



Industry 4.0

Background Paper on the pilot project
“Industry 4.0: Foresight & Technology Assessment
on the social dimension of the next industrial revolution”

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Vienna, November 2015

Institute of Technology Assessment (ITA)
Austrian Academy of Sciences

AIT Austrian Institute of Technology GmbH
Innovation Systems Department

Project leaders: Georg Aichholzer (ITA) and Matthias Weber (AIT)

Authors: Georg Aichholzer (ITA)
Wolfram Rhomberg (AIT)
Niklas Gudowsky (ITA)
Florian Saurwein (ITA)
Matthias Weber (AIT)

Literature research: Gloria Rose

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Owner:

Austrian Academy of Sciences
Legal person under public law [BGBl 569/1921 idF BGBl I 130/2003]
Dr. Ignaz Seipel-Platz 2, A-1010 Vienna

Editors:

Institute of Technology Assessment (ITA)
Strohgasse 45/5, A-1030 Vienna
www.oeaw.ac.at/ita

AIT Austrian Institute of Technology GmbH
Donau-City-Straße 1, A-1220 Vienna
www.ait.ac.at

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Summary

Industry 4.0 – Great Hopes and High Uncertainties

The term Industry 4.0 is used to describe an emerging fourth industrial revolution (related notions in the international discourse are Industrial Internet, Internet of Things or Smart Production). After the mechanisation of production through the emergence of steam and hydroelectric power (Industry 1.0), the electrification, and with it Taylorism (assembly line production – Industry 2.0), soon followed. These developments were then succeeded by the arrival of automated mass production through electronics and numerical control (Industry 3.0). The fourth phase, Industry 4.0, is defined by digital, intelligent, networked and largely self-managing production achieved through the union of production techniques, information technologies (IT) and the Internet.

*Networked
self-managing
production*

Industry 4.0 conveys the hope of being able to stop or reverse the decline of the industrial share of Europe's economic output. Presently, the industry sector only contributes to around 15% of Europe's economic output. In comparison, Austria can be counted among the industrially stronger nations with its industry making up 19% of economic output.

*Re-Industrialisation
of Europe?*

The value of industry, however, goes far beyond its immediate role in economic output. Industry creates the basis for many high value-added services. In addition, countries with a strong industrial core have shown themselves to be more resistant to the crises of the past few years. Taking this into consideration, the European Commission has formulated the goal of re-industrialising Europe. In order to achieve this goal, European countries must succeed in promptly investing and adapting to the dynamics of global demand markets and the increasing individualisation of products and services.

The rapid digitalisation and networking of production is creating a dynamic which allows Austria and other European countries the potential of successfully returning to the path of industrialisation. This development is currently in an early stage, with Germany being considered a forerunner. When viewed globally, the USA and China are also introducing important strategic initiatives for the advanced digitalisation of production.

*Important players:
Germany, USA and China*

This new phase of industrialisation and automation is perceived within public debate as holding large new opportunities. There are, however, considerable challenges which should not be overlooked if Industry 4.0 is to be an economic success as well as a social one. The effects of Industry 4.0 can be very far-reaching, touching upon areas such as the labour market, the educational system and changes on a societal level. Social consequences, such as income opportunities and unemployment, must therefore be considered. Furthermore, security, power requirements and the environment could be affected, as well as contextual factors such as business locations and regulatory framework (e.g. labour law, information privacy and questions of liability).

*Various social and
economic consequences*

Digital Network of Things and Services – Cyber-Physical Systems (CPS)

*Objective:
Increasing productivity
and efficiency*

The basis of Industry 4.0 is formed by interconnected, self-optimising production systems capable of working in real-time. These systems blur the lines between the areas of production, services and consumption, changes which can also be expected on the individual levels between work, consumption, services and production. Businesses are to be connected through direct and automatic data flows in real-time, transmitted through digital networks. Cyber-Physical Systems (CPS) will organise this network of things and services through the Internet (giving rise to the notion Industrial Internet). These virtual systems support interactions and communication, and “merge” physical and digital systems to form a cohesive, seamless and flexible value-added network. The main objective is the seamless horizontal and vertical integration of process steps and hierarchies in order to increase productivity, resource efficiency, quality and flexibility.

*Production systems
gain autonomy*

In its final expression, Industry 4.0 represents a highly autonomous, self-configuring, sentient people, machines, facilities, robots, logistics systems, equipment and sensor-based production system. Within this production system materials all communicate through embedded hard- and software, Internet-based wireless technologies, as well as through new interfaces. Machines and equipment should ensure that individual customer requirements are efficiently met through skillful self-organisation. Work processes interact with each other independently and steer the required materials to the right place.

*“Intelligent” products
aid in their own
production*

“Smart Products” arise next to the emergence of “Smart Factories” and are capable of actively supporting the manufacturing process through their “knowledge” about their own manufacturing process and future use. They are capable of informing machines about their current state and will be fitted with an artificial biography to inform about their history, current state and target state.

Positive economic effects are anticipated ...

*Expectations vary
depending on industry*

In practically all branches of industry, one can recognise potentials for positive economic effects of Industry 4.0, although expectations vary from branch to branch. According to a survey of industrial enterprises in Germany for example, the expected sales growth in industries with complex (discrete) products and versatile customer specifications such as the automotive industry, mechanical and plant engineering, the electrical/electronics industry and the ICT industry, were significantly higher than expectations in process manufacturing.

*A challenge also
concerning SMEs*

So far, the concept of Industry 4.0 appears to be a central topic primarily for large international leading companies. However, the question remains the same for SMEs as to what extent digitalisation of their products and services and the integration of their value chains will play a deciding role for economic success.

Positive expectations arise partly due to cost reductions for resources (financial, human, and material), which are, however, faced with high initial investments. Additionally, it is expected that with Industry 4.0 the optimisation of efficiency and productivity takes place continuously within the company, as well as throughout the entire value chain. Competitiveness of high-wage countries such as Germany and Austria is expected to rise through individualised production, flexibility and high quality standards. Digital networking also opens up new opportunities for novel business models and services.

*Cost reduction
– but high initial
investment*

... but there are high uncertainties regarding other effects

Despite the euphoria surrounding the possibilities promised by the concepts of Industry 4.0, there is a high degree of uncertainty with regard to other effects which might be entailed by implementation:

- The impact of Industry 4.0 on *employment*, both in quantitative and qualitative terms, is without a doubt one of the most controversial. To this day it is unclear whether Industry 4.0 can stop the breakdown of industrial jobs, or if it will even accelerate the process, as an increase in efficiency in regard to labour is also anticipated. In some sectors the reduction of simple manual activities is expected, while a qualitative enrichment of work tasks is also considered possible.
- In regard to *work organisation*, Industry 4.0 enables large leeway for companies. A broad range of different models of work organisation are expected through Industry 4.0, described by two poles: the polarisation of tasks, skills, and manpower (polarised organisation) and a maximum of openness and flexibility based on the high qualification of employees (swarm-organisation). The design of collaboration between humans and machines can have spill-over effects on flexibility and working hours, and can redefine the relationship between autonomy and delimitation of demands regarding time and effort.
- Industry 4.0 introduces the challenge of new requirements for *education and training* as well as for qualifications of employees. In order to master complex manufacturing processes and control data-driven processes and business models, new skills and qualifications are required; this entails new challenges for educational contents. One of the main challenges identified for Industry 4.0 is a possible shortage of adequately skilled workers for the introduction and operation of the new production systems, raising the question of consequences for individuals with low qualifications.
- Generally the use of CPS increases the degree of automation, and physically demanding tasks can be transferred to machines. In this respect, Industry 4.0 can contribute to avoiding negative *health and welfare* consequences for workers. New health risks are as of yet poorly understood; greater intensification of work and higher responsibility could lead to higher psychological strain.

*Challenge of
employment*

*Challenge of
work organisation*

*Challenge of
education*

*Challenge of
health and welfare*

<i>Challenge of resources</i>	<ul style="list-style-type: none"> ● Despite the high degree of uncertainty of estimates, more efficient <i>use of resources</i> is considered to be one of the most persuasive arguments for Industry 4.0. While one can expect a positive effect with respect to the use of materials, the anticipated consequences for the workforce are ambivalent.
<i>Challenge of competitiveness</i>	<ul style="list-style-type: none"> ● With regard to <i>economy and competition</i>, numerous positive effects are expected as a result of improved resource efficiency, higher flexibility and new digital business models. However, the increasing decentralisation in flexible value chains also entails problems concerning control, which are not yet fully understood.
<i>Challenge of security</i>	<ul style="list-style-type: none"> ● Digital <i>security</i> is recognised as being an important and critical success factor, however, it has to be regarded as a largely unresolved issue. Besides the technical safety aspects of networking and automation, the lack of security awareness and lack of acceptance of cyber security solutions are considered to be important starting points for improving the security and safety of Industry 4.0 processes.
<i>Challenge of standardisation</i>	<ul style="list-style-type: none"> ● The requirements for horizontal and vertical networking are clearly defined <i>technical standards</i> to ensure a seamless exchange of information between machines, systems and software. The establishment of such standards therefore determines the possibility and speed with which Industry 4.0 concepts can be realised.
<i>Challenge of regulation</i>	<ul style="list-style-type: none"> ● Industry 4.0 raises new questions regarding legal frameworks and <i>regulations</i>. Existing regulations could prove to be barriers. A need for new regulations could also arise in order to provide legal certainty for Industry 4.0 or to reduce upcoming new risks. Key areas in need for modifications are liability, privacy and labour laws.
<i>Consider high expectations with caution</i>	<p>The high expectations that are connected with Industry 4.0 in relation to the objective of re-industrialisation have to be considered with caution in the light of various secondary effects. In addition it should be clear that it is not about the question if Industry 4.0 concepts will shape the economy of the future, but in the face of global development dynamics, it is about the question of how and with what strategic targets and accompanying measures we wish to pave the road towards Industry 4.0.</p>
<i>Which development of Industry 4.0 do we wish to pursue?</i>	<p>In order to develop a guide for such design and policy-making processes, in-depth analyses are required for certain spheres of impact in order to better estimate the range of possible impacts, opportunities, risks and options for action. This concerns especially the following topics:</p>
<i>Certain spheres of impact require in-depth analyses</i>	<ul style="list-style-type: none"> ● New business models and impact on value chains and SMEs, ● Labour and employment, ● Education and training, ● Safety and security <p>Based on this, policy options should be developed for a long-term socio-compatible design of Industry 4.0.</p>

1 Introduction

1.1 Why Industry 4.0?

The ability to generate products with international competitiveness and to achieve productivity growth is central for the economic growth of an industrialised and knowledge-based country such as Austria. Moreover, Europe's economic future is closely linked to the success of its industry. The manufacturing sector still represents an indispensable basis for employment and value added in 21st century Europe. This is reflected in the aim of the EU Commission, formulated in 2012, to raise the value-added share of the manufacturing sector on the EU-level from an average 15% to 20% in order to promote the re-industrialisation of Europe.

With a share of almost 19% of total gross value added in Austria, the Austrian manufacturing sector (NACE C level) lies above the EU average of 15% concerning its significance. When regarding Western European countries, Germany has the largest industrial share of national value added with around 22%, followed by Austria and Switzerland (19%). Only Eastern European countries such as Poland, the Czech Republic, Slovakia, Hungary and Slovenia show similar or even higher industrial shares. In comparison, economies such as France, Spain, Portugal, Great Britain and the Netherlands have significantly lower industrial shares.

Essentially, to this date only Germany and the Eastern European countries have managed to increase their industrial share since the financial and economic crisis, making the manufacturing sector an engine of national economic development. The value share of the manufacturing sector of other Western European countries, including Austria, have stagnated since the crisis year 2009, or have fallen even further (e.g. in Finland and Sweden).¹

The economic strength of Austria is highly dependent on the manufacturing sector and thus the industry. In 2012, companies in the Austrian manufacturing sector generated 48.3 billion euro in gross value added with a total of around 616 thousand employees. Thus nominal value added is at the same level as before the crisis broke out in 2007, while the number of employees is lower by 3.4%.²

Austria's prosperity is also dependent on its industrial exports and international economic relations. The export share of the manufacturing sector is more than 60%. Germany is by far the most important foreign trade partner, followed by Italy, the USA, Switzerland and France. However, Eastern European countries, Russia and China also play an important role in the economic relations of Austrian export enterprises. Manufacturing and service industries are closely intertwined with every job in industry creating more jobs in upstream and downstream services.

