



# Advanced industrial robotics: Taking human-robot collaboration to the next level

*Impact of game-changing technologies  
in European manufacturing*

**Future of Manufacturing in Europe**

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## Executive summary

Advanced robotics can be defined as a sub-field of traditional robotics, characterised by the use and development of ‘smarter’ robots which are able to operate in tougher and less structured environments, rely less on human intervention, and can interact with the outside world. The ‘advanced’ dimension of this strand of robotics is linked to the existence of enhanced problem-solving, mobility, resistance, sensorial, intelligence and adaptability capacities which are not generally found in mainstream robotics. Advanced industrial robotics (AIR) basically means the application of advanced robotics in industry settings.

Despite the existence of a formal definition of what the term ‘advanced’ refers to in the context of industrial robotics, in practical terms the notion appears to be considerably more nuanced. Some robots for instance may include certain ‘advanced’ functionalities without meeting all the criteria which would qualify them as advanced in absolute terms. In addition to this, the notion of whether a robot is advanced or not often depends on the particular industry, value chain or company in which it is being deployed. As such, experts also use a context-specific definition of Advanced industrial robotics.

Rather than being a market-based concept, advanced robotics is a function-based concept. As such, advanced robotics can be viewed as an enabling technology which can be deployed across a wide range of industrial sectors and value chains. In addition, given that Advanced industrial robotics draws from different technologies and disciplines into the development of a single device or robot (i.e. machine vision, artificial intelligence, machine-to-machine communication, sensors, and actuators), advanced robotics is better described as a ‘technology bundle’ rather than as a single technology. In general terms, Advanced industrial robotics are still considered to be in the early stages of deployment in manufacturing industries. The use of ‘true’ AIR appears to be mostly restricted to a number of large and/or high tech companies. Moreover, it is unclear whether AIR, that requires substantial investments, provides added value for mass production of relatively basic products.

Given the functionalities and capacities of AIR, this technology allows industrial automation to occur in tougher and less structured environments; to adapt to exogenous conditions; cooperating with current skilled workers; and ultimately replacing human intervention for specific tasks. This automation in new environments will increase productivity and reduce product defects, taking care of repetitive or dangerous jobs currently carried out by professionals in different industries. It will also help to boost the trends of affordable mass customisation and supply chain integration. Ultimately, this will have an impact in the broader economy, both from the perspective of consumers and producers.

These enhanced system abilities however, particularly when it comes to higher degrees of adaptability, interaction ability and autonomy, are fundamentally changing the nature of the human-robot relationship. More in general, this implies changes in the role of human intervention in the context of industrial manufacturing. On the one hand, the greater level of sophistication of advanced robotics compared to traditional robotics, increasingly allows for the automation of tasks, including non-routine tasks. On the other hand, human robot-collaboration will be further enabled given the fact that AIR is equipped with sensors and functionalities which make them safe for a human to be around (e.g. automatically shutting down when they come into unexpected contact with a human being). This represents a significant move away from the traditional scheme of robots traditionally placed “in cages” on shop floors, in order to keep them isolated from human operators and support staff.

The main drivers (and barriers) shaping the uptake of advanced robots in European manufacturing industry are financial and technological. AIR is mostly seen as an opportunity to achieve productivity gains, leading to improved economic performance. Company representatives met as part of the case study however mentioned that in addition to the financial benefits of AIR, improving working conditions for humans/ employees played an important role in their choice to purchase robots. Other drivers such as social, political, regulatory and environmental drivers appear to play a more limited role in the uptake of AIR.

Some (sub) industries are mature in terms of AIR utilisation and have been a cornerstone of the robotics market for several decades. Examples are electronics assembly, automotive parts manufacturing and automotive assembly, general production of metal, rubber or plastic parts, aerospace, and domestic appliances. However, given the cross-cutting nature of this technology, the potential for applications is fairly broad in terms of industries and value chains including food preparation, and manufacturing of soft products such as textiles, clothing and shoes.

