Environmental drivers of IIoT concern the reduction of resources through optimisation of production and value chain processes. IIoT is enabled by developments in information (data) and communication technologies.

IIoT will be applied in many **sub-industries**, although its application is currently far from mainstream. Earliest applications of IIoT have been observed in worksite industries, such as the oil and gas sector, and in the automotive industry. Most often mentioned sub-industries for IIoT are (1) chemicals and chemical products; (2) motor vehicles, trainers and semi-trailers, (3) coke and refined petroleum products; (4) repair and installation of machinery equipment; (5) other transport equipment; and (6) food products. Other manufacturing sub-industries may be affected as well, such as textiles and machine manufacturing.

The **uptake** of IIoT is likely to be significant towards 2025 in Western Europe. Uptake by SMEs and uptake in less-industrialised countries is a concern. There are several **barriers** for the implementation of IIoT. Security and interoperability are the biggest barriers, but also upfront investment with uncertain return on investment, legacy equipment and technology immaturity are barriers for uptake. Barriers related to data and data-exchange have been found as well, such as privacy and data ownership (legal aspects). Barriers are also related to the behaviour of companies faced with many changes: changing business models and changing processes.

Impact on production processes

Value chains will be changed significantly by IIoT. Value chains are expected to become more flexible and will become **value networks**. Almost all elements of the value network will be affected. Original Equipment Manufacturers (OEMs) and other large companies are expected to take the lead in implementing IIoT and will likely push the use of IIoT further down the value chain. With new business models and servitisation as a new paradigm, large companies may start controlling larger

parts of the value chain. Trading and integration platforms are expected to emerge to facilitate transactions between companies and will become the integrator and brand towards customers. Moreover, modelling and simulation will be more often found at the beginning of value chains.

IIoT, and the mass customisation that it enables, will **change business models** in the manufacturing industry. Companies are expected to focus on their own core manufacturing competencies and outsource other activities in their value network. Data will be at the heart of many new business models. In such models, production will be much more distributed and thus closer to customers. There may be some reshoring due to IIoT.

Due to data-driven optimisation of processes, the use of raw materials and the consumption of energy are expected to be reduced, reducing costs as well. Improved resource management and predictive maintenance are expected to contribute to a reduction in waste and an **efficient use of resources**. The increased need for electronics may increase the use of scarce materials, although this may be counterbalanced by the miniaturisation of such devices and changing the materials used therein.

Work processes will be changed with IIoT. Quality management is expected to be improved due to more advanced analytics of process data. Processes will be more efficient and failures will often be predicted from data. Internal and external collaboration will increase: externally with more partners in the value network and internally between man and machine. Interactions will be more digitally and decisions will be assisted by intelligent systems and often based on data. This is not only due to the availability of data, but also due to the fact that process will be less standard (customisation). Decision-making may therefore also be more directed towards the work floor.

The next ten years will be characterised by a process of **transition** towards IIoT in a wide range of industries. It is however unclear how fast this process will be. IIoT is currently to varying degrees applied by some companies. Larger companies seem to be more involved in the transition than SMEs. However, to make a full transition the whole value chain needs to implement IIoT, including SMEs. This probably takes most time in the transition. Many technologies for IIoT implementation are already available, although they need to improve on aspects such as interoperability, standardisation and security. Business models are not yet fully developed, but will be in the next ten years.

Impact on work

IIoT has many impacts on **tasks** and on **skills needs**. It is therefore important that industry is involved in the formulation of future skills needs and in changing curricula of schools, universities and (private) training providers. The main skills needed for IIoT are related to ICT, data and mathematics. The changes in skills needs are illustrative for the associated changes in tasks of workers: ICT tasks will be much more pervasive, also in non-ICT occupations. There is a bigger need for (scarce) engineers and ICT and data experts. Every worker needs at least basic ICT skills. Physical tasks, such as manual tasks, are expected to be reduced in manufacturing due to IIoT, in combination with (Advanced) Industrial Robotics. Such tasks become assisted by machines or will be automated. Instead, intellectual tasks become more important (including creative tasks) just like social tasks (including internal and external collaboration). Examples of specific tasks are process modelling, collaboration in multidisciplinary teams, work-floor decision making, coordination in complex environments, and (technical) problem solving. Upskilling and reskilling is important, to update and broaden the knowledge of current employees, as multidisciplinarity and ICT skills will become more important.

Occupations change as well. At management level, IIoT introduces additional complexity and requires multidisciplinarity. Generally, IIoT will put manual 'blue collar' work under pressure, as this is expected to be replaced to some extent by smart machines. At the same time, new employment opportunities will appear. More self-employed experts and small cooperatives of designers, developers, engineers and repair/maintenance experts are expected. A shift of jobs is to some extent expected, most likely with a net effect of zero additional or reduced jobs. Workers who are currently in their forties need special attention: they will need to make a digital transition being from a non-digital generation.

With IIoT some **working conditions change**. Impact on working conditions seems to mainly concern health and safety (including stress) and training and personal development. Machines take care of less safe tasks and safety systems based on sensors and connectivity improve protection of workers. Job quality may be affected by the increased virtualisation of work on all levels, although teleworking and flexible work organisation models may contribute to a better work-life balance. IIoT may make work less social and may reduce autonomy for some employees. Machines may remove some intellectual tasks from people involved in processes.

Actions and strategies regarding IIoT are currently directed at the technology and its applications. Public and private partners are involved in platforms and clusters that focus on IIoT and related technologies. In many countries, social partners are not very active in discussions about the future labour market effects and the skills needs in manufacturing. Industrial partners should collaborate (more) to make sure that changes in curricula of education and vocational training institutions meet (emerging) skills demands of employers. Privacy of employees is an ethical issue that needs to be addressed when applying IIoT. However, as a final positive observation, IIoT also has the potential to improve inclusion of low-skilled or disabled workers in manufacturing.

Introduction

Purpose and context of the study

This report about the **Industrial internet of things** (and the underlying technologies) is one of the deliverables of a study that explores the impact of five technologies on manufacturing industries in Europe. Interactions with service industries are touched upon. The time horizon is 2017-2025.

The main purpose of the study is to better understand, and allow stakeholders to **anticipate and address** the impact of new technologies on production processes and work. As such, the three components of the study are:

1. The level of maturity and the scope of applicability of the **technologies**, in terms of specific sub-industries and geographic areas across Europe;
2. The (potential) qualitative impact on the **production process** including the impact on value chains, business models, productivity and output/products; and
3. The (potential) qualitative impact on **work**, in terms of employment (such as occupations that are emerging or disappearing), tasks (such as changes in physical, social and intellectual tasks), skill types and skill levels, education/training needs, working conditions.

The study also explores the interactions between companies, industry associations, trade unions, education/training institutions, governments and other stakeholders, during the changes that are affecting manufacturing industries. In short: actions by social partners. The detailed research questions are listed in 0.

To set the scene for this study:

- The study takes the **Industrial internet of things** as the point of departure…
- …but acknowledges that technological **trajectories** are influenced by established actors (with vested interests), new entrants (such as disruptors), path dependencies, social partners, policy and regulation, and much broader economic, social and environmental developments.
- The context of the study includes **cross-cutting technologies** such as ICT…
- …and **economic, societal and policy debates** about global value chains, industry 4.0 (and overlapping concepts such as factories of the future, smart industry and advanced manufacturing), re-shoring, 21st century skills, lifelong learning, flexible labour markets, resource scarcity, etc.

Note that the qualitative approach implies that the study **complements quantitative studies** about the impact of technologies (and automation and robotisation) on the number of jobs in specific industries and occupations. As such, this study is more about exploring the relevant mechanisms, uncertainties and important details such as changes in tasks and working conditions. This is done by means of looking into specific technologies and their application in specific industries.

The study about game changing technologies in manufacturing industries is part of the programme **The future of manufacturing in Europe** (FOME) financed by the European Parliament, under responsibility of DG GROW. The main theme of this programme is the revival of manufacturing in Europe. The FOME programme is executed by Eurofound, the European Foundation for the Improvement of Living and Working Conditions.

The study is conducted by Technopolis Group, between May 2016 and July 2017. The study team would like to **thank** the interviewees (Appendix B), workshop participants (Appendix C) and our clients and sparring partners at Eurofound (Enrique Fernandez, Eleonora Peruffo, Donald Storrie, Ricardo Rodriguez Contreras and John Hurley).

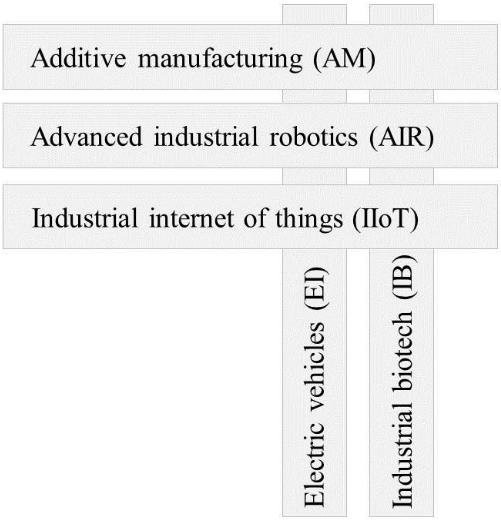
Five game changing technologies

This report is about the impact of **Industrial internet of things** (IIoT) on production processes and work in European manufacturing industries. In theory, IIoT can be applied in all manufacturing industries. The same applies two other technologies addressed in our study about game changing technologies: Additive manufacturing (AM) and the Advanced industrial robotics (AIR). These three technologies are at the heart of industry 4.0. They influence or redefine manufacturing processes and often also have an impact on products, such as customisation and enabling new product-service bundles (cf. servitisation).

In addition, the study addresses two 'vertical' technologies that are relevant for a smaller set of industries and products: Electric vehicles (EV) and Industrial biotechnology (IB).

Figure 1 visualises how the three cross-cutting technologies are relevant for Electric vehicles and Industrial biotechnology (and many other industries or products).