Our economic future is closely linked with development of industry

Re-industrialisation of Europe

Manufacturing as indispensable basis for value creation

Industrial employment is lower than before the financial crisis

Industry as a key factor for export and employment

¹ Source: Eurostat database

² Source: Statistik Austria database

<i>Individual products and services</i>	The ambitious goal of re-industrialising Europe is only feasible if the European countries and industrial companies succeed in promptly adapting to the dynamics of global demand markets and the increasing individualisation of product and service offerings as well as making appropriate investments. The necessary adaptability requires a high degree of flexibility in the provision of services as well as high versatility in technologies, processes, resources and structures. The manufacturing of products in Europe is exposed to strong pressures regarding costs, and therefore efficiency and productivity.
<i>Increasing flexibility and productivity</i>	

1.2 Re-industrialisation with Industry 4.0

<i>Digitalisation of production</i>	On the road to the re-industrialisation of European business locations and international competitiveness, high hopes are placed on digitalisation and the thorough networking of the industrial value-adding process, a development which has recently been referred to as “Industry 4.0” and conceptually originates from Germany. Industry 4.0 (in short I 4.0) is currently being intensively discussed in the light of a possible fourth industrial revolution and is perceived as a great opportunity, as well as a great challenge, for the industry and production sites in industrialised countries.
<i>Networked</i>	The vision of I 4.0 consciously differs from previous automation concepts in that it strives for a qualitatively new level of automation in production. The basis for I 4.0 is formed by networked, real-time capable and self-optimising production systems. These systems shift the lines between the areas of production, services and consumption as well as between labour, consumption, services and production on an individual level. Direct and automatic data flows are meant to connect businesses in real-time through digital networks. This networking of things ³ and services is coordinated by so-called cyber-physical systems (CPS) and is intended to take place over the Internet. These virtual systems support the interaction and communication and “merge” physical and digital systems into a cohesive, seamless and flexible value-added network. The overarching goal is the seamless horizontal and vertical integration of processes and hierarchies for the purpose of increasing productivity, resource efficiency, quality and flexibility.
<i>Self-optimising</i>	
<i>Real-time capable</i>	
<i>The design of CPS has consequences for production and employees</i>	The modelling and design of such CPS and their system architectures are deciding factors in how I 4.0 networking solutions will be embodied in practice and what consequences this may have on the workforce and future labour.

³ The connection of physical objects via a digital network structure is referred to as the „Internet of Things“ (IoT). The Internet no longer solely consists of human participants, but also of things. This creates a large potential for new Internet services for commercial or private users.

1.3 Diverse Impact Dimensions

The development of production and process technologies as well as information and communication technologies in the context of I 4.0 is central to securing business locations and social welfare from a European and Austrian perspective. In addition, positive effects for the environment as well as resource and energy consumption can be anticipated. In current debates, the far-reaching social effects of I 4.0 are becoming more prominent. From a wide-scale introduction of integrated production systems a lasting change of organisational and working structures is to be expected with significant impact on several levels.

Far-ranging impact

At company level, it concerns the interplay between technological innovations, the necessary standards, interfaces and safety requirements and the related staffing and organisational changes. The latter applies mainly to work organisation, staff deployment, qualification requirements and job profiles, both on a qualitative as well as on a quantitative level. The impact at the inter-company level concerns changes within the entire value chain, standards, security issues, planning, production, logistics and transport, that is to say changes in company alliances and inter-firm relations, including branch structures. At the societal level, the labour market and (vocational) education system are directly affected, which could lead to possible associated social impacts (e.g. income opportunities, unemployment). Moreover, impacts on dimensions such as security, energy consumption and the environment are to be examined, as are contextual factors such as location and regulatory frameworks (e.g. labour law, privacy and liability issues).

*Various changes
in diverse spheres
of impact*

To ensure a long-term and sustainable development of I 4.0, the following issues must be addressed:

- What consequences are to be expected at the company, inter-company and societal level through the implementation of I 4.0?
- What unintended and potentially socially undesirable consequences could certain I 4.0 developments entail?
- In which areas is there a need for political action?
- What are desirable futures for I 4.0 from the perspectives of different actors?
- What preferences for development options can be identified for different actors?
- What governance processes and (RTI) policy instruments are suitable to plan and design the long-term development of I 4.0?

*Design for sustainable
development*

1.4 Objective of this Paper

Assessment of impact and design options

The ongoing “pilot project Industry 4.0” for the Austrian Parliament investigates design options for the conceptual development and practical implementation of I 4.0. It aims to estimate the impacts on different levels of society and initiate a discourse between different actors and stakeholders to explore different expectations, needs, and innovative pathways. Based on this, policy options for the long-term socio-compatible design of I 4.0 are to be outlined, having the Austrian Parliament in mind.

Basis for an in-depth analysis of two spheres of action

This background paper serves as a basis for a first workshop with the parliamentary project advisory board and to enable an informed decision on which two impact areas should be chosen to be analysed in greater detail later on. Central impact dimensions (opportunities and risks), controversial topics and related challenges are to be discussed based on the characterisation of I 4.0 and the associated objectives and user expectations. Particularly the situation in Austria is to be covered in light of international developments. Finally, an initial conclusion will be drawn regarding the subjects or spheres of impact to be identified by the parliamentary advisory board as being of particular interest for an in-depth analysis.

2 Characteristics of Industry 4.0

The term Industry 4.0 is used to describe the fourth industrial revolution. After the mechanisation of production through the emergence of steam and hydroelectric power (Industry 1.0), the electrification, and with it Taylorism (assembly line production – Industry 2.0) soon followed. These developments were then succeeded by the arrival of automated mass production through electronics and numerical control (Industry 3.0). The fourth phase, I 4.0, is defined by digital, intelligent, networked and self-managing production, achieved through the union of production techniques, information technologies (IT) and the Internet. This will usher in a new phase of industrialisation and automation, bringing forth great opportunities as well as challenges.

The term “Industry 4.0” was coined in Germany and was defined as a future-oriented project during the formulation of the German High-tech-Strategy in 2012. The German platform “Industrie 4.0” promoted the project and was carried by three company groups consisting of BITKOM, VDMA and ZVEI until early 2015. Since then, it has been placed on a broader political and societal base (see also Chap. 5.2). There are 14 renowned German leading companies represented in the steering committee of the platform.

It is no coincidence that the concept of an integrated and self-controlling network of industrial value chains on the basis of the “Internet of Things and Services” is rooted in Germany, as Germany defines itself as the “factory supplier for the world” and boasts a strong industrial sector in which the latest production technologies are being developed and applied worldwide.

Other European and non-European industrialised countries next to Germany, as well as the European Commission, are recognising the development and application of new, increasingly networked production and process technologies as a strategic challenge for the future of industrial production. Hence terms like “Smart Production”, “Digital Manufacturing”, “Industrial Internet”, “Les Usines du Futur” or “Smart Industries” are internationally being used analogue to “I 4.0” to describe technology paths which enable a new form of industrialisation on the basis of intelligent, digital networks and new production techniques (cf. Davies 2015; Evans & Annunziata 2012).

In essence, I 4.0 is about a new quality of production technology and combinations of information and communication technology. Presently, IT systems already form the core of every production system, which will however be much more closely networked through the Internet in the future. Machine-to-machine communication can autonomously exchange information, trigger actions and control systems in global networks.

In its final expression, I 4.0 represents a highly autonomous, self-configuring, sensor-based production system. Within this production system people, machines, facilities, robots, logistics systems, equipment and materi-

The fourth industrial revolution

Fusion of production technology, information technology and Internet

Industry 4.0 – German term for a worldwide trend

Promoters from the outset: associations and leading companies

Strategic challenges of industrial manufacturing

Machines learn to communicate with each other

Production systems gain autonomy

*Value added in
intelligent factories
and networks*

als all communicate through embedded hard- and software, Internet-based wireless technologies, as well as through new interfaces. Machines and equipment should ensure that individual customer requirements are efficiently met through skillful self-organisation. Work processes interact independently with each other and steer the required materials to the right place.

I 4.0 takes place in so-called “Smart Factories”, intelligent factories which work in tightly knit and highly complex value networks with other producers, suppliers, service providers and customers.

Both the continuous vertical integration of several process steps and process hierarchies within the “Smart Factory” as well as the horizontal integration in the value network itself is organised through so-called “Cyber-Physical Systems” (CPS). These virtual systems support real-time interactions and communication and “merge” physical and digital systems into a cohesive, integrated and flexible network.

*Increasing automation –
Fewer people in
factories?*

Factories will become more digitalised, will possibly have fewer people, be electronically networked and will have an increasingly high degree of automation. The intensity of cooperation increases strongly in these kinds of production networks. The “Internet of Things and Services” is an infrastructural prerequisite.

There will thus be a paradigm shift in the interaction between human and machine, causing a new quality and intensity of socio-technical interactions. Within these value networks, human and machine are to make decisions together. At the same time, employees are to be given more control and flexibility with an increase in complexity.

*“Intelligent” products
aid in their own
production*

Next to the emergence of “Smart Factories”, “Smart Products” arise, which are capable of actively supporting the manufacturing process through their “knowledge” about their own manufacturing process and future use. They are capable of informing machines about their current state and will be fitted with an artificial biography to inform about their history, current state and target state.

The modelling and design of such CPS and their system architectures are deciding factors in how I 4.0 networking solutions will be embodied in practice and what consequences this may have on the workforce and future labour.

*Technological basis
for the development of
CPS and I 4.0*

The technological basis for the development of CPS has been significantly improved in recent years. The top ten key points which drive this convergence of technology and form a new potential are:

- Miniaturisation and performance increase in processors, memories and sensors
- Automation and control of processes and machines by means of sensors, actuator technology and processors
- Autonomous systems such as adaptive industrial robots and software agents

- Identification of objects, machines and people using Radio-Frequency Identification (RFID) etc.
- Expansion of the Internet of Services with the Internet of Things to an “Internet of Things and Services”⁴ due to a new Internet protocol (Version 6 – IPv6)
- Virtually unlimited communication between smart objects, machines and people via mobile networks using SIM technology
- Processing of different data in the “Cloud” with Big Data methods to for example predict the state of machines or human behaviour
- Access to data using new mobile interfaces and augmented reality applications
- Virtual design and digital modelling of products and processes along the entire value chain (integrated engineering)
- Further development of 3D printing and other decentralised production technologies which reduce the route from virtual design to physical realisation

Existing examples from production practice show that production systems and value-added networks in which intelligent products, machinery, equipment and network technology autonomously exchange information, trigger actions and control one another are not a distant vision, though they will certainly not become a reality overnight (see Bauernhansl et al. 2014).

⁴ The use of the Internet of Things and Services will not only change production but also many other sectors of the economy, in particular service and supply systems: concerning these one does not speak of Smart Factories but Smart Mobility, Smart Grids, Smart Buildings and Smart Health.

3 Objectives and Expected Benefits

The main objective of I 4.0 from a business perspective is “optimising the overarching goals of resource productivity and efficiency according to the situation” (translated from acatech 2013, 66). Specifically, this means that I 4.0 solutions should help reduce costs and increase productivity significantly. Resources should be used more efficiently, while humans and machines work (even more) productively (see Roland Berger Strategy 2014a, 10).

In order to remain globally competitive, production processes are to be further developed into “Smart Factories” by means of sensors, networked machines and new control algorithms. Presently, highly optimised manufacturing processes already exist, though they work in fixed sequences. The vision of continuous efficiency and productivity optimisation within the company and across the entire value network during operation is novel in I 4.0. Competitiveness in high-wage countries such as Germany and Austria is to be increased significantly this way.

In practically all branches of industry one can recognise potentials for positive economic effects of I 4.0, although expectations vary from branch to branch. According to a survey of industrial enterprises in Germany, the expected sales growth in industries with complex (discrete) products and versatile customer specifications, such as the automotive industry, mechanical and plant engineering, the electrical/electronics industry and the ICT industry, were significantly higher than expectations in process manufacturing. Nevertheless, several German industry sectors wish to invest heavily in the digitalisation of their value chains.

Currently the implementation of I 4.0 is still in its infancy for 55% of German production companies. Around 30% have already developed an implementation strategy. Merely 6% claim to be implementing I 4.0 capacities within the company (see Capgemini Consulting 2014). Starting from this relatively low level of implementation approximately 80% of the investigated companies wish to have achieved a high degree of digitalisation in five years’ time (see PwC 2014, 6).

So far the concept of I 4.0 appears to be a central topic primarily for large international leading companies. However, more and more SMEs are confronted with the fact that the integration of their value chains and the digitalisation of their products and services will play a deciding role for their international economic success. The question of cost-effectiveness and the implementation of the necessary investments as well as their financial feasibility pose a challenge for SMEs, which is not to be underestimated (see Deutsche Bank 2014, 7 and 16). 46% of German production companies recognise this as being one of the greatest barriers (see PwC 2014, 37).

What does the economy expect to gain from I 4.0?

What is novel about I 4.0?