The introduction of Advanced industrial robotics has the potential to considerably reshuffle the way in which assembly lines, production units, value chains are organised. First, the change most commonly associated with the use of AIR is the ability of industrial units or factories to develop more ‘agile’ and ‘leaner’ production processes. Agility generally comes in the form of production lines and processes which can be quickly adapted to respond to new and changing client demands (i.e. burst manufacturing for one-off products). Linked to this is the fact that AIR provides opportunities for resource efficiency gains, for instance through higher energy efficiency and fewer mistakes. Second, a certain degree of value chain integration is also expected to take place as a result of the uptake of advanced professional service robotics. For example, such devices make it possible to integrate production machinery, warehousing systems and production facilities into single cyber-physical systems. As such, the traditional frontier between the production and logistical tasks of manufacturing can be expected to become increasingly blurred. Third, an increased uptake of AIR will lead to a change in the robotics value chain itself. Suppliers, integrators and users are bound to collaborate more intensively which is already leading to new business models such as rental/leasing agreements, pay-on-production, predictive maintenance, etc.

While the implications of AIR on work processes and value chains are well understood, there is less information or evidence about the impact on work and specific aspects such as working conditions. When it comes to the potential of AIR to create or suppress jobs, the answer to this question appears to be far from straightforward. The information collected by means of this study, particularly through expert interviews, paints a very nuanced and fragmented picture. In principle, the introduction of more AIR will mean that, overall, the manufacturing process will require fewer jobs as several tasks (or even entire jobs) will be automated. This mostly concerns jobs that are made up of physical, manual tasks. However, it’s also explained that productivity gains due to the use of AIR (and advantages such as customised and higher quality products) will lead to lower prices and/or better products. This could mean that employment losses will be small. In addition, AIR is also considered to potentially spur job growth in specialised companies, such as those that manufacture robots and those providing robotics support services.

The incremental uptake of AIR solutions in manufacturing is expected to lead to the transformation of several existing occupations, as well as to the creation of new ones. AIR is expected to modify certain occupations (e.g. changes the types of tasks performed and the types of skills needed) as they become more focused on supervising the work of robots in performing tasks and collaborating with them. As such, occupations such as production line supervisor and operators, production or specialised services managers, or forklift operators are expected to undergo drastic changes and will require upskilling, mostly through on-the-job training. This will require significant investments in skills upgrading. The range of skills affected by the gradual uptake of AIR is very broad and includes engineering, data science, IT, mathematics, material/resource specific skills, equipment and machinery operation, and skills related to logistics and packaging.

The deployment and maintenance of AIR will bring about an increased need for certain types of occupations such as specialists in automation and programming, robotic systems integrators and robot maintenance. While these occupations are not entirely new, they are distinctive given the fact that they integrate a range of different skillsets and competences into a single occupational profile. This makes finding individuals with the right skillsets hard to come by in labour markets. For example, several interviewed industrial stakeholders cited difficulties in filling certain positions that require a mix of skills in engineering, IT and programming, and data and mathematics skills.

While AIR has the potential to improve the working conditions for specific types of occupations, there is also the potential for some drawbacks. In terms of job quality, the automation of manufacturing will result in fewer jobs requiring physical, manual labour (often associated with lower levels of education) but also less jobs that require specialised crafts. This shift away from physical, manual jobs is complemented by the improved ergonomics of the machines that workers interact with, as well as by an increased level of automation of hazardous and dangerous jobs. Contractual arrangements may be impacted by two emerging issues linked to the use of AIR: liability issues linked to potential accidents stemming from human robot-interactions; and privacy issues stemming from the collection of data (by robots) about human behaviour and performance. At this stage of AIR implementation, one can only speculate about the effects on work-life balance.

This study, particularly the expert interviews, provided some insights into the actions and strategies of public and private stakeholders in AIR. Trade unions, but also some politicians and governments, express some degree of reluctance to the ever-increasing use of AIR and automation in general. Their main concern is a too quick, too broad reduction in the number of jobs. In short: innovation is good, but changes can be too quick and not allowing persons and organisations to anticipate and adapt. This is also reflected in positive, yet nuanced support programmes of regional, national and EU level policy makers, under labels such as Industry 4.0, Factories of the Future and advanced manufacturing.

Trade unions do express positive views however when it comes to improving health and safety conditions for works, positions towards and inclination to acquire AIR skills appear to vary greatly between companies and between managers. While AIR technologies do not appear to be fully integrated into the curricula of education institutions and vocational training providers, some higher education institutions are moving fast to modernise their curricula. In close collaboration with industry, these higher education institutions increasing the attention of AIR-related skills into curricula (education as well as post-initial training) and in research programmes.