Figure 1: Five game changing technologies



Source: Technopolis Group, 2017

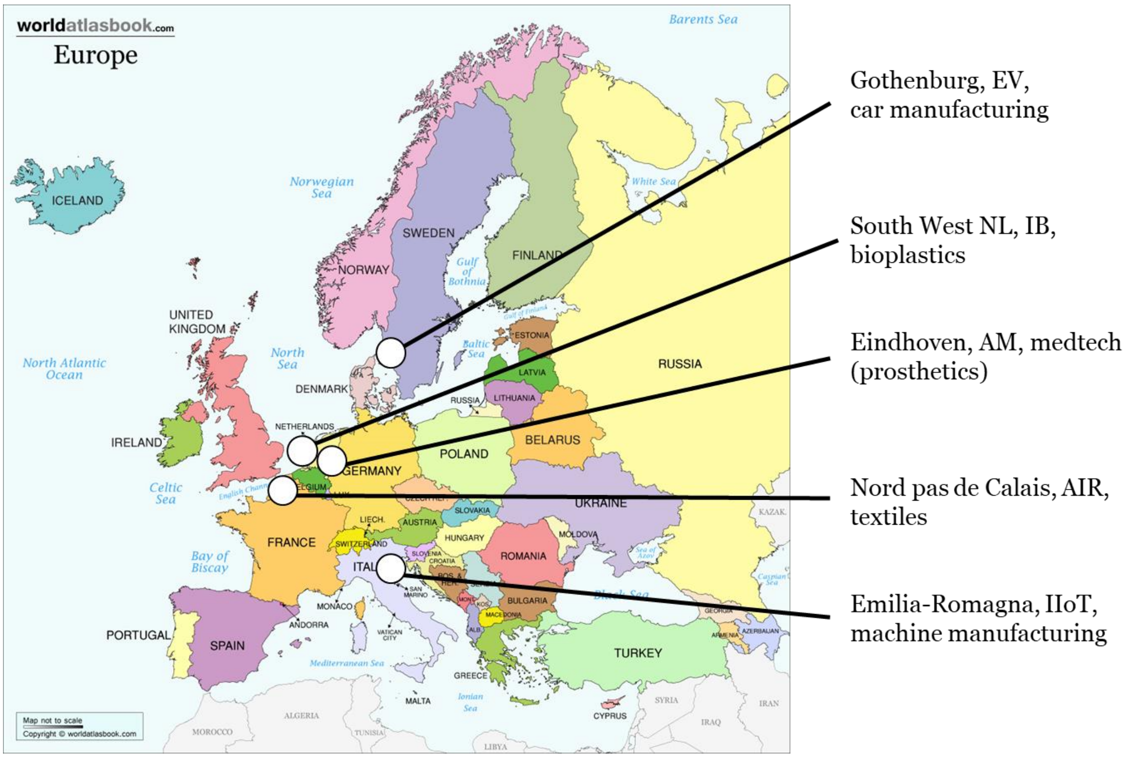
Research methods used

The study started with a **structured literature review**. Because the phenomena studied are quite recent, we used academic articles but also grey literature such as reports prepared for policy makers and industry associations and reports prepared by consulting firms. The Scopus database and Google Scholar were used to identify articles/reports with key words such as the five technologies and industry 4.0 combined with key words such as value chains, jobs, tasks, working conditions and social partners. The emphasis was on publications from 2013-2016 but in some cases older publications had to be used to fill white gaps (such as publications related to the impact of technologies on work). Appendix A contains the list of 100+ references. Using ATLAS.ti software and a coding scheme, relevant statements about drivers, barriers, industries affected, changes in tasks, etc., were coded and counted.

Subsequently, **interviews** were held with 30 leading experts, covering the five game changing technologies as well as specific backgrounds (such as industry, research and policy). A detailed questionnaire was used, to ensure that the three main parts of the study were covered (in short: technology, production process and work). Appendix B contains the list of interviewees that addressed Electric vehicles.

The third and final step consisted of five regional **workshops** (one for each technology) with companies, researchers, cluster organisations and other stakeholders. *Figure 2* introduces the five workshops.

Figure 2: Five workshops



Source: Technopolis Group, 2017

The workshops were effective for validating the findings of the literature review and interviews; for filling white gaps; for providing real-life examples of technologies being tested or implemented by companies; and for discussing responses by social partners.

Outline of the report

Next section addresses the Industrial internet of things, the underlying technologies, and the adoption in specific industries. The following ones explore the impact on production processes and address the impact of these changes in production process on work and mentions examples of responses of social partners. The final section concludes.

Appendix A contains the detailed set of research questions. Appendix B and Appendix C list the interviewees and workshop participants, respectively.

Characteristics and adoption of the technology

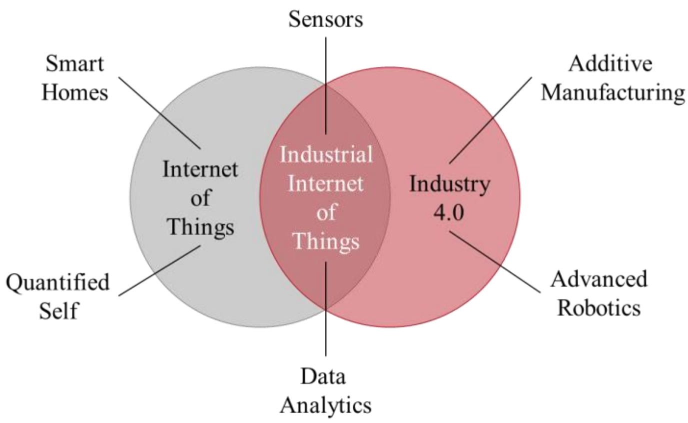
Introducing the Industrial internet of things (IIoT)

The concept of the Industrial internet of things (IIoT) refers to the integration of complex physical machinery with networked sensors and software. It integrates the use of predictive analytics ('big data') with the increased level of connectivity across different devices and manufacturing processes. This high level of connectivity is made possible through the pervasive use of miniaturised computing devices and sensors (such as Radio Frequency Tags and Interrogators: RFTI or RFID). The internet serves as the channel through which the information flows and through which objects are connected.

According to the World Economic Forum, this game changing technology *"will combine the global reach of the Internet with a new ability to directly control the physical world, including the machines, factories and infrastructure that define the modern landscape"* (World Economic Forum, 2015). This paradigm shift is sometimes dubbed 'industry 4.0', 'smart factories' or 'factories of the future', where advanced automation and sensing technologies, information exchange and new manufacturing technologies are setting up the basis of what is likely to be the new industrial revolution (Acatech & Forschungsunion, 2013).

The Industrial internet of things can be considered as a subsection of the broader concepts of internet of things and Industry 4.0, as is sketched in *Figure 3*. The Internet of Things is a concept that applies beyond the manufacturing industry; the smart digital connection of devices is also used by other industries and consumers, such as service industries, applications to create smart homes and the quantified self. Whilst the concept of Industry 4.0 does specifically cover the manufacturing industry, it covers much more than the internet of things only: it also concerns advanced robotics and Additive manufacturing. In this technology report, we focus on the area of overlap of both technology concepts applied in the manufacturing industry: the Industrial internet of things.

Figure 3: The position of Industrial internet of things with respect to Internet of Things and Industry 4.0



Source: Technopolis Group (2016)

Indeed, interviewees and workshop participants in our study stressed that the Industrial internet of things cannot be fully discussed without taking into account the broader changes that are driven by Industry 4.0. Links with Additive manufacturing and advanced robotics are obvious and are often brought into the discussion. However, not only should one recognise the links with other new technologies, one should also include the relation with the new service paradigm that they enable. This new paradigm in the manufacturing industry is dubbed servitisation: "the strategic innovation of an organisation's capabilities and processes to shift from selling products, to selling an integrated product and service offering that delivers value in use, i.e. a Product-Service System" (Jay, Kao, & Shanhu, 2014, p. 4). Servitisation is influencing new business models in the manufacturing industry and is in this technology report discussed as such.

The game changing aspect of IIoT in manufacturing

The exploitation of sensor data and information for better decision-making in manufacturing is not a new concept. During the past decades, manufacturing industries have been progressively incorporating a ‘sociotechnical system’ approach, integrating the interactions between people and technologies to the workplace. This includes the efforts to reduce waste and improve quality; to improve the control of inventories and producer-supplier integration (just-in-time manufacturing); and to respond to the information needs generated by global supply chain management, mass customisation and sustainable production. The experts that we consulted in our workshop therefore speak of the Industrial internet of things as an evolution and not so much as a revolution – although when fully implemented the manufacturing industry will be changed significantly.

At its very basis IIoT is associated with an increased use of actuators and sensors and, as a result, the increased flow of data – often termed ‘big data’ in current fashion. This has been a trend in industry for several decades already that increased with growing technological developments in data storage (such as cloud storage and SSD), data processing (such as artificial intelligence and big data analytics) and data transfer (such as fast industrial Wi-Fi networks and 4G/5G networks), but also developments in remote sensing (such as RFID and NFC tags). Indeed, one could say that there was an evolution towards the basic elements of IIoT. However, the new IIoT paradigm and the way in which these technologies are smartly used in conjunction make the revolution towards a game changing technology.

There are at least three aspects that make IIoT a game changing technology:

1. Autonomously exchanging large amounts of information;
2. Flexibility of processes and customisation of products; and
3. Connectivity between factories, customers and business partners.

These aspects especially influence the organisation and quality of the design process, production of parts, assembly and logistics of the manufacturing industry.

The methods and capacity to analyse much larger datasets, in conjunction with the always-connected nature of new manufacturing machinery, make IIoT a genuine step change. These new methods provide businesses with richer and more powerful predictive models that can be applied in near real time, especially in the production, assembly and logistics processes.

In this new approach to production, smart sensors and machines, storage systems and production facilities will be capable of autonomously exchanging information, triggering actions to control, reconfigure and adapt independently (Acatech & Forschungsunion, 2013). Simulation and optimisation of manufacturing activities will be possible end-to-end (Acatech & Forschungsunion, 2013). Autonomous information exchange implies that certain activities currently done by people may no longer be necessary and can take place continuously to optimise quality.

Many initiatives for IIoT so far have focussed on specific aspects of the technology such as sensing (Deloitte, 2016b). This particular focus may explain why wearable and connected sensors are increasingly used in industry for the safety of employees (World Economic Forum, 2015) – although one of our interviewees rightly questioned ethical issues such as privacy here. Sensors are also used for predictive maintenance and remote asset management to reduce failures and maintenance downtime. Companies such as ThyssenKrupp, Caterpillar, AG and Thames Water have been reported to analyse the data of sensors for these purposes (World Economic Forum, 2015).