Expectations vary depending on industry

Implementation is still in its infancy

A big challenge particularly for SMEs

3.1 Reduction of Costs

Potentials for cost reduction and efficient use of resources in three areas

Essentially, one can identify *three areas* of resources and their applications which should experience an increase of resource efficiency or reduction of costs (see acatech 2013, 66 and Deutsche Bank 2014, 7):

1. *Financial Resources* in terms of required investments and operating costs (capital costs): Companies which optimise their value chains and increase flexible manufacturing automation reduce their tied-up capital.
2. *Raw, auxiliary and operating materials* as well as all forms of *energy sources* including their conversion (raw material and energy costs): Companies can cut costs by reducing consumption. This can be achieved by more efficient processes, anticipatory maintenance, less waste, lower numbers of error, more efficient quality control and production planning. In addition supply risks are reduced and environmental sustainability increased.
3. *Human Resources* in terms of manpower (personnel costs): Companies with a high degree of automation require fewer personnel in relation to their production volume. The personnel costs in relation to production value are therefore reduced, possibly also in absolute terms.

High investment costs

At the same time, the cost savings generated through I 4.0 solutions may remain negligible for individual companies in full calculations of costs. Moreover, it may even be that economic efficiency decreases in total, at least in the short term, because production companies must first make vast investments in I 4.0 (see Deutsche Bank 2014, 12). Even if the continued use of existing production equipment should be possible, an I 4.0 network must be set up and corresponding interfaces must be created (see Roland Berger Strategy 2014b, 13f.). This generates considerable investment costs (e.g. for consulting, software, hardware, training and re-organisation), which can pose a significant barrier, particularly for SMEs. The estimates of the undoubtedly very high total investment requirements for I 4.0 diverge greatly: a current calculation (Roland Berger Strategy 2014a, 15) estimated an annual Europe-wide need of investment of 90 billion euro per year until 2030; another one (BCG 2015) calculates annual costs of 250 billion euro until 2025 for Germany alone.

Estimates of investment costs diverge strongly

Therefore, one of the main challenges for I 4.0 will lie in providing clear evidence that the additional requirements of resources through CPS and I 4.0 solutions, including the required infrastructure, hold a sufficiently high potential to increase resource efficiency and productivity (see acatech 2013, 66).

3.2 Manifold Benefits are to Increase Productivity and Sales⁵

I 4.0 is much more than just saving costs and increasing resource efficiency. The continuous vertical and horizontal integration and networking should have positive effects on different parameters such as flexibility and throughput time, whereby productivity and revenues can be increased significantly. Several experts see I 4.0 as the key to securing a competitive European industrial base.

What economic effects are to be expected?

The industrial value added could make a significant leap with I 4.0, or the “Industrial Internet” as it is known in the USA: General Electric and the World Bank see a growth potential of approximately 6 thousand billion US dollar for global BIP until 2030 – a growth of almost nine percent (see Z-Punkt 2014, 19). The consulting company Roland Berger expects significant growth effects through the spread of the digital industry: While the world economy is expected to grow 2.5% annually between the years 2014-2020, the I 4.0 segment (users and suppliers) have an expected annual growth of 6%, that is to say around 800 billion US Dollar (see Roland Berger Strategy 2014b, 32).”

According to a study by PwC, German industrial companies expect efficiency and productivity gains of more than 18% in the next five years due to better digital control of horizontal and vertical value chains. More than a third of the companies in the study expect even greater potentials. The digitalisation and networking of own products and services are expected to increase revenue by an additional 2-3% annually, which corresponds to an increase in revenue of up to 30 billion euro (see PwC 2014, 6). When applied to Austria, I 4.0 solutions would increase revenue for the Austrian manufacturing sector by around 2.8 billion euro per year (PwC 2015, 27).

Excessive expectations?

This growth potential in efficiency, productivity, sales and therefore value added is expected specifically through improvements in the following production parameters: flexibility/quality, throughput times, individualisation for small lot sizes, new business models and services as well as organisation of work (see acatech 2013, 19 ff. and Deutsche Bank 2014, 7 f.).

Company-wide and inter-company business processes can be made more dynamic and flexible, for example, in the dimensions of raw materials, quality, time, robustness, price, and environmental compatibility through CPS integration. Engineering processes can be designed to be more agile and production processes can be continuously optimised over the entire value network in a situation-specific manner. It is possible to react swiftly to short-term changes in demand or disturbances (e.g. on the supplier end). In the digital factory of the future, individual production lines are capable of self-organising autonomously and can adapt to fluctuations in demand. If a production machine fails, the production can be reorganised auto-

Flexibility/Quality

⁵ The currently available benefit estimates are largely based on business surveys and forecasts produced by consulting companies. At present there is a shortage of methodologically stringent scientific analyses.

mously. Machines report the need for maintenance in an anticipatory manner or are capable of self-maintenance. Resources and raw materials are used optimally. Transparency and reproducibility of sensor-supported processes enable a higher quality of processes and products. The advantages in contrast to these tasks being carried out by people include the fact that the autonomous control in real-time enables earlier and more rapid execution, as well as savings in resources.

Individualised production

One characteristic of I 4.0 is the custom-made mass production with small batch sizes and higher variability. The consideration of individual customer-specific criteria such as design, planning, production and operation as well as short term requests for changes can be implemented during the production phase. Even the frequent production of single pieces and small series (up to lot size 1), for example for the automotive and furniture industry, remain profitable due to generative manufacturing processes such as 3D printing and intelligent decentralised process organisation. The central advantages of this approach: ideally only those things are produced which are also sold.

Optimisation of throughput times

The seamless data collection and processing enables correct short-term decisions in a decentralised manner. The complete transparency in real-time enables an approval of design decisions early on in the engineering process and more flexible reactions to disturbances within production, as well as cross-site optimisation. Delivery times and storage costs are reduced, innovation cycles are shortened, products and services are adapted ad hoc. The real-time production of I 4.0 combines lean production, networked logistics and customised mass production to ensure a flexible and immediate supply of products on the market.

New business models and services

I 4.0 is seen as a great opportunity for the implementation of new business models and services, and thus for the development of value-added potentials and market potentials. The integrated use and analysis of data across the entire value network enables digital business models, which provide significant additional benefits for business and end users thanks to tailor-made solutions. Examples for this are offers in the areas of project management, maintenance, logistics, remote support, customisation and virtual/augmented reality. The collection and use of a large amount of production data („Big-Data”) by intelligent devices opens up new possibilities, such as in the field of development of downstream innovative B2B services for I 4.0 (cf. OECD 2015). This applies to both large as well as small and young companies (Start-ups).

Alternatives in work organisation

Through the support of intelligent assistance systems, mobile devices and interfaces there should be new room to manoeuvre, making it possible to organise labour in such a way that both the flexibility needs of the companies and that of the workers can be taken into account in a new quality. The interaction between humans and technical systems in connection to work organisation and skill development measures should be considered in this regard. This promises benefits such as attracting employees to a – despite continuing unemployment – shrinking labour market for certain professionals, as well as sustainable productivity in times of demographic change.

4 Spheres of Impact and Key Challenges

At the present, I 4.0 is much more a vision than reality. The concept of digitally networked and largely self-regulating production systems which span the entire value chain, aims to achieve the next industrial revolution. A transformation of this kind does not only entail multiple changes on the company and industry level, but carries the seeds of far-reaching societal impacts. It is therefore important to take a closer look at the main fields of impact of I 4.0 (cf. Helbing 2015). As there is not yet specific idea of what form I 4.0 will take, and as the first implementation steps are in their early stages, the expected impact in most areas is subject to a high degree of uncertainty. It is therefore of even more importance to detect leeway in design early on, in order to actively pursue the most positive development possible in the interests of all those concerned. The emerging changes and associated opportunities and risks, as well as the implicit challenges for further development are at the centre of probing various fields of impact.

4.1 Employment

Significant changes are to be expected in the area of the working world and employment, due to the coinciding of parallel breaks in traditional structures within the service sectors, demographic change and intensified global competition. The wide-scale introduction of integrated production systems, based on the concept of I 4.0, brings with it a lasting change of organisational and work structures, accompanied by significant consequences on several levels.

It is still uncertain what impact I 4.0 will have on the volume of employment (cf. Pew 2014), as it is dependent on a number of developments, such as the degree of substitution of human labour through automation within production, the extent of growth of jobs in other sectors, the development of wage costs or the success of Austrian companies as suppliers of components and services for I 4.0. For Germany, experts predict a decrease or increase of employment in the range of around 1.5 million jobs in the manufacturing sector, depending on the development of automation and labour costs (Spath et al 2013, 46). Recent studies expect 47% of all jobs to be replaced by automation in the USA, regardless of I 4.0 (Frey & Osborne 2013). In Finland the expected percentage of jobs replaced is 36% (Pajarinen & Rouvinen 2014). It is fairly certain that factories will have fewer people, even if new jobs are created elsewhere (see also Brynjolfsson & McAfee 2014; Ford 2015; Est, van & Kool 2015).

Impact on volume of employment is uncertain

<p><i>Reduction of simple manual tasks</i></p> <p><i>More highly qualified individuals</i></p> <p><i>More employees in ICT services, R&D and new occupations</i></p>	<p>I 4.0 will have consequences on the <i>employment structure</i>. The reduction of simple manual tasks is expected, which can cause a socially problematic exclusion of less qualified staff (see acatech 2013, 57). Two trends are emerging concerning the share of indirect employment: firstly, losses through automation of tasks concerning planning, management, maintenance and quality assurance; secondly, new and extended planning tasks and an increased need for industry related services (see Hirsch-Kreinsen 2014a, 38f.). At the same time, I 4.0 offers new opportunities regarding the <i>quality of employment</i>, by offering qualitative enrichment of work such as more interesting work contexts, greater self-fulfillment and more room for decision-making, as well as new risks and challenges caused by ongoing qualification pressure, increased responsibility and temporal and functional delimitation with the tendency of self-exploitation (see Table1).</p>
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Table1: Employment

Spheres of impact	Opportunities	Risks
Quantitative employment effects	<ul style="list-style-type: none"> • More [external] labour/employees in services [ICT] and R&D for I 4.0 • More higher-skilled workers and new professions 	<ul style="list-style-type: none"> • Fewer employees in factories, disposition/logistics and office/planning
Quality of employment	<ul style="list-style-type: none"> • Better and more satisfying, less stressful work • Upskilling • Higher autonomy/flexibility [Work/Life Balance] 	<ul style="list-style-type: none"> • Dissolution of work [time, flexibility] • Qualification pressure • Overtaxation, stress, self-exploitation
Structural changes	<ul style="list-style-type: none"> • Cushioning the shortage of skilled workers • Prolonging working lives • Dismantling hierarchies • New qualifications and employee groups 	<ul style="list-style-type: none"> • Devaluation of job profiles and individual groups of employees [manual labour, skilled labour] • Conflicts surrounding structural changes

<p><i>Challenges:</i></p> <p><i>Improving quality of employment</i></p> <p><i>Available professionals</i></p> <p><i>Solutions for surplus workforce</i></p>	<p>It will therefore be a challenge to improve quality of employment through the means of I 4.0. In Germany 30% of companies surveyed recognised “the inadequate qualifications of employees” as one of the two most important challenges for I 4.0 (PwC 2014). Companies in plant construction do not consider this much of a problem (acatech 2013, 29). The question of adapting qualifications, education and training will play a key role (see Chap. 4.3). Furthermore, new solutions, which enable a life of dignity and social integration, must be found in reaction to the foreseeable increase of automation and use of robots – favoured by the rapid decline in prices of hardware and software components – a development of progressive decoupling of productivity and employment.</p>
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4.2 Work Organisation

There are various challenges facing companies on the road to I 4.0 with respect to the design of the interaction between humans and technology as a socio-technical system and the future organisation of work (see Table 2). A wide range of different patterns of work organisation are possible, framed by two poles: the polarisation of tasks, skills and manpower (polarised organisation) and the maximum of openness and flexibility on the basis of the high qualification of employees (swarm organisation; Hirsch-Kreinsen 2014a, 39f.). Significant determinants of work design are the pursued automation concept (technology-centred or complementary) and the design and implementation process of the new systems. However, it is becoming apparent that the prospect of an automated factory with full automation is unrealistic, due to technological as well as economic reasons (Ausschuss 2009).

*Different models
of work organisation*

*Dependent on
automation concept and
implementation process*

Table 2: Work organisation

Spheres of impact	Opportunities	Risks
Operative level	<ul style="list-style-type: none"> • Individualisation of the workplace • Complementarity of humans and machines • Collaboration and support • Mobile working environments 	<ul style="list-style-type: none"> • Substitution of human labour through technology/automation • Human work as a residue • Loss of capacity to act through progressive virtualisation • Alienation
Engineering, planning and management	<ul style="list-style-type: none"> • Delegation of tasks • Advanced and new planning tasks • More development of creativity 	<ul style="list-style-type: none"> • Substitution of human labour through technology/automation • Loss of capacity to act concerning control and management of increasing complexity
Human-machine interfaces/cooperation	<ul style="list-style-type: none"> • Increase of human performance • Optimised decision-making in collaborative decision-processes by people and machines 	<ul style="list-style-type: none"> • Wrong decision-making due to detachment from the practical system flow • Uncontrolled data use through integration of sensors • Inhibition of improvisational and experimental work actions • Loss of control in humans • Health impacts
Across corporate boundaries through networks	<ul style="list-style-type: none"> • Transparency • Predictability • More flexible and dynamic business processes • Optimised decision-making 	<ul style="list-style-type: none"> • Increased dependence, substitutability, loss of control (in particular for suppliers)

Flexible human-machine interaction

“More teams, in which robots and humans work together” (translated from Spath et al, 2013, 46) are predicted, as well as the establishment of “forms of collaborative factory work in virtual mobile working worlds” (translated from acatech 2013). German companies in mechanical and plant engineering view process and work organisation as the second most important challenge after standardisation (see acatech 2013, 29). Thus, there is a need for coordination between the increasing flexibility of production on the one hand and human flexibility on the other (see Spath et al 2013, 46).