## Introduction

### Purpose and context of the study

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

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

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

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

To set the scene for this study:

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

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

The study about game changing technologies in manufacturing industries is part of the programme The future of manufacturing in Europe (FOME) financed by the European Parliament, under responsibility of DG GROW. The main theme of this programme is the revival of manufacturing in Europe. The economic and social importance of this revival are explained the 2014 European Commission Communication 'For a European Industrial Renaissance' (COM/2014/014/final). Under the umbrella of this policy agenda, specific policy actions coordinated by the European Commission address Key Enabling Technologies (such as ICT and biotechnology), research and innovation (e.g. the Leadership in Enabling and Industrial Technologies programme in Horizon 2020), the European internal market for products and services (e.g. standard setting for digital services), re-industrialisation of regions (e.g. using the Smart Specialisation Platform and the European Structural and Investment Funds), support for entrepreneurs and SMEs (e.g. the Enterprise Europe Network), skills development (e.g. the Erasmus+ programme) and collaboration between education institutions, research organisations and companies (e.g. the Knowledge and Innovation Communities within the European Institute of Innovation and Technology).

The FOME programme is executed by Eurofound, the European Foundation for the Improvement of Living and Working Conditions.

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

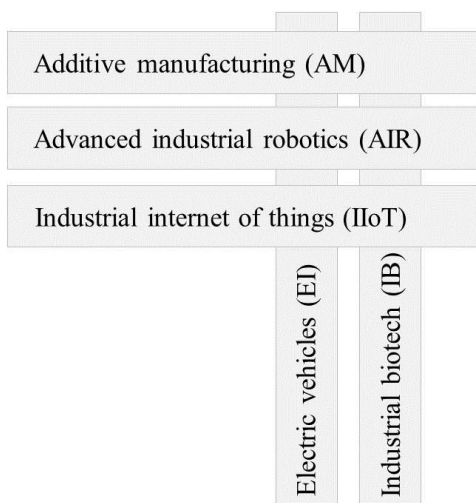
## Five game changing technologies

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

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

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

*Figure 1: Five game changing technologies*



*Source: Technopolis Group, 2017*

## Research methods used

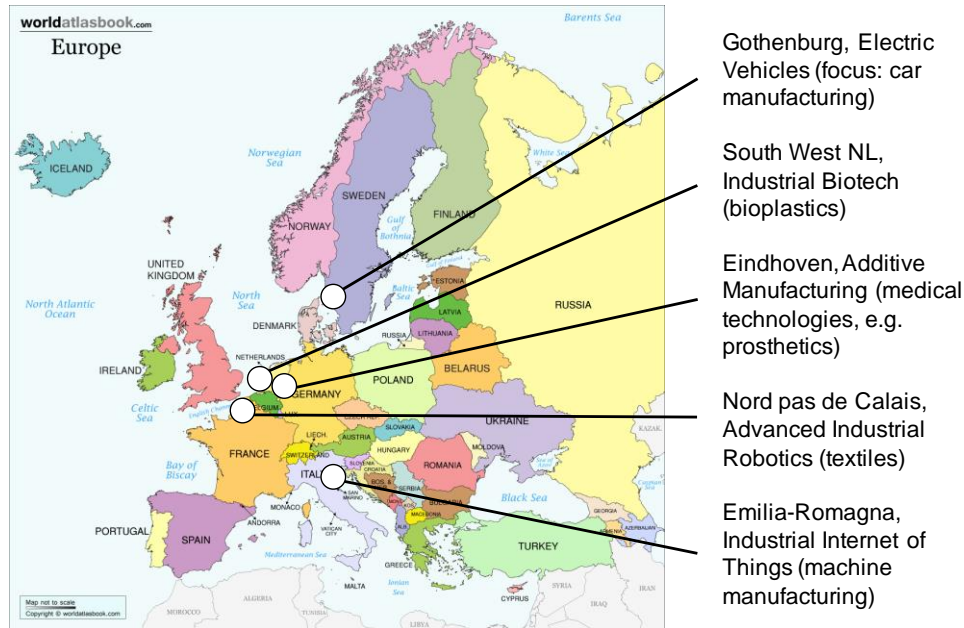
The study started with a structured literature review. Because the phenomena studied are quite recent, we used academic articles but also grey literature such as reports prepared for policy makers and industry associations and reports prepared by consulting firms. The Scopus database and Google Scholar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



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

The third and final step consisted of five regional case studies (one for each technology) with companies, researchers, cluster organisations and other stakeholders. In four cases, a workshop was organised. The case study about Industrial biotechnology relied on stakeholder consultation during a conference and a small-scale event. Figure 2 introduces the five regional case studies.