Sensor data is also increasingly used by companies to develop services related to predictive maintenance and improved product performance. One Italian multinational in our workshop, SCM Group, launched two pilots with some of its clients to explore this step towards servitisation. Interviewees mentioned that other large companies have taken similar routes to servitisation, such as General Electric that is transforming in a data company, Rolls Royce that sells ‘power-by-the-hour’ to their aviation clients and BMW that uses car sensors to predict maintenance and to keep services at BMW dealers.

New types of products and services can be expected with IIoT, as well as associated new production systems (Deloitte, 2015). Personalised products can be produced more easily – on demand and at low-cost – and will be in reach for the masses, hence the name ‘mass customisation’ (Antonova, 2013) or ‘customisation’ (Foresight, 2013). New innovative products can be produced, with higher expected performance and more flexibility due to greater freedom of design (Foresight, 2013).

With IIoT, production processes can attain greater levels of flexibility and modularity, not just customisation but also small-batch manufacturing. According to Brettel, Friederichsen, Keller, & Rosenberg (2014) production processes will be divided into “small value oriented units” (p. 38) that focus on specific steps in the production process. Information is shared between these units. This modular approach should result in more efficient production processes and allow for changes to be made to specific steps within the production process without disturbing the rest of the production process. IIoT is expected to lead to a higher output of products (Acatech & Forschungsunion, 2013). The flexibility created through IIoT thus provides the opportunity for greater variation in outputs of the manufacturing process, without losing significant speed or reducing volume.

To what extent flexibility and customisation also imply a drastic change in overall work organisation remains to be explored, although some examples can be given. One company in our workshop is transforming from large-batch production to small-batch production to follow current market demand. This company has changed a part its work organisation by installing an in-house design team that can first design the small-batch products with the client, based upon the client’s requirements. More focus has been put at the pre-production phase here.

One particular element of IIoT is that data and the exchange thereof will be both important in *production processes* as well in the *products* themselves – right from the design phase. In addition to changing the manufacturing processes, IIoT also enables for pushing product updates and upgrades to customers (McKinsey Global Institute, 2015). This can be part of a company’s servitisation business model. Apart from addressing servitisation, we will not focus on the ‘post production and delivery’ part of the value chain in this study.

Nevertheless, it is worth noting for the logistics step in the value chain that smartly produced products will be uniquely identifiable, incorporating total traceability, current status information and will be aware of alternative routes throughout the supply chain, from the moment an order is placed right through to outbound logistics (Deloitte, 2015; Acatech & Forschungsunion, 2013). This ‘product memory’ also allows for flexibility in the value chain: customer requested adaptations can be made anywhere in the value chain, such as during purchasing, production or sales. Deloitte (2015) states that this results in a *“kind of horizontal integration of both customers and business partners [that] can generate completely new business models and new models of cooperation”* (p. 7). To respond to this, IIoT will likely result in closer cooperation between business partners in the value chain (Acatech & Forschungsunion, 2013). If and when all these aspects indeed become reality, factories will be able to loosely connect horizontally, creating dispersed and dynamic value networks. IIoT is expected to lead to a *“much more distributed local and global production base”* (Foresight, 2013, p. 70). Future factories are expected to be closer to customers with more diversity in factories (Foresight, 2013).

Other game changing aspects of IIoT that we have found in this study are:

- Improved maintenance (McKinsey Global Institute, 2015) – sometimes offered as a service to clients;
- New synergies between product development and production systems (Deloitte, 2015) – a more integrated design process; and
- Business optimisation: improving efficiency (Foresight, 2013).

Why manufacturing companies invest IIoT

The drivers for IIoT are financial/economic, social and environmental. The financial/economic drivers are however most important for the uptake of IIoT. More specifically, IIoT is considered as an important technology for future competitiveness through mass customised products (Foresight, 2013). It is expected to save costs in the production process by improving productivity and reducing cost, but also generate more income by offering more variation to the products (flexibility) thereby increasing sales and by improving the quality, both of the product as well as during the production process (McKinsey Global Institute, 2015; World Economic Forum, 2015; Friedrich-Ebert-Stiftung, 2015). This is realised through predictive maintenance (Friedrich-Ebert-Stiftung, 2015; World Economic Forum, 2015), teleworking (McKinsey Global Institute, 2015) and optimised production processes (McKinsey Global Institute, 2015). Servitisation as a new business model that is enabled by IIoT is also driving companies to embrace IIoT.

Interviewees and workshop participants stress the importance of the financial/economic drivers for the uptake of IIoT. The market demand for large batches is shrinking as well: clients are less often ordering large batches of products, but want smaller batches or even unique products instead. Companies from one specific industry mentioned that the flexible production lines needed, however, are 30-40% more expensive, while the current premium for customised, high-quality products is 10-20%. This results in replacing production lines over a longer period of time. However, competition from Asian and other companies is another driver for IIoT. Timing is considered important, but it is mainly the larger companies that apply IIoT currently. We only found a few examples of small and medium sized companies that have made the transition, for example the Dutch SME 247TailorSteel that is in Box 1**.**

Box 1. An example of an SME applying IIoT: the Dutch SME 247TailorSteel is fully operated with IIoT and robotics

In this study, we predominantly found larger companies applying IIoT in their production processes. Interviews with Dutch IIoT experts directed our attention to 247TailorSteel, a Dutch SME in metal processing - laser cutting and bending - that is fully automated using IIoT and robotics.

247TailorSteel was founded in 2007 and currently employs about 125 employees (2015) in a fully automated factory that is located in a small town in the East of the Netherlands (Varsseveld) (Peters, 2015). The company has an annual turnover of 30 million euros (2014) and an average annual growth between 25-30% in the period 2009-2014 (Peters, 2015). The company is considered as a successful example of Industry 4.0 effectively exploiting IIoT in its manufacturing process.

Customers of 247TailorSteel can order their product 24/7 online and receive it within 48 hours. Products are ordered online through the in-house developed software tool SOPHIA – an acronym for SOPHisticated Intelligent Analyser. In SOPHIA customers upload the CAD design of their product, which is then analysed by SOPHIA and automatically transformed into production and logistics instructions for the factory. Based on the analysis of SOPHIA the client digitally receives within a few minutes an offer. Once accepted, the order is sent to the factory to be produced. So far, no person has been involved in the process – 247Tailor Steel has no front or back office. This has resulted in lower product costs and a faster process.

Within the factory almost everything is automated and digitally instructed through SOPHIA's output. A robotic vehicle autonomously picks the right metal plate for the next product and positions it into the automated laser cutting or bending machine. At each machine one 'process guide', as they are called at the factory, oversees the process and solves problems if needed (Gersdorf, 2014). At the end of the process they prepare the product for transport and the waste for disposal or reuse. This makes the whole factory floor remarkably clean and spacious (De Ingenieur, 2015) – a safe and attractive working environment.

The concept of 24TailorSteel allows clients to place orders for small batches or even a batch-one product. The costs of such a small batch or even of a single product are only slightly higher than that of larger batches. Customers basically control and use the equipment of 24TailorSteel over the internet without owning it. For this concept 24TailorSteels sees the potential to expand its business with another 100-150 small factories all over Europe located close to the customer (Gersdorf, 2014)

Source: Technopolis Group, 2017

In addition to financial/economic drivers, there are social drivers. IIoT can provide more safety and better working conditions for employees (see section 0) and improved customer experience through more variation in the products and early involvement in the production process, which is linked to the financial motive to also generate more income (World Economic Forum, 2015). Similarly, there is a strong link between the economic and environmental drivers. By reducing the use of resources, such as water, energy and materials, and creating less waste, businesses are also able to reduce costs (World Economic Forum, 2015).

Enablers of IIoT are the developments in information (data) and communication technologies and sensor and actuator technologies. Technologies such as big data, data security, blockchain, cloud computing, cyber-physical systems, Additive manufacturing, advanced materials, autonomous robotics are mentioned as enabling technologies for IoT (Lee, Kao, & Yang, 2014; Roland Berger, 2015a; Van Houten & Scholten, 2016; McKinsey Global Institute, 2015; Foresight, 2013). The evolution of IIoT is thus strongly linked to the general developments in ICT, data science, nanotechnology, miniaturisation and (advanced) robotics. Trends such as reduction of energy consumption and the increasing speed of wireless data communication are also instrumental to IIoT (World Economic Forum, 2015; McKinsey Global Institute, 2013; Roland Berger, 2015b). A key enabler to IIoT is the reduction of costs of sensors and other ICT-components; the increasingly mobile, digital and connected world; and new internet communication standards such as IPv6 (Zuehlke, 2010; McKinsey Global Institute, 2013; Foresight, 2013).

Applications of IIoT in sub-industries

According to McKinsey (2015) “the earliest implementations of the Internet of Things have been in worksite industries, and the oil and gas sector has been the most advanced user of IoT” (p. 74). Furthermore, the automotive industry is expected to be transformed due to new value chain models that IIoT enables. (Germany Trade & Invest, 2014). McKinsey (2015) estimates that in 2025, the deployment of IIoT in the automotive industry can result in a global value of 210-740 billion US dollars.

These kinds of predictions may stimulate the full application of the technology in manufacturing, but the reality is that IoT is far from being a mainstream in industry. The high cost of the necessary technologies, coupled with the cost incurred for the changes required to the work organisation and skill set of its employees, holds the industry back. IIoT is “still in early stages of adoption, but it has already a wide variety of uses, and the portfolio of applications is expanding daily” (McKinsey Global Institute, 2013, p. 53). Most IIoT data that are currently collected are not yet used at all or not fully/optimally used, often due to the challenging amount of data – big data – that has to be dealt with (McKinsey Global Institute, 2015). Companies such as Siemens and GE have made significant investments in building software platforms for IIoT; they are among the front runners (World Economic Forum, 2015).

Many manufacturing industries are expected to be transformed by IoT (World Economic Forum, 2015). In the reviewed literature, we most often found references to the following sub-industries (percentages in parentheses represent the share of mentions):

- Chemicals and chemical products is most often mentioned (19%); followed by
- Motor vehicles, trailers and semi-trailers (14%);
- Coke and refined petroleum products (14%);
- Repair and installation of machinery and equipment (14%);
- Other transport equipment (10%); and
- Food products (5%).

Sub-industries that can be classified as ‘other manufacturing’ have also been mentioned considerably (24%). This underlines that the number of industries affected is broad.

Experts participating in our interviews and workshop largely confirmed this overview of sub-industries, although they also added some sub-industries. Textiles and machine manufacturing were considered important industries for applying IIoT. Especially in textiles some large manufacturers effectively apply IIoT in their factories and supply chain. The Spanish Zara and German Adidas were mentioned in that respect. The case of Zara is further detailed in Box 2 and the case of Adidas is detailed in Box 3. Other examples of sectors that were mentioned but were less significant are metal processing, machine manufacturing and ceramics (tiles).