Partially contradictory spill-over effects

With the establishment of open, virtual work platforms and comprehensive human-machine interactions, “work contents, processes and environments ... see dramatic change – with spill-over effects on flexibility, work time arrangements, health, demography and the living environment” (translated from acatech 2013, 45). Enhanced development of creativity, personal responsibility and self-organisation are among the opportunities presented for employees, but at the cost of increased demands in terms of coping with complexity and an increased demand for abstraction capabilities, communication and problem solving skills. Associated risks include burdensome delimitation, increased flexibility and intensification of work, tensions between the virtual and the real world, estrangement, losses of creativity and productivity (see acatech 2013, 57), the possibility of work overload during incidents (Hirsch-Kreinsen 2014a, 37) as well as possible health risks. One must consider partially contradictory spill-over effects on the hierarchical level and indirect areas as well as the increase in value of improvised-experimental decisions and actions at the workplace (Hirsch-Kreinsen 2014a, 37f.).

Valuing improvisatory and experimental work

Challenges

Central challenges include the management of a disruptive change of process and working structures. Essentially, the design parameters of work organisation are concerned, particularly the human-machine interfaces and the role of humans in an increasingly autonomous production system. This relates to decisions about the specific automation and implementation concept as well as to questions of qualification, duties and job profiles, which ensure appropriate flexibility, system monitoring and the correction of system problems and additionally enable positive prospects for workers.

4.3 Education and Training

Qualifications, and therefore education and training, will play a central role for future intelligent production systems. The mastery of complex manufacturing processes and the development and control of data-driven processes and business models require new skills and qualifications (Pfeiffer 2015; PwC 2014; Wiesmüller 2014; Fidler 2015). The existing education and training offers are therefore currently being put to the test (see Table 3).

Standardisation of education and training is limited by the variety of possible fields of application. Future technicians and engineers will have to interact more, become more multidisciplinary and have a more networked education (Pfeiffer 2015; Wiesmüller 2014).

Existing approaches to link education and work-based learning offer the opportunity of being expanded to meet the challenges of I 4.0 enterprises. The promotion of cooperation and permeability between education and training systems is recommended, as is the promotion of dialogue between educational institutions and the manufacturing industry (Spath, et al. 2013, 126; acatech 2013, 59), the adapting of training content to demands of the digital world and awakening interest for technical fields of knowledge at an early age (PwC 2014).

Linking school and work-based learning

Table 3: Education and training

Spheres of impact	Opportunities	Risks
School education	<ul style="list-style-type: none"> Combination of theory and practice [dual system, corporate internships] New qualifications and activity profiles [e.g. mechatronics/ICT] Development of key skills 	<ul style="list-style-type: none"> Lack of focus on new requirements [flexible working, understanding innovation, continuing education] Intensification of problems for individuals leaving after compulsory school and unskilled workers
Academic education and training	<ul style="list-style-type: none"> Specialisation in I 4.0 specific challenges Interdisciplinary approaches New job profiles [e.g. data scientist] 	<ul style="list-style-type: none"> Detachment from operational work process [through increased visualisation of engineering processes]
Education and training at the workplace – lifelong learning	<ul style="list-style-type: none"> Cushioning the shortage of skilled workers Training close to work Learning-conducive work organisation Digital learning techniques 	<ul style="list-style-type: none"> Qualification pressure Exclusion and lack of consideration for resilience of employees

<i>Willingness for lifelong learning</i>	In most fields of application one can assume an increased importance of higher ICT skills, the willingness for lifelong learning, skills for interdisciplinary communication and for communication with machines and networked systems. Given the great uncertainty regarding the specific technical requirements for the various corporate worlds, it is advisable to place greater emphasis on the acquisition of key skills, as well as on the capacity-building for conditions of complex and rapidly changing demands (cf. Pfeiffer & Suphan 2015). These include fundamental attitudes like willingness to learn, flexibility and problem analysis and solving skills in particular.
<i>Key qualifications</i>	For a start, there is a need for qualifications regarding the design of innovation processes, especially skills for the interdisciplinary development of production systems and thus the interaction of mechanical, electrical and technical computer science. A range of new occupations such as data scientist, production computer scientist and professionals for system security and usability are expected to complement already established occupations, such as production planner, automation engineer or testing and certification service provider.
<i>New skills and job profiles</i>	It is predicted that the demand for mathematical, scientific and technical knowledge will rise, as well as the need for software developers and data analysts (PwC 2014, 37f.) and professionals in the field of operational technology (Dimberger 2015). Additionally, there is a need for generic competences (management, project management, problem diagnosis), as well as skills for the identification of application options and development partners in a global context. With increasing interdisciplinarity, networking and communication, the requirement for social skills increases also (acatech 2013, 55; Hirsch-Kreinsen 2014a, 38; Ovtcharova et al. 2014, 50). Furthermore, the demand for survey knowledge and the understanding of interactions between all actors in the production process will rise (acatech 2013, 59). The ability to organise and coordinate interactions between virtual and real systems will also gain importance (acatech 2013, 55-56; Ovtcharova et al. 2014, 56).
<i>Need for further qualifications</i>	Workplace-oriented learning, work organisation which is conducive to learning and the use of digital learning technologies (e-learning, blended learning, augmented learning) are all of great importance, especially in the context of (operational) training (acatech 2013, 59; Kärcher 2014, 25; Spath, et al. 2013, 126).
<i>Workplace-oriented training</i>	The main challenges concern the ability to cope with a possible shortage of adequately skilled workers for the introduction and operation of the new production systems and the development of solutions for the growing problem of employment for unskilled labour. Furthermore, it is important to avoid a detachment of work processes in cyber-physical production systems and to manage qualification pressure for older and less digitally savvy employees.
<i>Challenges</i>	

4.4 Health and Wellbeing

New challenges arise in the field of health and wellbeing, due to the introduction of new technologies in the context of I 4.0, entailing changes in work organisation and work tasks. In addition to physical strain, one must pay increased attention to psychological stress (see Table 4).

With the use of CPS the degree of automation generally rises, and physically demanding tasks can be transferred to machines. However, the use of CPS leads to much more time being spent standing at machines or sitting at a desk. There are advantages to be found here in regard to integrating physically impaired individuals in the labour market (Domingo 2012). The promotion of physical activity will, however, gain importance in order to balance out the increased sitting activity as to avoid unhealthy lifestyles (acatech 2013). I 4.0 also involves new characteristic assistive technologies such as data goggles, which need to be tested for potential health risks (Krüger 2014).

Physical strain

Table 4: Health and wellbeing

Spheres of impact	Opportunities	Risks
Physical health	<ul style="list-style-type: none"> • Less physically demanding labour • Better professional opportunities for people with disabilities • Ageing-appropriate work design 	<ul style="list-style-type: none"> • Lack of exercise • Physical hazards of technical assistance systems
Psychological health	<ul style="list-style-type: none"> • Increased variety through enrichment of activities • Increased autonomy • Possibility of self-development 	<ul style="list-style-type: none"> • Overburdening, stress • Loss of sovereignty • Alienation, stress, exhaustion

The changes in work organisation and design can lead to an increase of work intensity and demands on employees. Among the possible psychological strains caused through work in hybrid systems are cognitive overload (complexity, responsibility and pace), loss of control competence and sovereignty over time, alienation, monitoring and control of performance and behaviour (Gerst 2014). Illnesses such as burn-out are often consequences of structural strains (Baumgarten et al. 2014).

Psychological strain

The lines between leisure time and work blur due to higher demands in flexibility and constant accessibility (Krüger 2014). As a result of this development, regenerative capacity can suffer and lead to chronic fatigue. Along with the changes in tasks come changes in methods, as well as in planning and thought processes. In order to develop a suitable prevention management one must assess the mental strain of these new tasks (Dombrowski & Wagner 2014). Generally there is an increase in demand for demographically sensitive work design and aging-appropriate prevention management (Baumgarten et al. 2014).

*Challenges:
prevention measures,
age-appropriate
work design*

It is essential to create adequate regeneration times as part of the comprehensive digitisation and networking process. The evaluation of health effects of new assistive technologies is particularly difficult regarding long-term consequences. Aging-appropriate design of work and working environments and appropriate educational and training programmes represent major challenges.

4.5 Use of Resources

*Increased resource
efficiency and reduction
of costs as key benefit
expectation*

Proponents of I 4.0 see the increased resource efficiency and reduced costs as the key benefit of transitioning to a networked and self-regulating production system. They apply this to various types of resources, from raw materials and consumables including energy to human and financial resources (see acatech 2013, 66 and Chap. 3.1). In addition to optimising the use of resources, reducing production costs and increasing productivity, I 4.0 should contribute to a significant gain in flexibility and a greener, more sustainable economy. Attempting to achieve these expectations, however, involves some risks and challenges (see Table 5).

Table 5: Use of resources

Spheres of impact	Opportunities	Risks
Efficiency	<ul style="list-style-type: none"> • Reduction of resource consumption • Increased energy efficiency • Decreased dependence • Reduction of costs • Environmentally sustainable 	<ul style="list-style-type: none"> • Overestimation of the positive effects • Increased medium-term demand for energy, raw materials and transportation for the development of infrastructure • High pre-financing and investment costs • Lack of innovation capacity
Productivity	<ul style="list-style-type: none"> • Increased productivity • Extending market potentials • Reduced error rates • Reduction of set-up costs • Minimisation of quality defects 	<ul style="list-style-type: none"> • Uncertain evidence of productivity gains • Sacrifice of productivity gains through security expenses • Substitution and depreciation of human resources • Increased dependence on ICT updates
Flexibility	<ul style="list-style-type: none"> • Production costs independent of lot sizes • Faster responses to market demands • Shorter lead times 	<ul style="list-style-type: none"> • Increased system operating costs • Lack of acceptance concerning relocations of decision-making • No clear accountability

The possibility of achieving a long-term increase of productivity and efficiency is based on various potentials revealed by the digitalisation of processes and value chains. These include increased flexibility and adaptability of products, which enable production costs to be less dependent on lot sizes, as well as a decreased dependence on suppliers. In combination with optimised decision-making and higher transparency, I 4.0 promises to improve quality, reduce lead times and accelerate marketability and responses to market demands. The increased transparency in the field of planning allows for better utilisation of machinery and equipment (e.g. through optimisation of lot sizes). Work processes can be rationalised and productivity gains can be achieved through digitisation and greater connectivity of process organisation. The intelligent analysis and integrated use of data for production control promises a reduction of the reject rate (PwC 2014). Redundancies in process models can be reduced, minimising losses in quality, and more flexible responses can be made to disturbances (acatech 2013, PwC 2014).

Increased flexibility and adaptability of production

Current forecasts expect high productivity gains (see also Chap. 3.2): for example, the Boston Consulting Group (BCG 2014, 2015) estimates that with I 4.0, German producers can increase their productivity by 8% in the next 5–10 years and achieve gains in the range of € 90–€ 150 billion in the final stage. Through the reduction of set-up costs and system networking with suppliers, particularly strong increases in productivity are possible in the area of mechanical and plant engineering (BCG 2014). In an investigation on behalf of BITKOM, Fraunhofer IAO concludes that with the introduction of I 4.0 one can expect a cumulative increase in productivity of 23% (or € 78.8 billion) for six selected industries for the period up until 2025 (Bitkom & Fraunhofer 2014, 35). This potential arises from the sum of the expected additional gross value added for mechanical and plant engineering, electrical equipment, automotive engineering, the chemical industry, agriculture and information and communication technology.

High expectations of rising productivity ...

... too high?

These optimistic estimates of productivity gains, however, stand on relatively soft ground and are subject to criticism (see Pfeiffer 2014). It is methodically unclear how qualitative expert assessments, which form the basis for many of these forecasts, can be translated into seemingly unambiguous hard numbers. One must consider that predictions cannot be viewed isolated from significant investments (e.g. considerable increase in expenses for security; ICT dependency); the fact that differences in productivity gains in user and supplier industries are to be expected and that effects in different sectors cannot be added to one positive total account (see Chap. 3); and finally, the fact that impacts on major industries such as logistics remain excluded and that there are repercussions of the increase in productivity on a global scale (Pfeiffer 2014).