Figure 2: Five regional case studies



Source: Technopolis Group, 2017, based on worldatlasbook.com, 2011

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

### Outline of the report

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

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

## Characteristics and adoption of AIR

### Introducing AIR: the thin line between advanced and traditional robotics

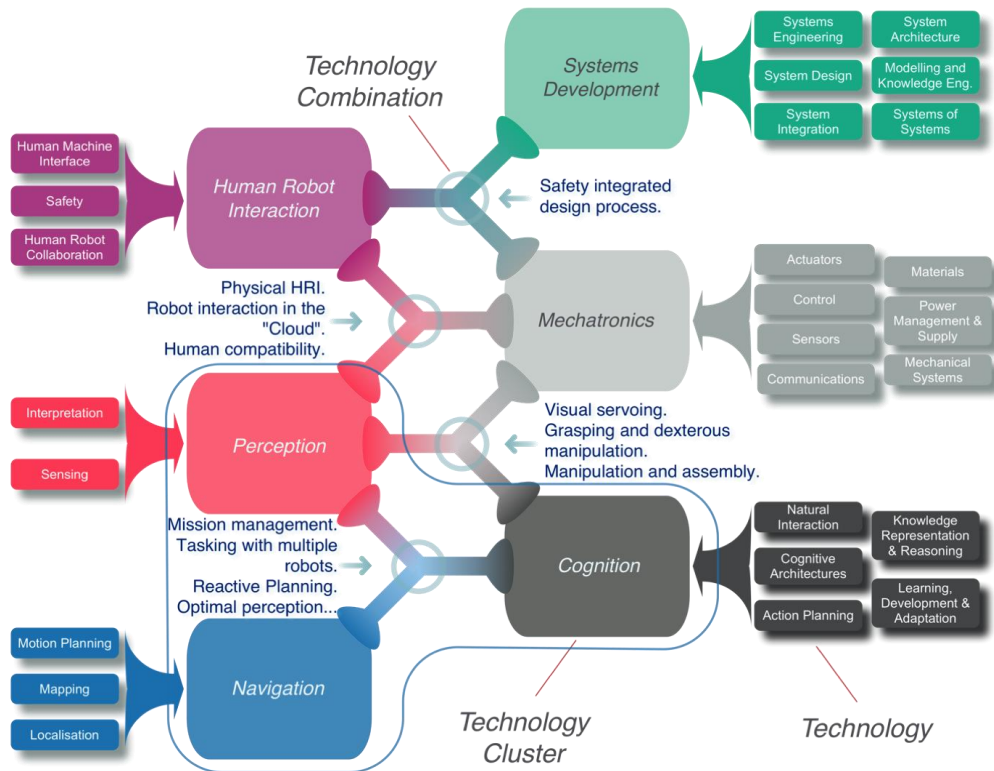
Advanced robotics can be defined as a sub-field of traditional robotics, characterised by the use and development of ‘smarter’ robots which are able to operate in tougher and less structured environments, rely less on human intervention, and are capable of interacting with the outside world. The ‘advanced’ dimension of this strand of robotics is linked to the existence of enhanced problem-solving, mobility, resistance, sensorial, intelligence and adaptability capacities which are not generally found in mainstream robotics (National Institute of Standards and Technology, 2011). The term Advanced industrial robotics (AIR) thus applies to robots working within *industrial* environments, which are equipped with advanced functionalities (for example, sensing potential collisions and halting or performing a programme motion with a small offset) allowing them to operate in less structured contexts.

Despite the existence of a formal definition of what the term ‘advanced’ refers to in the context of industrial robotics, in practical terms the notion appears to be much more nuanced. The border with ‘traditional’ or ‘non-advanced’ industrial robotics is blurred. Some robots for instance may include certain ‘advanced’ functionalities without meeting all the criteria which would qualify them as advanced in absolute terms. In addition to this, the notion of whether a robot is advanced or not often depends on the particular context in which it is being deployed.

Rather than being an industry-based concept, advanced robotics is a function-based concept. As such, advanced robotics can be viewed as an enabling technology which can be deployed across a wide range of industries and value chains (Robotics VO, 2013). Due to its tendency to draw from and integrate different technologies and disciplines into the development of a single device or robot (i.e. machine vision, artificial intelligence, machine-to-machine communication, sensors, and actuators), advanced robotics is better described as a ‘technology bundle’ (see Figure 3) rather than as a single technology (ITI Techmedia, 2008).