Box 2. An example of the application of IIoT in textiles: how the Spanish fashion manufacturer and retailer Zara uses IIoT

The Spanish fashion manufacturer and retailer Zara uses IIoT to improve its processes from manufacturing to sale. Zara has changed the fashion industry as a pioneer in “fast fashion”: a fast, optimised production process and supply chain so that stores receive newly designed clothes every two weeks based on customer demands. Zara basically introduced customisation in fashion. For that Zara uses data from its customers, stores and clothing, applying IIoT concepts since 2013 (Cordon, Garcia-Milà, Vilarino, & Caballero, 2016).

During the production of its clothes Zara labels its products with RFID chips (Cordon, Garcia-Milà, Vilarino, & Caballero, 2016). Each product can therefore be tracked real-time throughout the entire process from manufacturing to sale. By this Zara can do its stock management more accurately and improve its customer service. Customers can get accurate information on the availability of Zara’s products in any size and colour. At ZARA’s state-of-the-art underground distribution centre kilometres of rails and reading equipment sorts the clothing automatically to the right stores (Goulden, 2013). But the data is also used for identifying fashion trends, developing new fashion designs and improving production processes.

Zara digitally monitors the behaviour of its customers based on what they buy and on comments they make on the clothing to store personnel (Hansen, 2012). This information is reported digitally to Zara’s headquarters and used by Zara’s design team to develop new designs. This process and the production is optimised so that the production of new clothes takes only two to three weeks (Hansen, 2012) . This way, Zara can follow demand and customise products. Each store has only a few items of each product, with little stock at Zara centrally to minimise costs, while also creating limited editions.

Zara produces most of its clothing in Europe or close to its headquarters in La Coruña (in the industrialised North of Spain). At Inditex, the holding behind Zara, over 24,000 employees work of which about 10% work at the in-house production facilities (Heller, 2001). Zara owns factories in Spain and some of its production is outsourced to factories in Portugal, Morocco and Turkey (Hansen, 2012). All these countries have a high-wage economy, but higher costs are off-set by improved flexibility and fast turnaround speed that is at the basis of the “fast fashion” business model of Zara empowered by IIoT.

Source: Technopolis Group, 2017

It seems likely that IIoT will have a significant uptake towards 2025 in Western Europe (McKinsey Global Institute, 2013; McKinsey Global Institute, 2015). Raising awareness for the technology state and potential of IIoT in industry is called for in literature (Roland Berger, 2015b; World Economic Forum, 2015). Germany – which has a strong manufacturing base, especially in the automotive sector – seems to be best positioned for IIoT uptake (Acatech & Forschungsunion, 2013) and ‘Industry 4.0’ is being actively promoted by the German government (Germany Trade & Invest, 2014). Visitors to the 2017 Hannover Messe – one of the biggest industrial trade fairs in the world hosted in the German city of Hannover – must have seen the many IIoT and ‘Industry 4.0’ solutions that are already available and likely noticed the vast attention and interest they received at the fair. Companies that are mentioned as being involved in some aspect of IIoT are often large firms, such as ThyssenKrupp, Siemens, AG, Caterpillar, Bosch, SAP, BASF, Bayer and GE (Zuehlke, 2010; World Economic Forum, 2015). During this studies' workshop in Bologna (in the Emilia-Romagna region of Italy) the participating large companies SACMI and SCM Group also explained why and how they started using IIoT in some of their processes and products. From experts, we only heard a few manufacturing SMEs that involved in IIoT in their processes, most notably the Dutch 247TailorSteel that is discussed in more detail in Box 1. Supporting and stimulating SMEs in making the IIoT transition was considered by interviewed experts as an important challenge for the success of IIoT, as it needs to be adopted throughout the value chain.

Not much geographical information on the application and impact of IIoT is available. However, the impact of IIoT is perhaps most significant in European countries that have a large manufacturing sector and many people employed in these sectors. The five EU-countries with the largest turnover in the manufacturing sector are Germany, Italy, France, the United Kingdom and Spain[1]. For these countries especially, IIoT could be an important game-changer for their future economy, Germany has the largest number of persons employed in the manufacturing sector (by far), followed by Italy, France, the United Kingdom and Poland (see footnote 1). In terms of workers, IIoT could mostly affect work in these countries. Germany, France and the UK are also known as strong innovators (European Commission, 2016a). That might suggest early uptake of IIoT in these countries. During this study, examples of IIoT uptake and initiatives have been found especially in Germany (Industry 4.0 initiative, several companies), Italy (Fabbrica Intelligente initiative, several companies), the Netherlands (Smart Industries initiative, the company 247TailorSteel) and Spain (the company ZARA).

The challenges for uptake in less-industrialised countries are a concern, also considering possible tensions between mass customisation, handcraft and standard products (Mulani & Pinge, 2016; McKinsey Global Institute, 2015; Van Houten & Scholten, 2016).

During this study, we observed several **barriers** for the implementation of IoT in general (and IIoT in particular). A study from the World Economic Forum (2015) shows that almost two-thirds of their respondents agreed with "*the widely-held view that security and interoperability are the two biggest hurdles*" (p. 10) for IoT. This was confirmed in our interviews and workshop. A common, shared IIoT platform per industry or interoperability between platforms was seen as essential. At the Hannover Messe this was raised as a concern as well. Furthermore, upfront investment with uncertain return on investment (53%), legacy equipment (38%) and technology immaturity (24%) were often mentioned as barriers for IoT (World Economic Forum, 2015). Companies attending our workshop confirmed that IIoT production lines are more expensive, while the premium for more customised products does not (yet) compensate for the higher costs for these production lines. Replacing production lines for those that can be embedded in an IIoT environment is therefore done over longer periods than with normal replacements due to higher investments.

IIoT relies heavily on data exchange. A large number of barriers that are mentioned in the reviewed literature relate to data exchange: data/cyber security, privacy protection, data ownership and interoperability among devices (standardisation) (McKinsey Global Institute, 2015; Acatech & Forschungsunion, 2013; Roland Berger, 2015a; World Economic Forum, 2015; Zuehlke, 2010; Mulani & Pinge, 2016). As data is stored on the product and may be available throughout the value chain, intellectual property protection may also be a barrier for a fully integrated IoT in the manufacturing industry (McKinsey Global Institute, 2015). Software and IoT platforms need to be standardised for horizontal and vertical integration in value chains (such as intercompany processes and business networks) and need to be able to do predictive analyses in real-time and need to be able to reliably deal with many different data sources and devices (Acatech & Forschungsunion, 2013;

[1] Based on 2015 data from Eurostat: Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E), Manufacturing, Turnover or gross premiums written and Number of persons employed.

McKinsey Global Institute, 2015; Lee, Kao, & Yang, 2014). At the 2017 Hannover Messe several speakers addressed the topic of data security, privacy and interoperability and stressed their importance, but there seems to be no leadership. Therefore, industry encourages the EU to quickly develop a digital single market and to take leadership in the process towards IIoT standardisation.

Current infrastructures, systems and software need to be upgraded and ready for IoT (Acatech & Forschungsunion, 2013). Network infrastructures for high volume and high quality data exchange are needed (Acatech & Forschungsunion, 2013). Many of these kinds of network infrastructures, under the name of industrial wireless LAN, were displayed at the 2017 Hannover Messe. Sensors, that are an important part of IoT systems, need to be cheap, reliable and robust in harsh environments for a large-scale transition to IoT (McKinsey Global Institute, 2015).

The behaviour of companies needs to change too. To fully achieve the potential of IoT, companies must be willing to innovate and share information among partners – even if this is initially associated with costs and being very open to business partners (Brettel, Friederichsen, Keller, & Rosenberg, 2014). Companies need to considerably invest upfront (with uncertain RoI) and companies may need to make a transition to new business models that are currently not yet fully proven to be successful in practice (World Economic Forum, 2015). Legal and confidentiality issues regarding customer data and the willingness of customers to share personal data, such as on how they use products, may be a barrier for IoT and for servitisation (McKinsey Global Institute, 2015). These issues, if not well dealt with, may also affect the trust that customers have in a company and its brand and may therefore be a risk for companies. Experts at our workshop also named privacy as a barrier, especially those of workers. This more ethical concern is related to the large amounts of data on the behaviour of workers, both in terms of performance as well as physical behaviour, which might be collected in IIoT factories. This was referred to as the risks of big data.

Furthermore, companies need to attract people with different skill sets and talents (World Economic Forum, 2015), such as “data scientists, statisticians, and machine learning technicians” (McKinsey Global Institute, 2015, p. 80), and differently trained IT experts (Acatech & Forschungsunion, 2013). Section 0 elaborates on these skills needs.

Impact on production processes

The impact of IIoT on processes within the value chain

The impact of IIoT on the value chain primarily regards new business models and new, more flexible value chains. These two aspects were most often mentioned in the reviewed literature and confirmed by expert interviews and this study's workshop.

As mentioned in the previous chapter, value chains are expected to change with IIoT. They become more complex, more flexible and, in fact, become value networks or ecosystems instead of linear chains, due to all-digital connections with customers and companies in the value chain (World Economic Forum, 2015; Van Houten & Scholten, 2016). Due to data exchange, horizontally and vertically throughout the value chain the boundaries of manufacturing companies start to erode as they become digitally connected, reflecting some sort of horizontal integration and vertical networking of companies (Deloitte, 2015; Van Houten & Scholten, 2016; Acatech & Forschungsunion, 2013). The term horizontal integration in this context refers to "the integration of the various IT systems used in the different stages of the manufacturing and business planning processes that involve an exchange of materials, energy and information both within companies […] and between several different companies (value networks). The goal of this integration is to deliver an end-to-end solution." (Acatech & Forschungsunion, 2013, p. 20). This will allow companies to have an overview at the perspective of a single product that is being produced (Acatech & Forschungsunion, 2013). Not only companies will be digitally connected, customers will also be connected with the companies in the value chain, allowing for customer specific adaptations at any stage in the value chain (Foresight, 2013; Deloitte, 2015). For instance, in the future you may be able to track the production progress/status of the car you ordered and digitally change some of its features during any stage of production with just your smartphone at home. This results in more flexibility and transparency for customers (Deloitte, 2015).