Methodical doubt of forecast values

I 4.0 should contribute to improving resource efficiency by minimising resource expenditure. Material costs (especially for raw materials) make up approximately 40% of the production costs for a company (BMWFW 2014; Ramsauer 2013). The use of CPS enables a case-by-case optimisation of materials used within production (acatech 2013) and a resource-conserving, efficient design of processes (e.g. zero-waste processes).

Improved material efficiency

Energy consumption

Within industrialised countries, a high proportion of national energy consumption is used in the manufacturing sector, for example 30% in Austria.⁶ The European Commission estimates that between 2009 and 2020, 25% of energy within industrial production can be saved. A potential reduction of emissions of 16% is predicted through process optimisation in the field of ICT logistics. Energy savings can for example also be achieved by modelling, for instance in the chemical industry (EC 2009). A percentage of 20–30% of energy can be saved within production through systematic energy and load management, the optimisation of technologies and equipment, and investment in energy-efficient products (Wahren 2014).

Challenge: optimising by multiple criteria

One of the key challenges in pursuit of the desired increase in efficiency and productivity will be making the right decisions and finding a balanced position between what is technically possible, economically viable and socially and environmentally acceptable.

Methodological challenges

The presented estimates and quantifications of possible improvements in efficiency are to be regarded with caution for methodological reasons. Secondary and external effects, for example with regard to security-related additional costs or additional transport costs, are often unknown or not regarded. In order to improve forecasting accuracy, various trade-offs within the production process are to be considered (e.g. between potential savings and additional investment expenditure). Additionally, the three dimensions of resource use (material, energy and human resources) are not independent of each other. Thus, while higher efficiency and productivity are desired, this could have consequences on the use of human resources (see Chap. 4.1). Regarding energy resources, the question arises whether savings only occur as a side-effect of productivity-enhancing effects, or if conserving natural resources represents an explicit objective of I 4.0.

4.6 Economy and Competition

Positive effects on innovation, growth, share of industry

A number of positive expectations surround I 4.0 regarding macroeconomic objectives. The European Commission aims to increase the industrial rate from 15.1% (as of 2014) to 20% by the year 2020 in order to expand Europe's competitiveness and to set in motion a process of re-industrialisation (BMFWF 2014; see Chap. 1). Automation and digital networking play key roles within these concepts. Despite the decrease of production within Europe during the last decades, industry continues to act as an engine for economy and forms the basis of prosperity (Spath et al. 2013). For many countries, particularly Germany, I 4.0 carries the hope of increasing efficiency in the production of goods (see Chap. 4.5) as well as ensuring a leading position for the development, production, marketing and ex-

⁶ Source: Statistik Austria, energy balance 2013, http://www.statistik.at/web_de/statistiken/energie_und_umwelt/energie/energiebilanzen/, accessed on 19.04.2015

port of automation and manufacturing technologies (acatech 2013). Positive effects for innovation, growth and competitiveness are expected for the European market (see Table 6).

Table 6: Economy and competition

Spheres of impact	Opportunities	Risks
Macroeconomic	<ul style="list-style-type: none"> • Increased competitiveness and added value • Securing and expanding status as an industrial location • Potential employment growth • Higher tax revenues 	<ul style="list-style-type: none"> • High level of investment and funding costs • Lack of compensation for losses of sectoral jobs • Reduction of total wage bills and purchasing power • Less tax revenue of wage and value-added taxes
Value creation structures	<ul style="list-style-type: none"> • Increased flexibility • Business-to-business services for SMEs and start-ups 	<ul style="list-style-type: none"> • Increasing complexity of production systems • Strong pressure on SMEs within value networks • Increased outsourcing of risks to suppliers
New business models	<ul style="list-style-type: none"> • Opening new potentials of value creation • Opening new customer segments • New collaborations in value networks • Production according to individual customer requirements • Increase of customer satisfaction • Integration of customers into the value chain 	<ul style="list-style-type: none"> • Over-taxation, paternalism, incapacitation [customers] • Downgrading of the "human factor" • Data collection, privacy violation • Corporate internal barriers [e.g. knowledge, management, employees] • Corporate external skepticism/rejection • "Planned obsolescence" [intentionally reduced service life of products]

The production of goods was increasingly being outsourced to countries with lower wage levels, due to global competition, and the industrial shares of many (Western European) countries decreased. With I 4.0 and the stronger focus on automation, competitiveness of European business locations is to be improved (see Ramsauer 2013). Thus the potential arises to maintain production sites in Europe (acatech 2013). In effect, this should subsequently lead to the attraction of new business and expansions (BMFW 2014). This should in turn lead to increases in value creation, create impulses for growth and employment and lead to higher tax revenues.

Location policy and competitiveness

Among the risks are the high investment and funding costs for I 4.0, the uncertain compensation for job losses as a result of increased automation and thus a possible reduction in wage bills, purchasing power and tax revenues. Given the increasingly competitive situation it cannot be assumed that the relative competitive advantages remain stable in the long term.

Risks

<i>Value creation structures</i>	Value creation structures are changed within the course of I 4.0. Value-added networks and decentralised control gain importance while the central production and coordination within a single company lose importance. Traditional supply chains are fragmented, flexibility rises – processes which can be associated with various opportunities and risks. Production itself is to be strengthened locally and networked. Local production can be achieved through the establishment of small autonomous production cells (Roland Berger Strategy 2014a). On the other hand, it is possible that pressure is applied to SMEs within the supply chains (Butler 2015) and that enterprises find themselves in an eternal pursuit of exponentially developing technology (Spath et al. 2013).
<i>Complexity and control</i>	The complexity of production systems increases while controllability decreases with strengthened networking within the framework of I 4.0. The mastery of the resulting complexity and the ability to ensure that “autonomous objects, which network themselves, don’t get out of hand” (translated from Spath et al. 2013, 119) is a challenge. “Cultures of distrust” present an additional risk, caused by a lack of accountability in networked systems, as was observed in virtual factories (Schuh 2003). There is the potential of top-down decision-making mechanisms dissolving and being partially replaced by decentralised, interactive and collaborative bottom-up decision-making mechanisms within the development of I 4.0. The advantage of decentralised systems lies in the ability of coping with the increasing complexity of production (Spath et al. 2013). These approaches are made possible through decentralised control management (see Spath et al. 2013, 95f.), as well as modelling and simulation (acatech 2013, 46f.).
<i>Business model innovations</i>	It is predicted, that the rate of development of new business models in the Internet of Things will resemble the dynamics of the Internet, and that new business models will allow dynamic pricing, which takes into account the customer and competitive situation. Thus, various opportunities for businesses arise, especially in the area of business model innovations: production toward individual customer requirements (enabled by flexibility gains), opening up new customer segments and potentials for value creation, as well as new collaborations in value networks. The establishment of new business models cannot, however, be taken for granted. The development of new business models is considered to be one of the biggest challenges in the context of I 4.0 by about a third of the companies within mechanical and plant engineering (acatech 2013, 29).
<i>Capacities for data analysis</i>	The ability to analyse data will be crucial for business models (see PwC 2014, 22). The organisational and technical challenges therefore include the establishment of capacities for the data analysis of the growing amount of data. Not all companies possess the necessary experience and expertise; in particular for SMEs this expertise is often not available (Spath et al. 2013, 64). From a legal and business perspective, the question of preventing violations of privacy of employees and customers, despite the large amounts of data and data collection, is also an issue.

Against this background there are a number of important challenges for companies and governmental policy which must be considered when transitioning to I 4.0. They include the following:

Due to unclear profitability and uncertainties there is a need for more transparency, exchange of experience (PwC 2014, 38) and co-operation, so risks can be divided and lowered, e.g. by joint pilot systems and test factories for development and practical testing of prototypes and networked production systems.

In order to use the synergy potentials of new opportunities for collaboration, there is a need for new IT-based business models, for example through the cooperation of mechanical engineering, automation and computer science (Glatz 2013). The networking of production systems allows faster responses to market demands, for example (acatech 2013). SMEs and start-ups have the possibility of introducing B2B (business-to-business) services.

A powerful infrastructure with guaranteed latency, reliability and high quality of service is needed for the nationwide use of Cyber Physical Systems (acatech 2013, 49). This includes the supply of broadband services.

The development of CPS is the primary challenge from the perspective of IT and automation technology. Certain requirements arise, for example in terms of architectural models, data consistency and intelligent production units (see Vogel-Heuser 2014, 39f.; acatech 2011). For many companies the availability of such products is a key challenge for the implementation of I 4.0 (acatech 2013, 29); the maturity level of the required technologies is, however, partially estimated as being low (see PwC 2014, 37). On the other hand, the technical development of CPS provides great opportunities to increase the export of these technologies and products, and can thus strengthen the supplier industry (acatech 2013, 33).

*Challenge 1:
cooperation and
exchange of experience*

*Challenge 2:
development of new
business models*

*Challenge 3:
powerful IT
infrastructure*

*Challenge 4:
development of enabling
technologies*

4.7 Safety and Security

The increasing digitalisation and cross-company networking/integration of processes, production equipment, components and value chain participants are central characteristics of I 4.0. Digitalisation, automation and networking result in significant security risks and challenges at the company and intercompany level (see Table 7).

The question of security is still considered to be largely unresolved and is perceived to be a critical factor for the success of I 4.0 (acatech 2013, 50). Many of the current systems which are in use were initially developed for offline environments. Systems become more vulnerable to attacks and disturbances through networking via the Internet. This leads to challenges regarding the guarantee of operational and product safety (Safety) as well as security against attacks aimed at systems, information and data (Security) (see TÜV 2014, 9f.; Weidner 2014, 11).

*Security: largely
unresolved issue and
critical success factor*

Operational and product safety

Security against attacks

Data security and privacy

Safety risks in I 4.0 can be caused e.g. by increased automation. These include risks for humans and the environment generated by autonomously acting technical systems. Some of the largest concerns regarding I 4.0 have to do with *security risks* created through increased networking. This includes the targeted disruption or destruction of systems through outside manipulation, which may cause operational failures or delays. The variety of risks also increases in the area of data protection and privacy. Sensitive corporate information (industrial espionage and piracy) and (personal) data of employees and customers are affected.

Table 7: Safety and security

Spheres of impact	Opportunities	Risks
Operational reliability and product safety [Safety]	<ul style="list-style-type: none"> • Increased awareness of safety requirements • Incentive for holistic security strategy • Unique and secure proof of identity for products, processes and equipment • Transparency of processes 	<ul style="list-style-type: none"> • Hazards for humans and the environment through autonomous systems • Partial solutions and vulnerabilities in security architecture • Increased susceptibility to disturbances • Insecure data exchange in value networks • Breaches of privacy and data protection • Theft of know-how, intellectual property, product piracy • Targeted destruction and disturbances • Increased endangerment of privacy of employees and customers
Security against attacks, data security, information security [Security]		

Sources for security risks – in addition to increased networking and automation – include lack of security awareness, inadequate security precautions (e.g. security vulnerabilities in system architectures), complicated protection through lack of standardisation, unclear cost-benefit ratios for investments in security and a lack of acceptance of cybersecurity solutions on part of the user (e.g. as a result of low user-friendliness).

Identification and certification

The complete and automated networking between companies can only succeed when each networked end can recognise the other as safe and is able to automatically assess their trustworthiness. This requires the certification of products, processes, and equipment in terms of their security features (see TÜV 2014, 10).

Security projects of Fraunhofer SIT on topics such as Industrial Rights Management (protection of product and machine data), piracy protection (for applications in motion control) and Trusted Core Network (hardware-based security for industrial IT-networks) are exemplary for other relevant issues regarding I 4.0 and security.⁷

⁷ See <https://www.sit.fraunhofer.de/de/industrie-40/>

In summary, challenges arise particularly concerning the development of integrated security concepts, architectures and standards, as well as safe migration strategies from old systems to I 4.0 solutions. Security cannot be considered as an isolated issue, as it has close connections to questions regarding (1) a lack of standardised operating system platforms, (2) user-friendliness and affordability, (3) the protection of personal data, (4) informed and qualified employees, (5) acceptance of solutions and (6) awareness for the application of cyber security solutions of executive staff and employees. Acatech (2013), for example, therefore calls for a proactive approach to ensure security in I 4.0.

Challenges

4.8 Technical Standards

I 4.0 has far-reaching technical demands in order to achieve the desired degree of digitalisation and networking of all components of the value chain. Next to the development of basic technologies this mainly involves the establishment of uniform technical standards (see Table 8).