Traditional or ‘non-advanced’ industrial robotics has been around since the 1960’s and their technologies are mature; their markets well developed. Given the thin line between advanced and non-advanced robotics, it is very difficult to estimate the maturity and size of the AIR market. In addition, AIR being a ‘bundle’ technology, its level of maturity also depends to a certain extent on each of its individual components (for example, sensors, artificial intelligence, etc.). In general terms however, Advanced industrial robotics is still considered to be in the early stages of deployment in manufacturing industries. The use of ‘true’ AIR appears to be restricted to a limited number of large and/or high tech companies. Our workshop about the use of AIR in the textile industry in northern France confirmed this finding. In spite of this, recent trends show that the use of AIR is likely to further shift from large companies (such as Original Equipment Manufacturers) to small-and medium-sized enterprises located either upstream or downstream in the value chain. However, interviewees did mention the uncertainty as regards to widespread adoption of AIR: the flexibility of advanced robotics comes at a price, while mass production of relatively basic products may not require flexibility but ‘simple’ single-task robots.

Figure 3: Technology clusters in Advanced industrial robotics



Source: SPARC, 2014

### The game changing aspect of Advanced industrial robotics in manufacturing

The use of AIR in manufacturing industries presents game changing aspects at several levels. On their own and given their capacity to take the levels of production automation to a higher level, advanced robots present step changes in efficiency, productivity and quality of production for some tasks. However, this evolution fits into pre-existing patterns underpinned by constantly increasing levels of automation, driven by the uptake of different generations of robotics in manufacturing over the past five decades.

Advanced robotics on its own involves step changes in the following system abilities: adaptability, cognitive ability, configurability, decisional autonomy, dependability, interaction ability, manipulation ability, motion ability and perception ability<sup>1</sup>. However, it is important to note that step changes in system abilities are enabled by incremental technological improvements across the 'technology bundle' that industrial robots comprise and integrate. As a result, it is useful to think of AIR as an incremental evolution of different parts of this technology bundle, resulting in industrial robots that gain revolutionary capabilities (see Figure 3).

These enhanced system abilities, particularly when it comes to higher degrees of adaptability, interaction ability and autonomy, are fundamentally changing the nature of the human-robot relationship, as well as the role of human intervention in industrial manufacturing. The greater level of sophistication of advanced robotics compared to traditional robotics, increasingly allows for the automation of tasks - including non-routine ones - that have until recently been mostly performed by humans. This leads to displacement of humans in certain steps of the production process (i.e. highly hazardous ones). In many other cases, AIR continues (and changes) collaboration between robots and

<sup>1</sup> Derived from the 2016-2017 ICT and Robotics Work Programme of the European Commission's Horizon 2020 programme.

humans. This applies, for instance, to specific activities and tasks which still cannot be easily or fully automated. Human robot-collaboration will be further enabled given the fact that AIR is equipped with sensors and functionalities which make them safe for a human to be around (for example, automatically shutting down when they come into unexpected contact with a human being). This represents a significant move away from the traditional scheme of robots traditionally placed “in cages” on shop floors, to keep them isolated from human operators, assembly line workers and other staff. This is of particular relevance given the fact that a great majority of manufacturing tasks still requires some form of direct human intervention.

Typical examples of advanced robots that are blurring the line between human and non-human performed task in manufacturing are collaborative robots or ‘cobots’. These robots are designed to work *with* humans and not *for* humans, unlike traditional industrial robots. Due to their specific capacities to safely interact with humans, cobots act as an assistant, and are involved in complex, sensitive tasks that can’t be automated. Cobots are generally easy to program, and can thus be reprogrammed to performed different types of tasks at relatively low transaction/migration cost. Furthermore, they are capable of learning. Cobots are often light and mobile, which also means that they can be easily relocated.

*Figure 4: The Baxter cobot by Rethink Robotics*



*Source: <http://www.rethinkrobotics.com/baxter/>*

Table 1 on the next page summarises two of the game changing aspects of cobots and indicates the ground-breaking technologies behind them. As demonstrated, the game changing aspect of cobots is not linked to one particular technological development, but rather to the combination of several technologies.