IIoT changes almost all stages of the value chain. The keywords here are again flexibilisation and digitisation. The example of Zara in Error! Reference source not found. showed that inventories are igitally monitored and that production and distribution are data-informed as well. Changes in materials and products follow demand, which may change fast, as well as be diverse due to customisation. OEMs and other large companies will therefore push IIoT to their suppliers. Experts warn that if SMEs that currently supply to such companies do not follow the trend to IIoT they may risk being cut out of the value chain, as they would slow-down the production process at large companies. This is currently one of the big value chain bottlenecks that holds back industry to make a fast transition to IIoT. At the same time, large companies may therefore feel the need to control more of the value chain. Servitisation is one of the trends that large companies use to control and to have a stronger position at the end of the value chain. Platforms may be used to control, monitor and interact in the earlier stages of the value chain.

Trading or integration platforms emerge to facilitate transactions between companies or become the integrator and brand towards customers, according to interviewed experts. Both IT and large manufacturing companies are said to be working on these platforms or technologies behind such platforms, such as SAP, IBM, Google, Apple, Siemens and GE. One technology that is said to currently receive a lot of attention for these platforms is blockchain – the technology currently used for cryptocurrencies like the Bitcoin – to safely, effectively and real-time share decentralised data about (available) production capacity throughout the value chain without the need of a third party. Expert interviewees also stressed that with IIoT, modelling and simulation are more often found at the beginning of value chains. The requested products of customers are modelled and the needed production process may be simulated to optimise production processes a priori or to calculate costs and pricing – like 247TailorSteel (cf. Box 1) does with its SPOHIA platform. Similar platforms may indeed also appear *between* companies.

Mass customisation is expected to change the production architecture fundamentally, impacting also business models. New business models are often mentioned in the context of IIoT, but concrete examples are limited. Companies are expected to focus on their own core manufacturing competencies and outsource other activities in their value network. As products will be more unique and personalised, manufacturing competencies becomes a higher valued asset than being able to produce a single high-quality product, in large volumes, yourself. Business models will thus focus on "offering superior manufacturing capabilities – instead of offering superior products" (Van Houten & Scholten, 2016, p. 37) and on the "shared use of assets, such as data – instead of ownership of these assets" (Van Houten & Scholten, 2016, p. 37). In new business models, data – such as on the design and the production process of a product – might become the competitive asset that is sold by some companies, instead of the final product itself. (Van Houten & Scholten, 2016; Foresight, 2013). Generally, IIoT drives new business models towards hybrid solutions that merge physical products with digital services. Fleisch, Weinberger, & Wortmann (2014) term this business model pattern 'digitally charged products': "classic physical products are charged with a bundle of new sensor-based digital services and positioned with new value propositions" (Fleisch, Weinberger, & Wortmann, 2014). One step further are business models where the physical product is no longer involved, the sensor data itself is the primary currency: Fleisch, Weinberger, & Wortmann (2014) call this business model pattern 'Sensor as a Service'. At the 2017 Hannover Messe expert speakers stressed that IIoT business models in manufacturing often include concepts from servitisation and predictive maintenance. This was confirmed by the Italian companies that participated in this study's workshop.

Production will be more distributed and is expected to be nearer to customers and employees. Companies will be located in smaller hubs and are expected to be more mobile (Foresight, 2013). This concept is also part of the business model of 247TailorSteel that was illustrated in Box 1. Value chain partners do not necessarily have to be close to the company, as most interaction is digitally. Production will be more decentralised, as through the digital value networks, more actors could become part of the production process (Antonova, 2013). Lower entry barriers to manufacturing industries can be achieved by Additive manufacturing, for example by means of 3D printing at home or in local printing centres (Antonova, 2013). However, in the reviewed literature, we have not identified any concrete new entrants.

Although we have not found much reference to off- or reshoring due to IIoT in this study, developments at the German Adidas may exemplify how IIoT could lead to reshoring. The new Speedfactory of Adidas in Germany's Bavaria brings back some shoe manufacturing to Germany. Most shoes are currently produced in Asian low-wage countries, but with IIoT technology it becomes profitable to produce unique shoes close to customers in Europe. Currently, this is additional production capacity that not replaces production in Asia – so one could argue that it is not full-blown reshoring. However, customisation may very well bring back or create some production capacity in Europe as it becomes more important to be close to customers and suppliers. The example of Adidas and its value chain aspects are discussed in more detail in Box 3.

Box 3. An example of a company where IIoT changed value chain processes: Adidas' Speedfactory in Germany - shortening the supply chain with customised footwear thanks to IIoT

Adidas has opened a brand new high-tech sports shoe factory in its German home state Bavaria last year. This factory, called the Speedfactory, uses IIoT concepts to produce shoes fully customised to its wearer. By employing techniques such as Additive manufacturing and advanced robotics, Adidas can produce these customised shoes within a day (Roazen, 2016). A revolutionary improvement, considering that a current brand-new model of an off-the-shelf sports shoe has been designed two years in advance (Roazen, 2016). Most of these shoes are produced in Asia. With the new Speedfactory, Adidas brings a part of its shoe manufacturing back to Europe. The new factory should complement current production facilities in Asia (The Economist, 2017). The production start at the Speedfactory was planned for mid-May 2017.

For the Speedfactory Adidas has copied concepts from digital manufacturing in the automotive and aerospace industry. Adidas uses motion capturing tools to scan the foot of customers and to understand precisely where the foot needs support and where the skin needs to twist and move (Roazen, 2016). This results in customer specific data that is digitally analysed and used in the individual design of the shoe. The digital design is then digitally tested for fit and performance and the production process is simulated. Eventually the digital model is send to the Speedfactory to produce the fully customised shoe within less than a day. Thanks to this customised approach the shoe optimally supports the wearer in its sports activities.

The production at the Speedfactory is almost fully digitised and automated, using computerised knitting, robotic cutting and 3D printing techniques. Still, about 160 people work at the new factory in Bavaria – additional jobs as the factory does not replace capacity in Asia (Roazen, 2016; The Economist, 2017). The number of workers is however less than the thousands that currently work in a typical shoe manufacturing plant in Asia. The skills of these employees are different as well. The employees at the German factory are more highly skilled and take, for example, care of the modelling and the final shaping of the shoe (The Economist, 2017). Once the Speedfactory is fully up and running it should produce up to 500,000 pairs of customised sport shoes a year (The Economist, 2017).

For Adidas, the Speedfactory is a means to stay ahead of competition and to reduce costs and waste (Roazen, 2016; The Economist, 2017). The demand for “fast fashion” is increasing, while the traditional supply chain is hindering an effective response to this trend. With the Speedfactory, sports shoes are produced where the demand is, fast and fully customised in high-wage countries. For Adidas, the cost reduction is therefore not so much in labour costs, but mainly in costs for transportation and reductions due to a shortened supply chain. At the same time, less energy is wasted in the supply chain. In the Speedfactory the amount of waste is reduced and new materials are tested as well, such as synthetic bio silk from a German biotech company (The Economist, 2017). Adidas mentions sustainability as one of the motivations for the Speedfactory (Roazen, 2016).

Adidas plans to ramp up local production of customised footwear by opening a new Speedfactory in Atlanta (US). This factory is currently being built. The ambition of Adidas is to further expand the network of local Speedfactories in the future (The Economist, 2017).

Source: Technopolis Group, 2017

The impact of IIoT on materials and resources

In this study, we found no reference to the use of new or different (natural) resources, as IIoT not so much changes materials used in manufacturing but the *processes* in manufacturing. However, specific components and equipment were mentioned to become more important. Much specific information regarding resources and equipment has not been obtained.

With IoT in the manufacturing industry, machines and devices will be connected to interact with each other and with humans. For that, sensors and actuators are essential, as well as other electronics, most importantly those related to computing, storage – both of data and energy – and wireless data transmission (Van Houten & Scholten, 2016). The demand for these kinds of electronics can be expected to increase. This may affect the use of scarce materials, such as precious metals used in electronics. However, the effect is not so clear, as there may be a trade-off between increased demand for such electronics and the increasing miniaturisation thereof. Devices tend to be smaller for improved wearability, reduced energy consumption and increased storage capacity, which may lead to an overall reduction in the use of scarce materials, such as precious metals. This development is not so much shaped by IIoT, but is the context in which IIoT technology develops.

Autonomous optimisation of processes can be used to reduce the use of raw materials and the consumption of energy (Van Houten & Scholten, 2016). All in all, production will be more resource efficient with an improved resource productivity (Germany Trade & Invest, 2014; McKinsey Global Institute, 2013; Deloitte, 2015). Zooming out from IIoT to Industry 4.0, Acatech & Forschungsunion (2013) state that “Industry 4.0 provides the opportunity to optimise delivery of the overarching goals of resource productivity and efficiency on a case-by-case basis” (p. 62). Interviewees stress that optimisation of processes with IIoT certainly has the potential to improve energy efficiency in manufacturing – and by doing so reducing costs. This reduction is not limited to the manufacturing process alone, as IIoT affects the whole value chain. IIoT therefore has also the potential to improve energy efficiency along the value chain in processes such as packaging, warehousing and logistics (given that manufacturing is expected to be closer to customers).

Just like products, with IIoT resources can be located anywhere and anytime (through RFTI or RFID), as all stages of the production process are logged. Companies like the Italian SCM Group in our workshop and Zara in Box 2 do this already. This has a potential for resource management (Foresight, 2013). Also, predictive maintenance might have the potential to reduce resources – for example by responding more quickly to leaks (World Economic Forum, 2015). Interviewees and workshop participants have mentioned predictive maintenance as an important aspect of IIoT. At the 2017 Hannover Messe the example of predictive maintenance of printing machines was given. The data of each machine is analysed by the printing machine manufacturer to predict when maintenance is required and to learn from failures. Moreover, machines are serviced before anything gets broken – a form of servitisation – which reduces resources by preventing further damage or full replacement of the machine. Through a platform, all printing machines are connected and learn from the failures of others. Software updates are automatically pushed to the machines. Siemens is developing these kinds of platforms to constantly monitor and develop a fleet of intelligent machines. Servitisation in combination with IIoT thus creates incentives for longevity of machines and for efficient use of energy and materials.

The combination of IIoT with other game changing technologies, specifically Additive manufacturing, may further reduce the use of resources. Optimised production will then be combined with a very resource efficient technology: “With Additive manufacturing, such as in 3D printing, virtually no raw material is wasted, since the product is directly built by adding small layers of material.” (Van Houten & Scholten, 2016, p. 37). Indeed, the biggest potential for energy and resource efficiency lies in the combined technologies of Industry 4.0.