Table 8: Technical standards

Spheres of impact	Opportunities	Risks
Manufacturing processes	<ul style="list-style-type: none"> • Inter-company reference architectures [networked, integrated] 	<ul style="list-style-type: none"> • Incompatible architectures
Networked devices	<ul style="list-style-type: none"> • Community-building through co-operation 	<ul style="list-style-type: none"> • Different "worldviews" in various disciplines
Software applications	<ul style="list-style-type: none"> • [Legal] security 	<ul style="list-style-type: none"> • Development of monopolies or cartels
Engineering	<ul style="list-style-type: none"> • Accelerated and broad implementation of I 4.0 solutions 	<ul style="list-style-type: none"> • Mistrust and blockages • Loss of competitiveness and market share [from view of established industries]

Clearly defined standards for the smooth exchange of information between machines, systems and software are a prerequisite for horizontal and vertical networking. Common standards promote inter-company (networked, integrated) value networks and contribute to the increase of efficiency of manufacturing processes. On the inter-company level, standardisation promotes common perspectives, legal certainty, cooperation and trust. The risks of an absence of standards include a lack of interoperability, friction losses in manufacturing processes and higher entry barriers in areas where the market is dominated by proprietary corporate standards (see Table 8). Missing standards are seen to be a challenge for the implementation of I 4.0 by many companies (PwC 2014, 37; acatech 2013, 29).

Common standards/norms as prerequisite for networking

Challenges The area of standardisation presents an enormous challenge, seeing as I 4.0 requires the cooperation between different sectors and disciplines which all have their own perspectives, procedures and standards (production technology, mechanical engineering, process technology, automation technology, computer science and Internet). Acatech (2013, 45) therefore suggests an incremental development of reference architecture, with consideration to different starting points. Current project-specific concepts should gradually be transferred to international standards.

4.9 Regulation

Appropriate legal framework The trend towards I 4.0 has several implications for legal framework. The uncertainty about the legality of a new technology and its application can inhibit acceptance and innovation (acatech 2013, 27). New technologies can also put into question the adequacy of existing regulations, complicate their enforceability, or lead to new risks and corresponding regulatory challenges. Liability, data protection and labour laws are key areas in which adjustments are needed due to I 4.0 (see Table 9).

Table 9: Regulation

Spheres of impact	Opportunities	Risks
Protection of corporate data/liability	<ul style="list-style-type: none"> • Design of new technologies, business models and contract models with legal conformity • Innovation-adequate development of law 	<ul style="list-style-type: none"> • Insufficient protection of sensitive corporate data • Lack of assignability of accountability within the network → • Uncertainty about liability
Personal data	<ul style="list-style-type: none"> • Anonymisation, pseudonymisation • Corporate rules and operating agreements 	<ul style="list-style-type: none"> • Insufficient protection of personal data [employees, customers] • Evaluation of data in third countries [outside of the EU]
Labour law	<ul style="list-style-type: none"> • Right to temporary inaccessibility • Protection of measures to promote flexibility and further education through labour laws. • Work design promoting health and learning 	<ul style="list-style-type: none"> • Conflicts concerning regulations of labour laws in I 4.0 • Legal uncertainty
International trade	<ul style="list-style-type: none"> • Reduction of trade barriers for I 4.0 applications 	<ul style="list-style-type: none"> • Trade barriers and legal uncertainty [e.g. encryption technology]

Depending on the application, there are other areas of law which may be relevant: copyright law, provider liability, transport law, regulations regarding standardisation and certification, insurance law, tax law, product safety law, medical products law, environmental protection standards (e.g. recycling), as well as legal issues regarding possible trade restrictions (competition law) or the use of cryptography.

Potentially affected legal matters

I 4.0 is characterised by a higher degree of networking and the intensification of interactions and transactions. The vulnerability of a system increases along with its openness. Issues arise regarding liability for damages to equipment, products, assets and people (see Hilgendorf 2014).

Liability issues

Another risk is the inadequate protection of sensitive corporate data. Plant operators entrust know-how and profitability in their systems. In I 4.0 design and configuration data are digital and are increasingly exchanged between companies and machines. The prerequisite for the acceptance of this kind of availability is the protection of sensitive corporate data (protection of expertise, protection against product piracy). Technical and legal safeguards are essential for an adequate level of protection (see also Chap. 4.7).

Protection of corporate data

I 4.0 calls for increased data protection requirements – for example due to the technical possibilities of collecting and evaluating information about the health or quality of task performance of employees in Smart Factories (acatech 2013, 64). The greater involvement of customers and their interests and usage patterns in value networks also leads to risks regarding the protection of personal data (see also Chap. 4.7).

Protection of employee and customer data

I 4.0 leads to new forms of human-machine cooperation, which entail new challenges for labour law and occupational safety law. Heterogeneous demands of employees concerning work organisation, job design, flexibility and compatibility must also be addressed by companies through correspondingly flexible models. Moreover, social security systems must be adapted to new and more flexible working and living models (see IG Metall 2014). Suggestions include, for example, the right to be temporarily inaccessible to reduce stress (Baumgarten et al. 2014).

Labour Law

Adequate regulatory frameworks are to establish legal certainty, ensure the feasibility of regulations and strengthen acceptance, responsibility (e.g. liability) and competition (e.g. reduction of trade barriers). The high dynamics of development will pose a fundamental challenge for the state of law. Rapid innovation cycles lead to a continual need for adjustment and a chronic lack of enforcement. New approaches intend for the examination of legal compatibilities of technologies to be performed *before and during* their development (acatech 2013, 27). Overall, the legal challenges in relation to I 4.0 are considered to be substantial and their solution represents a critical success factor. “Solution” does not necessarily mean more legislative action, rather a mix of instruments is often required which must consist of legal, technical and political components (acatech 2013, 65).

Challenges

5 Implementation Status

5.1 European Union and Member States

One of the European Commission's stated priorities is the establishment of a single digital market, for which there are currently 16 initiatives (EC 2015f). In addition, the European Commission has recently declared the digitalisation of the industry and a corresponding innovation strategy for the European manufacturing sector to be a high priority. Alongside a row of EU initiatives⁸ there are national initiatives e.g. in Germany, Finland, Poland, the Netherlands, the UK, Belgium, France, Portugal, Spain, Greece, Italy and Austria.

The aim is to develop pan-European platforms to expand the EU-initiatives and link them with the national initiatives (EC 2015a). The *Strategic Policy Forum on Digital Entrepreneurship* drew up a plan for the digital transformation of European economy (EC 2015e). EU-Task Force for Advanced Manufacturing aims to contribute to the modernisation of manufacturing companies within the EU. Advanced Manufacturing is one of the six Key Enabling Technologies (KETs), which serve as the basis for innovation in all industrial sectors. The European Commission promotes investments in KETs and the access of SMEs to KETs technology platforms (EC 2015b, c, d). The European Factories of the Future Research Association (EFFRA) promotes the development of innovative technologies within the manufacturing industry and was founded by the technology platform MANUFUTURE and key industrial associations. EFFRA established the public-private partnership „Factories of the Future PPP” with the aim of supporting European SMEs in adapting to global competitive pressures through the development of key technologies (Günther 2014).

Indicators for progress in digitalisation include e.g. the automated data exchange between manufacturing companies, suppliers and customers or the use of RFID technology⁹. There are many efforts made by the industry, science and politics in Europe to promote the areas M2M (Machine to Machine), WSN (Wireless Sensor Networks) and RFID (Radio Frequency Iden-

*EU initiatives
for the digitalisation
of production*

*Automated data
exchange as indicator
for implementation*

⁸ Examples are Application PPPs, I4MS, Smart Anything Everywhere – SAE, and ICT PPPs.

⁹ The percentage of companies with automated data exchange lies in a range of 8% in Romania, 18% in Austria up to 26% in Denmark for Member States (Eurostat 2014).

tification) in the context of the Internet of Things (IoT)¹⁰ (Gubbi et al. 2013; IERC 2015). Regarding the state of implementation of I 4.0 on the international level there is currently still a lack of solid and comparable data¹¹.

5.2 Germany as Pioneer

Platform Industry 4.0

Already in early 2011 the “Forschungsunion Wirtschaft – Wissenschaft” (Research Union Economy – Science) promoted “Industrie 4.0” as a future project at the Hanover expo in Germany (Kagermann et al. 2011). In 2013 three industrial associations – BITKOM (information economics, telecommunications and new media), VDMA (machine and plant engineering) and ZVEI (electrical and electronics industry) – founded an I 4.0 initiative; and in March 2015 two federal ministries – the Federal Ministry of Education and Research and the Federal Ministry for Economic Affairs and Energy – have taken over the coordination of “Plattform Industrie 4.0” (Platform Industry 4.0). In total they provide € 200 million in research funding. Focus points include SMEs, standards, IT security and qualifications (BMW 2014, 2015; BMBF 2015a; BMBF 2015b).

Standardisation and first pilot projects

Currently several I 4.0 projects and initiatives are ongoing on the state level, for example in Baden-Württemberg, Bavaria and Thuringia as well as in several regional joint initiatives. The Fraunhofer Society founded the international open data room “Industrial Data Space”. Companies gain access in order to find safe solutions for the digitalisation and changing production and business processes by adhering to common standards (Fraunhofer 2015). Overall it is expected that the fields of mechanical and plant engineering, electrical engineering, automotive manufacturing, agriculture and ICT, but also the chemical industry, will benefit the most from I 4.0 (Bitkom & Fraunhofer 2014). Fraunhofer is planning the construction of Germany’s first distributed I 4.0 production system in Karlsruhe, Lemgo and Ilmenau for testing I 4.0 technologies (Fraunhofer IOSB 2013). In addition there are pilot projects by major companies such as Audi, Bosch, Siemens and Trumpf for networking system processes. Siemens, for example, has equipped the first plant with smart machines (Hessman 2013). By 2016 four pilot applications for I 4.0 should have been constructed in Germany (Schneider 2014a).

¹⁰ At this point only selected examples are mentioned. In addition to several large research projects on the IoT promoted within the framework programmes (e.g. CASAGRAS2, IoT-A), the European Research Cluster on the Internet of Things (IERC) is also doing research on future IoT solutions. Other initiatives are developing large testing environments in Spain, England, Germany, Serbia and Australia (IoT-Initiative, Smart Santander Project). New approaches for IoT-infrastructures are being researched within the Italian project Netergit (Shin 2014). In 2015 Spain established the “Startup boot camp” in order to promote IoT-oriented enterprises and innovation.

¹¹ Possible indicators for the implementation at the enterprise level include: an increased use of information technology, modeling and simulations, automated data exchange between manufacturing companies, innovative management of global supply chains or an increase of flexibility in production (Shipp et al. 2012).

German SMEs recognise the value of I 4.0 in particular in the areas of networking equipment, the supply chain, order processing and shop floor management (Fraunhofer IAO 2014). The majority of German industrial companies, specifically SMEs, have, however, not yet adopted the topic of I 4.0 (acatech 2013, DB 2014).

*Not yet broadly adopted
– SMEs with
reservations*

At the country level, the United Kingdom and Germany are planning a joint investment of € 100 million in IoT projects, with the first aim being the development of faster mobile Internet access (5G) (BBC 2014). The United Kingdom is pursuing the so-called “Future Internet Initiatives” (Shin 2014) with Siemens and Hewlett-Packard having constructed a first digital factory in 2014 in Coventry (Nathan 2014).

5.3 Further Developments at International Level

As stated above, the United Kingdom and Germany are jointly funding the development of faster mobile internet access (5G) and a first digital factory has been constructed by Siemens and Hewlett-Packard in Coventry in 2014 (BBC 2014; Nathan 2014). The innovation centre for high-quality production attempts to support I 4.0 applications on their way to marketability (Catapult 2015).

*First digital factory
in the UK*

For the time being, progress in the implementation can be observed through the development of strategic funding and innovation platforms. Large governmental and industrial initiatives to further develop the IoT can be found in the USA, China, South Korea, Japan and Australia; this includes Smart City initiatives, Smart Grid programmes with smart metering technologies and the introduction of broadband internet (acatech 2013; Gubbi et al. 2013; Shin 2014; GSA 2014, Yanrong et al. 2014). The IPSO Alliance has been working on the establishment of the Internet Protocol as the basis of communication of Smart Objects along with over sixty member companies since 2008.

*Strategic funding
programmes*

There is close collaboration with standardisation bodies such as the IETF, IEEE and ITU (Gubbi et al. 2013; IPSO 2015). Japan has been working on making IT available anytime and anywhere since 2006 (Shin 2014, Myoken 2008). Humanoid robots are already being used in a pilot project of a mechanical engineering company in Yokohama, which are expected to achieve 80% of the productivity of a human worker (Roland Berger 2014a). In Brazil, for example, the very low automation rate (as measured by the use of industrial robots) makes the implementation of I 4.0 difficult (Schneider 2014b).