*Table 1: two game changing aspects of cobots*

<b>Cobot characteristics</b>	<b>Description</b>	<b>Technologies</b>
<b>Safer</b>	Industrial robots are traditionally kept in cages and are isolated from humans in order to avoid accidents. Cobots have the ability to interact with humans due to their capacity to understand their environment and detect potential safety threats.	Detection sensors Force sensing
<b>Flexible / scalable</b>	Advanced robots are capable of learning, rather than having to be programmed. They are able to mimic humans for example, and memorise and repeat movements which are taught to them. Certain cobots are also capable of self-programming.	Deep learning Flexible actuators Advanced sensors Vision Force sensing

*Source: Technopolis Group, 2017*

Another game changing aspect of AIR stems from its ability to allow for new ways of organising production and supply chains. AIR's strong synergies with other technologies for manufacturing, particularly with the Industrial internet of things (IIoT), create the potential for profound restructuring of industrial activity. This is often referred to as Industry 4.0. Under the umbrella concept of Industry 4.0, AIT and IIoT are two of the main drivers of radical changes in the way production lines are set up and managed. Examples are real-time, data-driven management of teams of robots, but also supervised autonomy of robots. In both cases, the goal can be to continuously increase efficiency of the production process or to increase the quality of products (features, durability, customisation, etc.). There are many pilots to harness collaboration between robots within and across industries. One example is the recent partnership between Kuka and the Chinese technology giant Huawei. These companies created a joint team to explore using imitative deep learning techniques in advanced manufacturing environments<sup>2</sup>.

One of the key distinctive features of AIR is the ability for manufactures to set up leaner and more agile production lines, allowing quickly adapting to changing demands, and producing small batches of tailor-made products, at relatively low transaction costs. This capacity for AIR to lead to more flexible factories has profound implications on the business models of manufacturing companies and shall be explored in the following sections.

### **Fast, efficient and safe: why manufacturing companies invest in AIR**

The main drivers (and barriers) shaping the uptake of advanced robots in European manufacturing industry are financial and technological. This picture emerged quite clearly from the literature review and the expert interviews. Workshop participants mentioned that in addition to the financial benefits of AIR, improving working conditions for humans/employees played an important role in their choice to purchase robots. Other drivers such as social, political, regulatory and environmental drivers appear to play a more limited role in the uptake of AIR.

More knowledge about the capabilities of robots will help companies to explore the potential of AIR in their specific context, and to experiment and implement AIR. Especially robots that have a high

<sup>2</sup> <http://roboticsandautomationnews.com/2016/03/19/kuka-to-build-global-iiot-network-and-deep-learning-ai-system-for-industrial-robots/3570>

degree of autonomy (such as using artificial intelligence technologies) have the potential to greatly increase productivity. This includes productivity of the existing workforce, partly by making this process less dependent on human needs (in terms of working hours, team work, toilet breaks, etc.) and by allowing humans on activities where they add most value. AIR will reduce consumption of raw materials and generation of waste, for instance by making less mistakes. In addition, AIR has the potential to influence the design and functioning of value chains and production processes (as mentioned in section 0). AIR allows production systems to become more modular and flexible. These increased possibilities for ad-hoc reconfiguration of production processes, used for producing a broader range of (customised) products, make AIR a very appealing option for increasing productivity, diversification and competitiveness. All this makes a very strong case for the uptake of AIR.

*'A recent McKinsey study into disruptive technologies estimates that by 2025 RAS [Robotics and Autonomous Systems] technologies will have an impact on global markets of between \$1.9 and \$6.4 trillion per annum. One pan-national survey of industrial robot usage estimated that if the UK optimised its current RAS technology it would raise productivity in manufacturing by up to 22%, with a long-term employment increase of up to 7%.' (RAS 2020, 2014, p.9)*

Productivity and competitiveness gains as drivers of AIR uptake are compounded by additional factors, such as increasing wages for skilled employees and an ageing industrial workforce (especially in Western Europe). A substantial part of the industrial workforce retires between 2015 and 2025, which increases the momentum of AIR. The option of replacing some tasks and occupations with robots is becoming more attractive as the price of advanced industrial robots decreases and as the technology matures. While advanced robots are still expensive and price remains one of the strongest barriers to uptake, interviewees expect that the commoditisation of robot hardware will start showing some similarities to that of other business and consumer electronics. This will make new robots affordable not just for large companies but also for medium-sized enterprises, high-tech start-ups and even 'low-tech' start-ups that need a robot for specific activities.

The increased availability of robots with higher levels of versatility and of smaller size will further drive the uptake of AIR. Examples of providers of these robots are Universal Robotics' UR3, ABB Robotics' YuMi and KUKA Robotics' LBR<sup>3</sup>. As mentioned above, another factor is the potential of linking AIR to the Industrial internet of things and to explore additional advantages created by data-intensive production processes (within and between companies), artificial intelligence and managed or autonomous improvements of production processes.