Impact of IIoT on work processes

The most often reported effects of IIoT on work processes are related to quality management and internal and external collaboration. We found no impact related to work timing and no specific information regarding the time horizon of these changes or regarding specific companies or industries.

IIoT is expected to enable better quality management due to more advanced analytics of the many data flows in the factory of the future. Potential performance issues can be actively prevented by analysing the data and acting if needed (Lee, Kao, & Yang, 2014). The data can also give insights in optimisation of jobs and tasks (McKinsey Global Institute, 2015) and optimisation of quality performance of complex products (Foresight, 2013). Thanks to all digital connections with machines and devices, machine malfunctioning and quality issues can be detected and resolved remotely by engineers (trouble-shooters), sometimes with assistance of colleagues on the factory floor (World Economic Forum, 2015; Foresight, 2013). Robotics can be controlled and programmed remotely, if necessarily (Foresight, 2013).

Internal and external collaboration will be somewhat differently with IIoT. There will be more external collaboration – as already discussed when we touched upon value networks – but also the internal communication between man, machine and product will increase (Brettel, Friederichsen, Keller, & Rosenberg, 2014). Closer cooperation is expected between employees and machines and between employees, customers and companies elsewhere in the value network: a “smart, networked world” (Acatech & Forschungsunion, 2013, p. 19). Data between departments needs to be freely shared, for example between the service department and product development department (McKinsey Global Institute, 2015).

With IIoT and mass customisation, the number of standardised processes will decrease, which necessitates more control and autonomy at the work floor level in order to make quick decisions and to react fast (Brettel, Friederichsen, Keller, & Rosenberg, 2014). Decisions will be taken less based on experience – as each product might be different – but will be assisted by intelligent systems that make use of centralised data and process models (Brettel, Friederichsen, Keller, & Rosenberg, 2014).

New work and organisation models are triggered by IIoT (The Boston Consulting Group, 2015; Friedrich-Ebert-Stiftung, 2015). As decision making is more directed towards the work floor, organisation models need to change accordingly. Companies need to adapt the work organisation to the information flow along production lines and value networks, resulting in better organisation and more transparency (Lee, Kao, & Yang, 2014).

Expectations of IIoT for the next ten years

The next ten years are most likely characterised by a process of transition to IIoT in a wide range of industries. It is unclear how fast this process will go. We have seen that some companies have applied IIoT concepts to a varied extent, while others have not applied any real IIoT at all. For the coming years, the variables will be how many components, products, activities, departments and organisations are ‘in’ the IIoT. Currently, larger companies seem to be more involved in this transition than SMEs are. However, to make a full transition the whole value chain needs to implement IIoT, including the SMEs supplying to large companies.

Many technologies underlying IIoT are available and received a lot of attention at the 2017 Hannover Messe. This clearly showed the interest of the industry. But the diversity of products also shows that standards still need to develop and some issues regarding interoperability need to be solved. This was also raised in interviews and during this study’s workshop, alongside data security.

The different business models enabled by IIoT do not seem fully developed yet. In the next ten years, these business models will develop more and unexpected new business models may be introduced. This will also affect work processes and the roles that workers will have in factories, including how they interact with the new technology.

Impact on work

The impact of IIoT on working tasks, skills and competences

The main skills for IIoT are ICT related skills, data and mathematics skills and equipment and machinery operation skills. We found no reference to other skills or competences. However, it might very well be that the transition towards IIoT would also ask for improvements or changes in other skills.

The changes in skills needs are illustrative for the associated changes in tasks of workers. For example, the pervasiveness of ICT tasks, also in non-ICT occupations, is associated with an increased need in (basic) ICT skills among workers at all levels in the manufacturing industry. These changing tasks have not much been mentioned in literature, but have been discussed with experts participating in this study's interviews and workshops. In this section, the discussions about tasks and skills are linked.

More workers with data and ICT skills will be needed: data scientists, statisticians, machine learning engineers etc. (McKinsey Global Institute, 2015). The Boston Consulting Group (2015) expects approximately 70,000 new jobs for industrial data scientists in Germany alone. The skills associated with current ICT jobs will be relevant, but up-to-date skills related to big data (manufacturing) analytics, privacy, security and user experience design will be highly important as well. (World Economic Forum, 2015) In the transition period towards implementing IIoT, additional IT managers and infrastructure specialists are needed (World Economic Forum, 2015). Furthermore, the IT skills of all workers need to be at least basic: "using spreadsheets and accessing interfaces" (The Boston Consulting Group, 2015, p. 10). This is relevant for all manufacturing industries and all manufacturing companies.

Changes in skills needs must be reflected in education and training. Digital skills need to be part of education on all levels. At the 2017 Hannover Messe, GE stressed the importance of these skills for all its employees. At GE, a global programme has been developed to teach its employees IT skills. Every new employee, from top floor to work floor, receives a basic IT training that includes learning to code. This helps them to understand how IT and IT-related processes work and gives them an understanding of the possibilities of IT. Acatech & Forschungsunion (2013) state that it is important that educators engage in a dialogue with the manufacturing industry to "ensure that the requirements of the digital economy are reflected in training provision" (Acatech & Forschungsunion, 2013, p. 55). We have seen for instance in Italy that such interactions take place (see Box 4).

Employees need to learn how to efficiently work with robots and need to have analytical skills (The Boston Consulting Group, 2015; Deloitte, 2015). Engineers and product designers need to learn to design and develop products in such a way that they are compatible with IIoT (McKinsey Global Institute, 2015).

Physical tasks, such as manual tasks, are expected to be reduced in manufacturing. Workers are still involved in manufacturing, but physical tasks become more and more assisted by machines or robots or will even be fully automated. Operators can work more remote – experts believe even from home – and have more machines or (complex) processes to operate, introducing more complexity in their work.

Social and intellectual tasks will become more important in the manufacturing industry. There will be more interdisciplinary collaboration between team members, but also between teams, between departments and between organisations. Value chain networks imply more (and more diverse) interactions within the value chain. More diversity of products increases interactions between different teams and (digital) interactions with customers. More complex technology often means more collaboration between different technical experts, operators and external service providers. At the same time, the increased complexity necessitates more intellectual tasks. These are related to problem solving (often technical) and creativity. The latter is for instance needed for the modelling of the more customised products. More flexibility is needed as well, as dynamics are expected to change in digital factories that are directly driven by unique, digital orders of customers.

Soft skills will also become more important. Employees need to be more flexible to deal with changes in roles, work and environments (also virtual environments) and to be willing to learn continuously – most importantly engage in interdisciplinary learning (The Boston Consulting Group, 2015; World Economic Forum, 2015). Decision-making skills, often based on data or supported by technology, will be important for many workers in the manufacturing industry, as decisions need to be made more often on the work floor (on-the-spot) (Acatech & Forschungsunion, 2013). Organisation and coordination in complex environments will also become an important skill, as mass customisation will make processes less standard and more complex (Acatech & Forschungsunion, 2013). Communication will become another important skill, as clear communication becomes even more important in complex environments (Acatech & Forschungsunion, 2013). Being closely linked to communication, cooperation will also become more important, be it both the cooperation between man and machines (robots) (Van Houten & Scholten, 2016) and between business partners (Acatech & Forschungsunion, 2013). In sum, abstract problem-solving skills, an initiative taking attitude and good organisation, communication and collaboration skills become increasingly important in the manufacturing industry (Acatech & Forschungsunion, 2013).

Upskilling and reskilling, of soft and hard skills, is important for many employees. Employees need training to stay updated or to broaden their knowledge, as multidisciplinary skills become increasingly relevant. For example, managers of multidisciplinary teams need to understand the technical processes and the data analytics and they need to be able to communicate effectively with people of very different backgrounds. Other skills that will become more important for management are new ways of (digital) customer interaction, changing business models and value chains/networks and different ways of work organising and work interactions.

Generally, with IIoT, management and operations of production processes becomes more decentralised, resulting in the need for an increased responsibility of employees in processes, more independent decision-making by employees and an increasing need to understand related processes to assess the impact of their actions on other parts of the processes. For that, leadership competences become more important as well as interdisciplinary thinking and working. This is relevant for designing and operating processes but also for problem solving.

Interviewees stress the importance of companies being involved in the identification of future skills needs. Industry should spend money and time to shape education to ensure that the workers of tomorrow are skilled for the industry's needs of tomorrow. Universities, for example, are still very much subject oriented and do often not reflect in their education the multidisciplinary that industry needs. Industry is said to be too little involved in shaping education and is not investing much in training or the educational system in general. At the same time, companies in several countries have experienced a deficit of engineers on the labour market. In this study's workshop, we have seen that industry, government and universities in the Italian region Emilia-Romagna indeed take action together to make sure that engineers are better skilled for the industry's needs (Box 4).

Box 4. An example of regional action to address skills needs related to IIoT: how regions struggle with the lack of engineers - an example from Italy

With IIoT there is still a clear need for engineers at all levels in the manufacturing industry, while currently many countries have a deficit of engineers. During this study's workshop in Italy this issue was stressed by all companies attending the workshop. Italy was said to deliver great engineering graduates, but there are simply not enough students to fulfil the current and future need for engineers at the middle and higher educational levels – including PhD level engineers.

IMA Group, a large Italian manufacturer of industrial packaging machines, said it invests substantially in training of its workers. This lifelong learning was considered important for employees to upskill and to stay up to date on current technologies, such as IIoT. Especially for Italy this was considered important, as it is still very common for Italians to work at a single company during their entire career.

Training specifically on topics related to IIoT has also been undertaken in the Italian region of Emilia-Romagna. For example, the regional industry association Confindustria ER has been involved in a project funded by the European Social Fund (ESF) in which over 3,000 managers and other workers took at least one module about Industry 4.0.

Regional universities, the University of Bologna and the University of Modena and Reggio Emilia, agree that there is a shortage of engineering PhDs in the region. Furthermore, they acknowledge that PhDs are often considered too theoretical for a non-academic career, lacking the right skills for industry. To close this skills gap, the regional universities, industry and government have funded together an industrial doctorates programme. In this programme industry has some influence on the topics for PhD students that are being educated at the fore-front of new technology development. The PhDs educated in this programme have a better balance between theory and practice, making them better suitable for the needs of regional industry.