Innovation platforms

5.3.1 USA

Cyber Physical Systems as US version of I 4.0

In 2011 the Obama administration invested over \$ 500 million in the Advanced Manufacturing Partnership (White House 2011). The financing of projects concerning Advanced Manufacturing was increased in 2013 and the “National Network for Manufacturing Innovation” (NNMI) was established (Kurfuss 2014). A total amount of \$ 2.2 billion were made available for the modernisation of manufacturing industries (Sabo 2015). The NIST (National Institute of Standards and Technology) is leading the Advanced Manufacturing National Program with the aim of implementing technologies in the manufacturing industry. To achieve this, a framework for the standardisation of systems has been developed in the course of this programme (NIST 2015). The National Science Foundation is promoting projects regarding “Cyber-Physical Systems” since 2009 (Hinrichsen & Jasperneite 2013). In the US the involvement of SMEs is also seen as central for the implementation of I 4.0, in particular through the umbrella organisation Manufacturing Extension Partnership (MEP). In the course of networking activities, the Industrial Internet Consortium (IIC) was founded in 2014. It brings together organisations and technologies of the industrial Internet and is meant to identify and bring together best practices. Reference architectures and interoperability frameworks are also promoted (IIC 2015a). The US government is investing more than \$100 million in CPS research (Sabo 2015 with reference to Riemenschneider 2014). The University of Berkeley has started a large initiative with the Smart Cities Research Centre, to deal with the subject of complex systems. The DARPA (Defence Advanced Research Projects Agency) has also launched competitions for humanoid robot systems and unmanned land vehicles and is thus an important promoter for the development of complex ICT systems (Prem & Ruhland 2014).

5.3.2 China

World’s largest M2M market

China is making great strides in the area of IoT and is, according to some experts, more advanced than Europe and the USA in this respect. Asia has 50 million Machine to Machine (M2M) connections, more than a quarter of the global M2M market in 2013, and currently has the largest regional M2M market (GSMA 2014). China is pursuing the “National IoT Plan” of the Ministry of Industry and Information Technology (Shin 2014). Central themes include Smart Grid, intelligent transport, Smart Logistics, Smart Home, industrial control and automation, healthcare and defence. In 2014 the establishment of a Smart City fund, endowed with € 7.5 million, was announced (CBR 2014). The European Commission and China have come to an arrangement regarding the development of faster mobile Internet (5G by 2020), in which European telecommunication companies are to gain better access to the Chinese market and research funding (EC 2015g).

6 Situation in Austria

6.1 Starting Point

The manufacturing industry is of great importance for the status of Austria as a business location. Around 616,000 people are currently directly employed in around 25,000 companies in the manufacturing sector in Austria. Jobs in the industry also create more jobs in upstream and downstream service sectors. Companies of the manufacturing sector achieved a gross value of € 48.3 billion for the fiscal year 2012. The industry is responsible for 19% of Austrian gross value added and for two thirds of Austrian exports. Around 30 major Austrian production companies are deemed to be leading companies and rank among the world leaders. However, 99.6% of industrial companies¹² are small and medium-sized enterprises (SMEs), which generate 58.8% of value added. Two thirds of workers are employed in SMEs.

Fundamentally, Austria has very good conditions for I 4.0: The “Bloomberg Innovation Index 2015” lists Austria as one of the five top locations worldwide for the area “Manufacturing” (production processes and manufacturing capacities).¹³ The “Industry 4.0 Readiness Index” also judges Austria (together with Germany, Sweden and Ireland) to be one of the countries with the best conditions for implementation (Roland Berger 2014a). Austria’s strengths in the manufacturing sector are in the fields of electronics, mechatronics, pharmaceutical industry as well as paper production (KMU Forschung Austria 2015, Wasserfaller 2014). Between 15-34% of companies from the mentioned sectors conduct their own research and therefore raise high R&D investments (mainly in the fields of electrical equipment, automobile and vehicle production) (Prem & Ruhland 2014).

However, the concept of Industry 4.0 seems to have not yet arrived at the majority of Austrian industrial enterprises: according to a recently conducted survey by Gallup for FESTO, 53% of the surveyed industrial executives were not familiar with the term; around a fifth consider it a temporary hype (FESTO 2015, 22f.). Moreover, according to other sources, every second company lacks professionals with combined IT, production and logistics knowledge. Exactly these skills will however be needed due to the new production processes in I 4.0 (CSC 2015). Smaller and medium-sized enterprises are faced with special challenges, such as limited investment budgets for automation and IT-know-how. On the other hand, small lot sizes and many different product lines are typical for SMEs, for which I 4.0 holds many promises (see Chap. 3; acatech 2013; Bleicher 2014, Industrie-web 2014). Currently only a few Austrian companies are occupying themselves with Big Data applications, SMEs in particular are rather skeptical

*Good conditions
in Austria*

*Low adoption rate
of I 4.0 in SMEs*

*Special challenges
for SMEs*

¹² ÖNACE Sections B-S, Statistik Austria.

¹³ <http://www.bloomberg.com/graphics/2015-innovative-countries/>

in this regard as they assess the data to be “unmanageable” (Köhler & Meir-Huber 2014). At the same time there are many innovative SMEs which could collaborate with business partners and/or public research institutes (IIT 2015).

6.2 Distribution Status of Innovative Production and Process Technologies

It is possible to describe the distribution of production technologies, which are gaining importance in the context of I 4.0, through the European Manufacturing Survey (EMS) from the year 2012.¹⁴ The technology of robotics and automation as well as digital factories and IT networking were surveyed among other things.

I 4.0 relevant applications already in use

The results of the EMS for Austria (see Figure 1) show that innovative, industry-relevant applications are already being used to varying degrees in the Austrian manufacturing sector. Most commonly used are robots and handling systems, followed by Supply Chain Management and automated warehouse management systems. To date, these technologies are implemented in more than a third of the around 250 Austrian production companies surveyed.

The implementation of I 4.0 is a gradual process, which will take place in different sectors at different speeds. Therefore, differences according to technological intensity of the companies surveyed can be seen. Companies in the high-tech industry are pioneers in the advanced application and use of virtual reality and solutions for human-machine cooperation.

Large companies as pioneers

In addition, a large effect of company size can be observed. Large companies (250+ employees) deploy the mentioned technologies the most, followed by medium-sized enterprises (50-249 employees) and small businesses (up to 49 employees). Knowledge management systems, virtualisation, life cycle assessments and automated logistics are already quite widespread, in particular in large companies. In contrast, relatively few small businesses use advanced production and process techniques. Handling systems and industrial robots are the exception, with one in five producing small businesses already using these technologies.

¹⁴ The European Manufacturing Survey (EMS) measures the use of technical and organizational innovations in production and the achieved performance improvements in the manufacturing sector. Available data for Austria stems from four survey rounds, whereby the last survey was held in 2012 (enterprises of manufacturing sectors with 20 employees or more, a total of 250 businesses for the year 2012; representative for all businesses in the manufacturing sector).

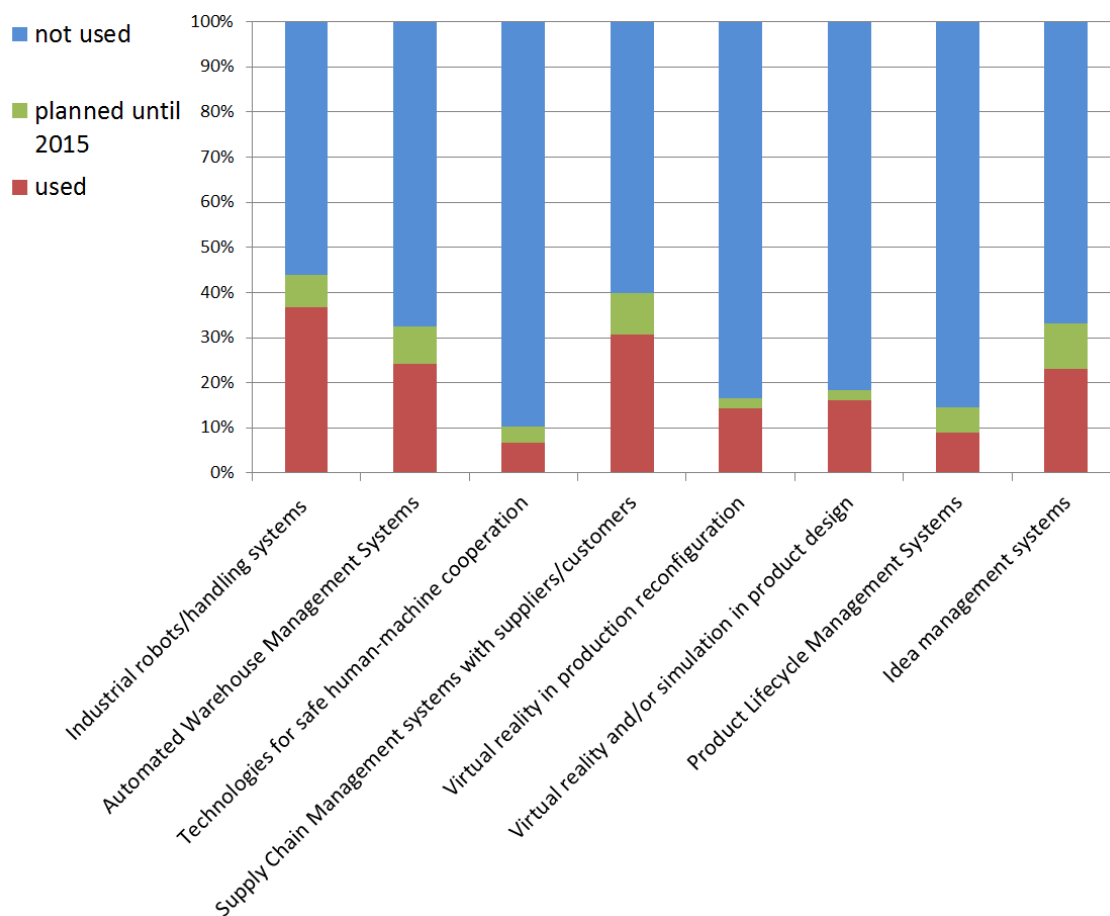


Figure 1: Use of selected production technologies in Austrian manufacturing
 Source: European Manufacturing Survey (2012), calculation AIT

6.3 Industry 4.0 Initiatives in Austria

In Austria, one of the first impulses for tackling the subject of I 4.0 was given by the initiative “TUWin 4.0”, which was founded in spring of 2013 at the TU Vienna. At the end of 2014, a national “Platform Industry 4.0” was launched at the suggestion of the industry and on initiative of the Austrian Ministry for Transport, Innovation and Technology (BMVIT). At the end of June 2015 the association “Industry 4.0 Austria – the platform for intelligent production” was founded. The platform is designed to coordinate and interlink existing and future activities, initiatives and measures at the federal and state level. Founding members are BMVIT, the Federation of Austrian Industry (IV), the Chamber of Labour (AK), the production union (PRO-GE), the Association Machinery & Metalware Industry (FMMI) and the Association for the Electrical and Electronics Industries (FEEI).

BMVIT initiates the national Industry 4.0 platform

*Target: competitive
production and quality
employment*

The platform is to contribute to creating and ensuring competitive production and quality employment at a high level, and is to strengthen Austria's position as a sustainable production site. Future developments and innovations in industrial production (I 4.0) should be used for all involved parties and risks should be minimised.

Four working groups of the platform are dedicated to the topics "human in production", "research, development and innovation", "communication, framework conditions and analytics" as well as "regional strategies".

*Endowed professorships
and pilot plants as
new promotional
instruments*

Since 2004 the BMVIT has invested a total of € 1 billion for the research and development of technologies or processes, which also form the basis for I 4.0 (Wiesmüller 2014). For 2015/2016 around € 250 million in subsidies are expected to flow into the improvement of performance of the industry from the BMVIT (Zimmermann 2014, EC 2015a). The funds are invested not only in R&D programmes such as "production of the future", "ICT of the future" and "FFG basic programmes", but also in endowed professorships surrounding I 4.0 and I 4.0 pilot factories.

The first of these pilot factories opened in late August 2015 at the Technology Centre aspernIQ. On initiative of the BMVIT and with support of the City of Vienna, the Vienna University of Technology developed a factory in which local companies can experiment and gain experience in order to adjust to the future of industrial production. The factory has a focus on human-centred cyber-physical production systems (HCCPPS) and is to find solutions for SMEs which can be implemented swiftly (Gerhard 2014). Furthermore, the pilot plant is to be used as a learning laboratory for education and training. In total € 4 million will be invested in the pilot plant by 2017. Half of this amount is funded by the BMVIT, the rest will be invested by the TU Vienna and participating companies¹⁵. The pilot plant will continue to grow until 2017: The Vienna Business Agency is planning to construct their own factory building for the pilot plant in the immediate vicinity of the current location. Three further pilot plants are to be opened in other parts of Austria by 2017. The BMVIT is planning the invitation to tender for late 2016.

In autumn 2014 the BMVIT and the Marshall Plan Foundation promoted three endowed professorships in Tirol, Styria and Vienna for production and I 4.0 with a total of € 5 million (see appendix). They are to improve cooperation between science and industry as well as training opportunities (BMVIT 2014b). In 2015, four more endowed professorships devoted to I 4.0 followed in the fields of logistics, data science, integration and flexibility and lightweight construction/materials (FFG 2015).