Interviewees touch upon several other drivers for the uptake of AIR. The ever-increasing quality requirements of production processes, as well as health and safety requirements for human workers, can be addressed by means of AIR. Robots with better algorithms/intelligence can deal not just with stable and clear requirements, but can also meet these requirements in unstructured and dangerous environments. As such, the flexibility of robots is approaching the flexibility of humans. Moreover, the pressures to recycle more consumer waste products will also drive the uptake of AIR. Advanced robots can be used for rapid disassembly and recycling operations. For example, Apple is already piloting such ideas for the iPhone with its Liam recycling and disassembly robot<sup>4</sup>.

### **Applications of AIR in specific sub-industries: AIR as cross-cutting technology**

Several industries are very mature in terms of using AIR in production processes and have been an important client in robotics market for several decades. Examples are electronics assembly, automotive parts manufacturing and automotive assembly, general production of metal, rubber or plastic parts, aerospace, and domestic appliances. As a result, these industries are the major source for revenues for robotics providers and allow them to continue investing in robotics and AIR. However,

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<sup>3</sup> <http://www.roboticstomorrow.com/article/2015/04/automate-2015-new-era-of-industrial-robots/5840>

<sup>4</sup> <http://mashable.com/2016/03/21/apple-liam-recycling-robot/#TwedXAmkGkqQ>

pinpointing specific industries which make the heaviest use of AIR is often challenging given the truly crosscutting nature of this technology. In addition, it's believed that the use of AIR in specific industries which are part of larger value chains is currently 'under the radar'. This is for example the case of the textile industry which acts as a supplier to a range value chains such as the automobile, fashion or health.

**Box 1. Textiles: a hidden user of AIR and other advanced manufacturing technologies**

Our literature review did not reveal the textile sector as a key user of AIR. Interviewees however highlighted the importance of AIR for textiles. This applies to industrial textiles and textiles in general. Consequently, we organised a workshop with stakeholders in the textile industry in northern France. The focus was on industrial textiles. It was explained how industrial textiles is part of multiple other industries and value chains (including automotive, buses, trains, architecture and construction). This means that industrial textiles are less 'exposed' to research about the use and uptake of new technologies, as opposed to industries such as automotive. Workshop participants provide numerous examples of industrial textiles producers experimenting with or implementing AIR. For instance, AIR combined with industrial internet of things and other technologies will play an important role in the development of smart and technical textiles.

*Source: Technopolis Group*

The heaviest users of robotics are large industrial companies and conglomerates, with well-defined and well-planned requirements and upgrade cycles and sufficient access to capital. Still, there are industries with automated processes, yet a low penetration of conventional robotics, let alone AIR. As total cost of ownership (acquisition, deployment and maintenance) of robotics decreases and flexibility increases, advanced robots become relevant for more industries and for large and small firms within these industries (SPARC, 2014). Table 2 on the next page highlights three of these industries where the introduction of advanced robotics can be a game changer.



Table 2: Potential for uptake of AIR in manufacturing industries

Industry	Potential for uptake
<b>Food preparation</b>	<ul style="list-style-type: none"> <li>Automation in tasks involving manipulation of raw foods with different shapes, textures and consistencies;</li> <li>Tasks where traditionally there was a need for manual labour, responsive production and fast turn-around;</li> <li>Tasks where there is a risk of contamination (deboning, preparation of ready-made foods, packaging of delicate products), as higher levels of hygiene and controlled atmospheric environments and cleaning requirements can be achieved; and</li> <li>Quality control in all the above activities.</li> </ul>
<b>Manufacturing of 'soft' products</b>	<ul style="list-style-type: none"> <li>Manipulation of flexible goods (such as clothing and shoes), which presents technical challenges in terms of understanding material behaviour during different manufacturing operations; and</li> <li>Potential for reshoring industrial activity from Asia to Europe in these activities.</li> </ul>
<b>Crafted and bespoke production</b>	<ul style="list-style-type: none"> <li>Processes where advanced robots could improve mass customisation without increasing costs and production time; and</li> <li>Potential for reshoring or moving some manufacturing activities closer to the location of consumers.</li> </ul>