In Emilia-Romagna, industry is involved in discussing adaptions to curricula through round tables with the local technological schools and universities. This should contribute to a better match of (technical) graduates' skills with the needs of industry. Participants to the workshop also stressed that collaboration between students, teachers and workers at different educational levels would be good. This could be through innovation projects and internships. Multidisciplinary collaboration is an important skill in future manufacturing with IIoT. Such collaboration projects with students provide learning opportunities for all involved and may promote working in manufacturing industry.

Source: Technopolis Group, 2017

Changing occupations in manufacturing due to IIoT

Regarding the impact of IIoT on the types of occupations, references were mainly made to ICT professionals and science and engineering professionals. The impact on other workers was hardly mentioned, although they might be impacted by IIoT as well.

One impact of IIoT on many workers is related to privacy. The digitisation of factories is associated with more data-collection of workers as well. Interaction between workers and machines may be logged and analysed. Sensors in the working environment may also collect information about workers. Being connected through the internet means data-exchange in- and outside the company. As analyses of this data may reveal information on workers, their privacy may be at stake. During this study's workshop this concern was raised, although the reviewed literature scarcely addressed such ethical issues.

On management level, IIoT introduces additional complexity and requires multidisciplinarity. With IIoT, business models, value chains and production processes change. This needs to be understood to some extent by management. Management teams need to be multidisciplinary to cover the various complex aspects of IIoT and need to have data literacy to understand processes. The role of ICT professionals and engineers is important at this level as well, as products, processes and their interactions become increasingly digital and technology dependent.

Generally, IIoT will put manual 'blue collar' work under pressure, as this is expected to be replaced to some extent by smart machines. At the same time, new employment opportunities will appear, such as employees who install and maintain sensor networks (McKinsey Global Institute, 2015). There will also be tasks that cannot be automated (easily) and will remain important, such as "system planning, engineering, exception handling, coordination and orchestration" (World Economic Forum, 2015, p. 22). The number of jobs in the fields of data science, IT and engineering will however grow (The Boston Consulting Group, 2015).

The examples of 247TailorSteel and Adidas, in Box 1and Box 3 respectively, illustrate the changes in work. Indeed, these 'smart factories' employ less people than traditional factories, but as more and smaller regional factories are needed, new jobs are created regionally as well. Moreover, the case of Adidas illustrates the reshoring of some manufacturing work to Europe – 160 people at the German Speedfactory. These include somewhat higher skilled and more creative jobs, for example on the modelling and shaping of the shoes. Instead, at 247TailorSteel some higher skilled jobs at the front and back office have largely disappeared. The work is now done at the work floor, where each machine is still accompanied by a worker who oversees and understands the full process in the factory – of which the machine is just a part – and who can solve problems if needed. The workers furthermore prepare the product for transport and take care of the disposal and reuse of waste. As such, 'blue collar' work has changed, asking for technical, creative and overview skills.

A shift of jobs is to some extent expected, perhaps with a net effect of zero additional or reduced jobs. Less workers will be partaking in the production process itself – especially manual work will be more and more automated. The roles of people at the work floor shift to process operation, processes assistance, trouble-shooting and quality control. More jobs will appear in the processes before and after manufacturing, such as designing, R&D, marketing, sales or leasing (servitisation), customer support, (predictive) maintenance and data analysis. More jobs may also appear elsewhere in the value chain, in processes such as software development, logistics, cloud computing and at other digital and technical service providers.

One group of workers is especially vulnerable in making the transition towards IIoT. One interviewee stressed that the group of workers who are currently in their forties needs special attention. These workers did not grow up with computers and the internet and had no digital skills training in their education, but had to make the ICT and internet transition later. This group of workers still has to work for 20-30 years before retirement and thus needs to make the transition to more digitalisation and connectivity in manufacturing processes. Younger groups are more digitally minded and older groups will retire before the (full) implementation of IIoT.

Security specialist may very well become a more common function in the manufacturing industry. Interviewees stressed the importance of security specialists to develop secure IIoT devices and or to set-up secure connections between devices in companies or between companies in value networks. Due to a lack of knowledge, many products currently have a weak digital security. With IIoT, digital business is more important and thus security specialists will become important to protect a company's business.

Interviewees expect more self-employed experts and small cooperatives of designers, developers, engineers and repair/maintenance experts. These self-employed experts will contribute to specific stages of the manufacturing process (such as design), specific phases of organisational transition (such as digitalisation and introduction of IIoT technologies) or specific activities (such as maintenance). This trend is to be expected for the mid-level and higher educated jobs or creative jobs. With mass customisation and digital interactions with factories, designers can work at home in small cooperatives to serve many companies with services as model creation and website design.

Regarding the impact on the characteristics of occupations, the literature review revealed changes in team work, routine tasks, problem solving and information processing. Changes in endurance/conditioning, strength or engagement of stakeholders are not mentioned in the reviewed literature. However, regarding impact on the characteristics of occupations, the literature was not very spot-on. Most often, slightly related or non-specific issues were mentioned.

Changes to working conditions due to IIoT

Impact on working conditions seems to mainly concern health and safety (including stress) and training and personal development, according to our literature review (see *Table **1***). For all Industry 4.0 technologies, including advanced manufacturing and advanced robotics, we see that these two are most often mentioned. Only a few references were made to work organisation, job quality, work-life balance and contractual arrangements. These observations were confirmed by participants to this study's workshop.

Table 1: References to changes in working conditions for IIoT and Industry 4.0 at large

Changes in working conditions	**Number of references for IIoT**	**Total number of references for all Industry 4.0 technologies**
Health and safety including stress	17	38
Training and personal development	15	43
Work organisation	4	8
Job quality	3	7
Work life balance	3	6
Contractual arrangements	2	4
Total	*44*	*106*

Source: Technopolis Group, 2017

Training and personal development will be important for the introduction of IIoT; people need to be trained and retrained to keep pace (The Boston Consulting Group, 2015). These training programmes need to be tailor-made, as IIoT is associated with a very wide range of potential applications (Acatech & Forschungsunion, 2013). This would suggest more importance of on-the-job-training (Deloitte, 2016a).

IIoT has the potential to improve the health and safety of employees, as work becomes less dangerous. Sensors can be used to increase the safety of employees by making those sensors wearable and connected with other systems (World Economic Forum, 2015). Less safe procedures can be done by smart systems and machines to reduce the exposure of employees to – for instance – loud noises and hazardous materials (World Economic Forum, 2015). McKinsey Global Institute (2015) calculated that IoT technologies can cut insurance costs with 10-20% by preventing accidents and injuries with sensors and tags on employees and equipment. An example is that potentially dangerous equipment shuts down automatically when a sensor detects that an employee gets too close (McKinsey Global Institute, 2015). According to McKinsey Global Institute (2015), reviewing an IoT pilot: “By limiting exposure to harsh conditions and ensuring that employees are getting the rest they need, the initiative reduced sick time from 7 percent of employee hours to 4 percent” (p. 79). All in all, a better working environment is expected (Lee, Kao, & Yang, 2014).

Interviewees however state that it is important to invest in the safety of new IIoT processes. Robots and other smart machines will co-work with humans. This interaction should be in a safe manner.

Job quality may be affected by the increased virtualisation of work. The tension between the virtual world and real world may result in workers “experiencing a loss of control and a sense of alienation from their work as a result of the progressive dematerialisation and virtualisation of business and work processes” (Acatech & Forschungsunion, 2013, p. 53). On the other hand, the quality of work may increase due to offloading employees from the more physically demanding and dangerous tasks, while giving them more room for human added value in creative and social tasks (Van Houten & Scholten, 2016). Teleworking and flexible work organisation models may contribute to a better balance between employees’ work and private lives (Acatech & Forschungsunion, 2013). More people will be able to work from home, giving them more flexibility in personal and family life.

However, interviewees notice that virtualisation, digitalisation and automation may make work less social and may reduce autonomy for some employees. Fewer colleagues in production processes and increased interaction with machines weaken the social context of workers – although depending on the work organisation. Smart machines will take over more responsibility of some workers. Some workers that currently partake in processes may receive instructions from machines (via interfaces), reducing their autonomy. The control of systems over these workers and their tasks may even give rise to a feel of alienation. On the other hand, other workers may provide smart machines information and thus have autonomy over the process. Machines may remove some intellectual tasks from processes, for example by indicating what the most optimal procedure may be and as such remove the freedom to use own preferred procedures. In the end, some manufacturing workers will experience more challenging intellectual work (overseeing processes and instruct machines), while others will be confronted with less challenging work (part of processes and being instructed by machines). This may create a new divide among manufacturing workers.

Contractual arrangements may change due to the introduction of the earlier mentioned value networks of companies and role of self-employed experts, although literature does not explicitly address the impact thereof. Work organisation might change due to teleworking and automatically optimised production processes – that may change often due to the customisation of products. Work organisation will at least be more flexible than nowadays and be improved by smart assistance systems (Acatech & Forschungsunion, 2013). These systems may also contribute to organising work in such a way that both the requirements of companies as well as those of employees can be fulfilled, which may improve the work-life balance of employees (Acatech & Forschungsunion, 2013).

We have found no literature about the responses of social partners to changes in working conditions, occupational demands and skills needs, driven by IIoT.

Actions and strategies

The actions and strategies regarding IIoT that were found in this study mainly concerned technologies and their applications. Public and private partners are involved in platforms and clusters that focus on IIoT and related technologies, such as Industry 4.0 in Germany, Fabbrica Intelligente in Italy and Smart Industry in the Netherlands. The impact of work in terms of working tasks, skills, competences, occupations and working conditions has hardly been addressed in such platforms. Education and training were discussed, albeit at a high level of abstraction.

Interviewees mentioned that in many countries, social partners such as trade unions are not very active in discussions about the future labour market effects and the skills needs in manufacturing, due to IIoT. In that sense, trade unions are not well-prepared for IIoT, even though they can be an important partner in these discussions. Some social partners have tried to bring the discussion to the attention of their members, without much success. For many, the urgency is not there, as the developments are not that visible yet – digitalisation is sometimes only ‘under the hood’. It will become however more visible and prominent in the coming years. Involvement in discussions is however seen in European countries with a strong manufacturing sector, such as Germany and Italy. In Germany, Industry 4.0 is a big theme driven by the large domestic manufacturing industry. Trade unions, industry, governments and knowledge institutes collaborate around Industry 4.0 themes. In the Netherlands industry associations have taken a role within the national Smart Industry initiative, but still with limited urgency.