*Broadband billion
accelerates
infrastructure expansion*

Moreover, the so-called "broadband billion" is promoting the expansion of high speed Internet by 2020, which is a prerequisite for networking in I 4.0; € 300 million are to be invested in 2015 (BMVIT 2014a).

¹⁵ Further details on pilot plants can be found in TU Wien (2015).

At the national level, the BMWFW is also taking an active part next to the BMVIT in the funding policy and coordination of matters relating to I 4.0, assisting in thematic prioritisation in various R&D programmes managed by the FFG and aws. This includes the promotion of I 4.0 projects in FFG programmes such as the “service initiative” and “research skills for the economy” with a total of around € 15 million in funding for the years 2014 and 2015, as well as “Research Studios Austria” with a tender of € 10.6 million in autumn of 2015. With the aws-funding programme “proTrans – I 4.0” the BMWFW is providing funds of € 6 million for I 4.0 projects for the years 2014/15. The goal is strengthening SMEs and assisting them in research, development, and innovation services regarding the subject I 4.0. There was a pilot project for established growth-oriented companies in October and November 2014 in which staff costs, consulting, feasibility studies and consumable supplies were funded (aws 2014).

BMWFW places a focus on I 4.0 in funding programmes

In addition, the multi-annual programme of the ERP reserved € 50 million for loans with a focus on “Future I 4.0”. Furthermore, the National Cluster Platform, which was initiated 2008 by the BMWFW, has defined Industry/Production 4.0 as its own central focus and has established its own special working group “I 4.0 and innovative services” in the summer of 2014 (BMWFW 2015).¹⁶

The Federal Council of Austria is currently also active regarding the topic “Digital Transition”. Together with the democracy platform “#besserentscheiden”, ideas regarding “digital transition and politics” are being collected and debated in accompanying discussion events since summer 2015. The question, which legal and political changes are necessary in order to use digital transition in society and economy as an opportunity, is central. The subject of I 4.0 is explicitly mentioned. As a concrete result of this process, a green paper will be developed, which will serve as preparation for a federal inquiry. Concrete demands are to be decided by the end of 2015 by the government and National Council (#besserentscheiden 2015).¹⁷

Federal Council developing a green paper on “Digital Transition”

On the industrial side there are companies such as Infineon Austria, Siemens or AT&S which can be considered I 4.0-pioneers in Austria. In September 2014 the establishment of the “pilot room I 4.0” has begun at an Infineon site in Villach. In total up to € 290 million are to be invested in this local extension as well as research and development in Villach by 2017. In this new factory part I 4.0 a new concept with interacting automated production systems and digital information technologies are to be implemented (Austria Innovativ 2014; economy austria 2014).

Industrial pioneers pilot new concepts

On the provincial level, Upper Austria and Styria are considered to be pioneers in I 4.0 initiatives. Upper Austria is to be expanded into a model region for Smart Production (Wasserfaller 2014) and in July 2014 the “Platform I 4.0” was founded. The Federation of Austrian Industry recognises

Even the federal states are active in matters I 4.0 in various ways

¹⁶ Source: BMWFW (2015). I 4.0 und digitale Produktion. Wien.

¹⁷ Source: #besserentscheiden (2015). Digitaler Wandel und Politik, www.besserentscheiden.at/#!digitaler-wandel-und-politik/s5tlb, accessed 13.10.2015

favourable conditions for the transition to I 4.0 in Upper Austria, seeing as the classical engineering disciplines, IT and logistics are already established there and merely need to be networked and aligned (IV Oberösterreich 2013). The same can be said for the “Innoregio Süd”, the innovation network of Styria and Carinthia (IV 2014). Styria and Upper Austria plan to jointly set up a model region and cooperate more closely in regional policy in order to pool competences of leading companies and research institutions (Bast 2014). Regarding SMEs, large potentials are seen in the services sector. The SFG (Styrian business development) is providing € 1.5 million for a project in the area “Smart Production and Services” (SFG 2015).

An overview of the main I 4.0 activities/networks at the provincial level can be seen in Table 1 of the appendix (Industriemagazin 2015).¹⁸

6.4 Research and Development

Roadmap for complex ICT systems

The BMVIT has published an Austrian roadmap to mastering complex ICT solutions (Prem & Ruhland 2014). Austria’s competence areas and strengths regarding I 4.0 lie in the fields of micro-electrics, IT security and real-time systems, according to this study. At the interface of these three areas there is the potential of finding solutions for complex ICT systems such as CPS. It is recommended that Austria build on these strengths and focus on application areas such as the automotive industry and aeronautics. Strengths can also be identified in the areas of secure systems and embedded systems; two areas which should be more closely interconnected. The areas of power electronics and safety of microelectronics can be further expanded through the collaboration of different actors (Prem & Ruhland 2014).

Central role for autonomous systems

Autonomous systems are hereby expected to play a central role for the future. By 2020, mass produced semi-autonomy, for example in vehicles or robots with self-maintenance, is expected. The use of adaptive systems adapting to their environment and users is considered to be a priority objective which can be achieved in the short term, and is expected from 2015 on. However, complex interfaces and intelligent sensors are required for advanced interactions, which are not expected to be in development until 2025.

Another important topic falls within the same time frame: the certification of subsystems and the convergence of partially certified systems to form complete systems. This depends on international regulations and standardisations (see above Chaps. 4.8 and 4.9).

The issues of safety and security are considered a research priority within the short term from 2015 onwards. Connections to the cloud of real-time systems will increase with the controllability of safety aspects (2020-2025).

¹⁸ Source: Industriemagazin (2015). Vollvernetzt. Ausgabe 09/2015. Wien.

The lack of research on the adaptation of security of existing systems (legacy systems) poses a continuous challenge. The constant development of system environments lead to a large number of legacy systems, which cannot simply be replaced due to cost reasons, but must be adapted. An industrial interest in the topic “system evolution” is expected to arise from 2020 onwards.

*Ongoing adaption
of old systems*

Embedded systems, mobile communications, visual computing, artificial intelligence and semantic systems, electronics, mathematics and electronic fundamentals form the existing priorities of the scientific and industrial ICT research in Austria. The areas of real-time systems, security, microelectronics, formal verification, artificial intelligence and mathematical and logical fundamentals are considered to be specific strengths (Prem & Ruhland 2014).

7 Interim Conclusion

In leading industrialised countries a new stage of modernisation of production systems is on the agenda, with the vision of a comprehensive digital network. In German-speaking countries the term for this concept is “Industry 4.0”, also known internationally as “Industrial Internet”, “Smart Manufacturing” or “Smart Factories”. Key drivers are global competition in the marketing of industrial and commercial products, the targeted expansion of the industrial quota as part of the re-industrialisation of EU-Europe, as well as a wide range of new technologies. The heart piece of the vision of I 4.0 is the networking of industrial value chains to cyber-physical systems (CPS) on the basis of the Internet of Things and Services. Within these new systems, humans, machines, systems, robots, logistic systems, workpieces and materials all communicate with each other via built in hardware and software, Internet-based radio technologies and new interfaces, allowing a new level of decentralised, self-regulating, flexible production.

I 4.0 is a project with enormous visibility, mainly promoted by business organisations and their leading companies, the IT industry and IT consulting companies, and is now adopted by industrial and innovation policy. The implementation promises high economic benefits: an increase of productivity, resource efficiency, flexibility, value added, and in the long term positive effects on employment. Furthermore, I 4.0 is to contribute to a qualitative improvement of labour and to support sustainable development. However, there are also concerns: the rising degree of automation could cost more jobs than are created, and work could become more psychologically burdensome and be degraded to residual functions.

There is large uncertainty concerning the actual impact of the implementation of I 4.0, as the visions and potentials have only partially been implemented in certain areas and mainly by industrial leading companies. It is, however, a certainty that there will be significant changes in the foreseeable future regarding production environment, including upstream and downstream sectors of the entire value chain. This conclusion is not based solely on the outlined constellation of driving forces but also on new business models and trends of digitalisation and virtualisation which are already being exercised in the service sector. We have already begun treading the path to I 4.0; digital networking will also shape the industrial future. Questions where this path will lead, or whether it will be expanded into a high-level road and how this road will run, are still largely open. It is therefore necessary to proactively address the range of potential impacts, risks and opportunities, as well as emerging challenges, in order to derive possible options for a desirable development of I 4.0. The central part of this paper made a start on the basis of several important fields of impact.

Integration of value chains – the centrepiece of I 4.0

Industrial associations, leading companies and consulting firms push I 4.0

Great uncertainty about actual effects

Changes in manufacturing landscape are coming

*Forward-looking
proactive shaping is
necessary and possible*

According to estimations, the conditions for implementing I 4.0 in Austria are favourable in principle. Nevertheless, the manufacturing sector as a whole is only at the beginning of adopting the subject. The opportunity to actively design and support the most positive development of I 4.0 possible, in the interests of all concerned, through frameworks and political instruments is all the more present.

*Further clarification
especially needed in
areas such as:*

New business models

Labour and employment

Education and training

Safety and security

In some areas the challenges and tensions regarding the generation of positive frameworks are relatively clearly identifiable, in others there is still considerable need for clarification. This applies to the area of new business models and the impact on SMEs, suppliers and industry structures. The subject of work and employment needs deeper investigation, due to its far-reaching social consequences. The introduction of integrated production systems are likely accompanied by a lasting change in the relationship between humans and machines, as well as for organisational and work structures, for which the consequences are still difficult to predict. Similar can be said for the area of education and training, in particular because of the very contradictory and heterogeneous assessments of perspectives. Lastly, the impact on safety and security deserves to be examined in detail, because a new quality of dependencies and risks for production systems and sensitive personal and corporate data arises, due to the automation and networking of I 4.0.

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Appendix

Table A1: Activities on Industry 4.0 in Austria

Province	I 4.0 Activities	Agents	Involved	Aims (Budget)
Burgenland	Programme RTI-Strategy 2025 [Eisenstadt]	Burgenland industry	Industry, Burgenland Chamber of Commerce	Increasing R&D share in intelligent manufacturing
Carinthia	Industry 4.0 pilot lab [Villach]	Infineon Austria	Infineon	Pilot factory based on advanced cyber-physical systems
	Platform Industry 4.0 [planned; Villach]	Province of Carinthia	Carinthia Association of Industry, key companies	Strengthening regional "hidden champions"
Lower Austria	Project Enterprise 4.0 [St. Pölten]	ecoplus cluster initiatives in mechatronics and plastics	Lower Austria Association of Industry/Cham. of Commerce	Strengthening digital innovation capacity
	Bachelor course Smart Engineering [St. Pölten]	FH St. Pölten	National & internat. industrial partners	Understanding intelligent information flows
Upper Austria	Programme Production Location 2050	Province of Upper Austria [execution by FFG]	Upper Austrian partners from industry & research	Digitalisation of production, automation in light weight construction [3 mio. euro]
	Platform Industry 4.0	Province of Upper Austria	e.g. Rübiger, Fill, Voestalpine group, Greiner, JKU, FH OÖ	Deeper understanding of integration issues
Salzburg	Training network Industry 4.0	Research Studios Austria	Companies from Salzburg & Upper Austria	Networking in technology areas of the future
Styria	Endowed I 4.0 chair in High Performance Materials [Leoben]	Montanuniversität Leoben	Voestalpine group, Ebner Industrieofenbau	Novel alloying and processing-concepts for enhanced steel goods
	Programme Smart Production & Services	Province of Styria [execution by SFG]	Styria Association of Industry	Impulses from new forms of work and production [max. 1.5 mio. euro]

Province	I 4.0 Activities	Agents	Involved	Aims [Budget]
Tirol	Endowed I 4.0 chair in Advanced Manufacturing	University of Innsbruck	e.g. Getzner Textil, Fussenegger, Grabher, Benninger, Alge, Schoeller	New production techniques for flexible technical textiles, lightweight structures and sensors
	R&D Platform Tirol	Association of Industry Tirol, Innsbruck	e.g. Siemens, Jenbacher	Strengthening research and innovation space Tirol
Vorarlberg	Industry 4.0 Network Vorarlberg	Businesses Vorarlberg	e.g. Vorarlberg Chamber of Commerce	Technology transfer
Vienna	Association Industry 4.0 Austria – National Platform on Intelligent Production	BMVIT	Siemens (directorate), PRO-GE, FMMI, FEEI, AK, IV	Generating new opportunities of growth and employment
	Industry 4.0 pilot factory	TU Vienna	e.g. Atos, Bosch, EMCO, evolaris, Festo, GGW Gruber, IGM Robotic Systems, Jung-heinrich, plasmo Industrietechnik, SAP Austria, Siemens Austria, Zetes Austria, ZOLLER	Increased machine intelligence and human-machine scenarios [ca. 2 mio. euro]
	Endowed I 4.0 chair in Production Research	TU Vienna	e.g. Hörbiger, Metal Essence, Geberit, GW St. Pölten, VOITH, Indat, Test-Fuchs, Miraplast, Research Tub, FFMI, FCIÖ	High variability of manufacturing processes with low batch size