Some interviewees said that industrial partners should collaborate (more) to make sure that changes in the curricula of education and vocational training institutions meet (emerging) skills demands of employers. A combination of STEM and transversal skills, such as ’learning skills’, has been mentioned in interviews to be relevant at all educational levels. Training in manufacturing processes is however expensive. At the 2017 Hannover Messe, several new virtual technologies for these kinds of trainings have been exhibited. For instance, with a Virtual Reality headset and connected controllers, students can construct and deconstruct every element of a complex machine in immersive 3D to understand its working and the effect of removing parts. Industry could invest in such digital technologies to help (new) employees and students understand the complex processes at factories and the operating of machines without disturbing actual production processes.

Privacy of employees is an issue that needs to be addressed when further digitising manufacturing industry. This issue has also been raised in a report, for the European Parliament, about the ethical impacts of cyber-physical systems such as IIoT (Van Houten & Scholten, 2016). With IIoT, robotics and big data, production systems collect lots of data about the actual behaviour of individual workers. This data collection does not include just the performance of workers, but may possibly also include health related and body specific information. Two or three companies in Italy (Emilia-Romagna region) are already proactively asking employees whether they want to know if the sensors in production systems have identified (minor) health risks such as those revealed by fluctuations in body temperature, heart rate and awareness. In a digitally networked factory with sensors everywhere, privacy of employees (and even visitors) must be guaranteed.

While discussions around IIoT (and robotics) are often focused on the threats for low-skilled jobs, IIoT has also a potential to improve inclusion of low-skilled or disabled workers in manufacturing. This positive contribution to work and workers is studied in an EU research project, in which Italian public and private organisations from this study's workshop are involved.

Box 5 gives more information on this collaborative project. This example shows that it is good to involve public and private partners in exploring also the positive potential of new technologies for workers.

Box 5. Example of actions by public and private partners to address the impact of IIoT on workers: collaboration on making the manufacturing industry more inclusive with IIoT

The INCLUSIVE project is an EU funded Horizon 2020 project in which smart and adaptive interfaces in the manufacturing industry are studied to contribute to a more inclusive work environment. The goal of the INCLUSIVE project is "to develop methodologies and technologies to include all the individuals with their background and cognitive capabilities in a smart [i.e. IIoT] working environment, making easier the interaction with complex machines." (INCLUSIVE Project, 2017) Several organisations participating in this study's workshop in Italy are involved in this project, including the University of Modena and Reggio Emilia, SCM Group and ASTER. Partners from several other European countries contribute to the study as well, making it a truly European effort.

With IIoT, manufacturing systems are becoming increasingly complex, while workers still need to interact and supervise these systems. Workers interact with machines through interfaces – therefore called Human-Machine Interfaces (HMI) by scientists – that become complex and often require some ICT skills. Some workers may experience difficulties working with these interfaces. Especially middle-aged workers, young inexperienced and disabled people are targeted in the INCLUSIVE project as groups that are likely to experience difficulties.

The INCLUSIVE project works on developing new concepts of interaction between workers and machines. Smart interfaces that adapt to the capabilities of the worker that operates the machine are being developed. This should make the IIoT factory floor more inclusive to groups of workers that experience difficulties in interacting with (digitally) complex machines.

Source: Technopolis Group, 2017

Concluding remarks

The Industrial internet of things (IIoT) is a true game changer in the manufacturing industry. It puts data at the heart of manufacturing processes and it digitises factories. This transition is just staring and is expected to impact many aspects of the manufacturing industry in the next ten years. These impacts extend beyond technology and production processes; they also concern value chains, business models, work and workers themselves. These concluding remarks address the key findings of this study with some reflection and an outlook.

A main change that IIoT enables is mass customisation and servitisation as new paradigms for products and services. Mass customisation enables customers to digitally order unique products that may even be designed by the customer itself, at prices similar to off-the-shelf products. The manufacturer digitally receives the order after which digital systems plan production, arrange inventories, prepare the production process and manage logistics – an optimised process that includes interactions with value chain/ network partners. This is clearly a change in manufacturing, of which only a few examples exist to date. Servitisation uses the data that products or processes produce to add additional services to products, such as predictive maintenance services. These services are sold to customers, while the product may be leased. Such services change business models in manufacturing fundamentally – shifting focus from product to service – and may benefit factories by reducing downtime and as well as shifting risks to equipment suppliers.

Value chains become value networks and manufacturing will be distributed. Due to IIoT, companies are expected to interact differently: digitally and in networks. The whole value network should be aligned and act fast to optimise manufacturing processes and to be able to quickly supply customised products to clients. To survive in such a value chain, SMEs need to adopt IIoT. New platforms of interaction with customers may appear and manufacturers will be closer to customers. This enables them to deliver quickly – reducing logistics – and better interact with customers. Smaller, distributed factories focusing on flexibility and production capabilities are expected to appear. Combined with customisation this provides potential for reshoring, as manufacturing will be done more regionally.

The digitisation of manufacturing with IIoT introduces complexity and changes skills needs. ICT skills will become very important for every employee – from the top floor to the work floor. More engineers, IT, data and security experts will be needed for future manufacturing, although these vacancies are already hard to fill. Physical tasks will become less important, as they will be assisted by machines or fully automated. Instead, social and intellectual tasks will become more important. Communication skills and being able to interact in multidisciplinary teams and contexts is important – making T-shaped professionals valuable. Creativity skills (such as for modelling processes) and decision-making skills will be important as well.

Although IIoT indeed will put some work floor jobs under pressure, other jobs will appear. Manual production work may disappear, but jobs in process operation/guidance and quality control appear. Jobs shift. More jobs are expected before and after production: designing, data-analysis, marketing, sales/leasing etc. Creative and technical professionals may be more self-employed and working in small cooperatives. Discussions about effects on working conditions need to be held, but should also focus on the opportunities. For instance, IIoT may contribute to a better health and safety of employees and to a more inclusive workforce, as is currently studied in the INCLUSIVE project.

Although IIoT will have clear impacts in the manufacturing industry, social partners such as trade unions and industry associations have not been very active in discussions about the impact of IIoT on work. Public-private platforms on IIoT or related concepts exist in many European countries, but mainly focus on the technologies and their applications. Collaboration on understanding and influencing the wider impact of IIoT would be good. Given the future skills needs and the importance of engineers, it is important that industry, education and training providers (public and private) discuss curricula. Companies should invest in training for up- and reskilling of employees, specifically for those employees that grew-up in a pre-computer era.

The expectations of IIoT for future manufacturing are high and literature and experts are positive about the potential of IIoT. However, it remains to be seen how the future develops – and at what pace. Especially the fact that whole value chains need to change and need to be compatible with IIoT to reap the full benefits of this game changing technology, may be challenging and may take many years. Business models still need to be further developed and tested. Many SMEs are still reluctant to make the change. Safety, security and interoperability issues are not yet solved. Digital interactions throughout value networks are not yet (fully or optimally) in place. Literature and technologists are often optimistic – which is important, but there are still many hurdles to take.

For the same reasons, statements about the impact of IIoT on work are based only on expectations expressed in literature or by experts. Only a few cases have demonstrated the effects on work. See the examples of 247TailorSteel and the Adidas Speedfactory discussed in this report. Information about the impact on work is very much qualitative and often not very specific. Time horizons are generally missing. Academic reports on the topic are scarce. Further research could focus on specific industries and value chains and/or on pilot factories.

The next decade is crucial for further developing and applying IIoT. This development should be 'responsible' and involve discussions about the impact on tasks, occupations, skills needs and working conditions. These discussions should engage industry, governments, trade unions and research and education institutes.

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Appendix A : Research questions

1. What aspect of new technologies can be considered game changing to the manufacturing industry?
2. In what area of the industry are technologies entering into the manufacturing process?
3. What drivers and motives of enterprises shape the uptake of these technologies in the subsectors of the European manufacturing industry?
4. How likely is the increase and uptake of the technologies within manufacturing?
5. To what extent are the five technologies changing processes within the value chain?
6. How are these technologies affecting the demand for materials and products required within the European manufacturing industry?
7. In what way does the adaptation of the technologies impact work processes within the industry?
8. How are these impacts likely to expand and evolve in the next ten years?
9. How are the technologies changing employment, notably in terms of:
   - The need for new skills and competences
   - Increased demand in existing skills and competences
   - New occupation development
   - Increased demand of existing occupations
10. How are the (potential) changes caused by the technologies affecting working conditions in terms of job quality, contractual arrangements, health and safety and work organization?
11. How are social partners responding to and preparing responses to the changes in working conditions, occupational demands and skill needs?

Appendix B : Interviews

Expert	**Organisation**
Mr. Ulrich Ahle (D)	Head of Manufacturing, Retail & Services at Atos IT Solutions and Services and CEO FIWARE Foundation
Mr. Richard Foggie (UK)	Knowledge Transfer Manager IoT at the Knowledge Transfer Network and member IoT Special Interest Group of Innovate UK
Prof. Ben van Lier (NL/D)	Director Strategy & Innovation at Centric, professor at Steinbeis University Berlin and professor at Rotterdam University of Applied Sciences
Mr. Saverio Romeo (UK)	Chief Research Officer at Beecham Research and Research Associate at the University of Oxford
Prof. Egbert-Jan Sol (NL/EU)	Vice President of the European Factories of the Future Research Association (EFFRA), CTO TNO Industry, Professor Radboud University Nijmegen and Director programme office Smart Industry
Mr. Roland Sommer (A)	Director of the Industry 4.0 Platform in Austria

Appendix C : Workshop participants

Expert	Organisation
Francesca Bergamini	Emilia-Romagna Region (government)
Claudio Biasetti	Cisita Parma (education/training)
Leda Belogni	ASTER (regional agency)
Gildo Bosi	SACMI (company)
Franco Gallegati	University of Bologna (research)
Rita Cucchiara	University of Modena and Reggio Emilia (research and education)
Maria Grazia D'Angelo	ASTER (regional agency)
Cesare Fantuzzi	University of Modena and Reggio Emilia (research)
Carmen Galassi	CNR ISTEC (research)
Stefano Golinelli	SACMI (company)
Giuseppe Lucisano	SCM Group (company)
Lucia Mazzoni	ASTER (regional agency)
Dario Rea	IMA Group (company)
Luca Rossi	Confindustria ER (entrepreneurs association)
Sergio Sangiorgi	Unveil Consulting (work psychologist)
Maddalena Suriani	ITS Maker (education/training)
Elisabetta Toschi	ASTER (regional agency)