Source: Technopolis Group

So far, almost all studies consulted point out that adoption of AIR will show significant growth rates over the coming years. However, there are many barriers that could stifle growth of AIR adoption. In addition to the financial barriers linked to the fact that AIR are still more costly than traditional incumbents, there are a range of additional legal and social issues which may still limit the uptake of

### Box 2. A reality check on AIR adoption: the case of the textile sector in northern France

The workshop (case study) about the state of AIR adoption in the textile sector in northern France provided insights into the actual level of uptake of AIR in a specific industrial setting. Despite the significant buzz and attention given to robotics currently, the level of uptake of AIR remains low as only a handful of companies in the textile industry have adopted AIR. This is mainly linked to the fact that:

- AIR is still an emerging technology, with medium Technology Readiness Levels (e.g. TRL-4-8);
- The regional industrial ecosystem is mostly composed of SMEs focused on traditional know-how. About 75% are not in the position (financially and in terms of skills) to implement automation for most tasks. Certain sub-sectors such as the production of high-quality lace still rely heavily on traditional manual labour and traditional tools/machines which cannot be automated;
- AIR requires high operational expenditure, in addition to the important capital expenditure. This is linked to the costs of design, software, programming, testing and maintenance which can be higher than for traditional robots or machines, and generally have to be outsourced.

In addition to this, for a great majority of small and medium firms in the sector purchasing robots is a very important decision, with far-reaching financial, managerial, procedural and even spatial implications. This stems not only from the financial investment needed, but also the consequences of AIR for the rest of the production process. Integrating an advanced robot implies radically modifying existing processes and the layout/organisation of the production lines. For instance, some companies may be limited by the existence of free space to set up and run the robot. In other words, production line, infrastructure, process reconfiguration and location/building may act as key barriers to any decision to invest in AIR.

Source: Technopolis Group



AIR solutions. Ethical and legal uncertainties remain around robot safety, liability and privacy of humans working together with robots. These are often not technical problems. Still, they can hinder mass adoption by more risk-averse industries and companies.

Security of communication networks and protocols used by industrial robots will also be one of the main challenges for adoption. Companies and governments may become more risk-averse to the technology after incidents related to hacking and major disruption of production systems and critical infrastructures.

Also, the introduction of advanced robots requires specialist skills that will not be widely available in all countries, industries and (small) companies. Skills adaptation and retraining will take time and will limit the pace at which industries are able to adapt. This can drive up the costs of implementing these solutions, at least during a transitional phase. Moreover, companies with large sunk costs in existing manufacturing robots may lack the ability to adopt newer solutions before they have recouped these capital expenditures, and will therefore wait according to their upgrade cycles.

The International Federation of Robotics (IFR) estimates that new market opportunities will allow industrial robot sales (currently around 110,000 units per year) to grow by around 5% per year over the next 10 years. Despite the recent Asian robotics boom driven mainly by the growth of the Chinese market, Europe remains the world leader in terms of robot density: 92 robots per 10,000 employees in the European manufacturing industry in 2015, compared to 86 in the Americas and 57 in Asia (International Federation of Robotics, 2016). Existing capacity is strongly concentrated in Germany and its automotive sector, but other countries such as Italy and France have recently gained significant strength and capabilities.

## Impact on production processes

### The impact on factory floors, business models and value chains

#### *Internal production line and process reconfiguration*

The introduction of Advanced industrial robotics has the potential to considerably reshuffle the way in which assembly lines, production processes and value chains are designed and managed. The change which is most commonly associated with the use of AIR is the ability of industrial factories to develop more ‘agile’ production processes. Agility generally comes in the form of production lines and processes which can be quickly adapted to respond to new and changing client demands (i.e. burst manufacturing for one-off products). This enables the production of different and often more customised types of products, in larger but also smaller batches, based on short-term demands and opportunities. Advanced robots allow for this agility because the overhead cost linked to the set-up of new or different production lines (essentially the programming cost), as well as the capital investment necessary to change the production process, are drastically reduced.

Agility is often associated with geographical proximity of production tools, skilled staff, clients, partners and other stakeholders. In industries and markets where rapid innovation and the capacity to quickly respond to changing demands is given priority over, for example, hourly labour rates, proximity between production facilities and clients becomes paramount. To reap the benefits of having the capacity to respond to specific client requests swiftly, manufactures must also demonstrate the ability to reduce production-to-market times, and communicate with clients in a cost-efficient manner. As such, AIR allow manufactures to automate and increase the efficiency of getting the product to market, as well as better respond the needs of the client (PwC, 2014).

Experts consider AIR, and automation in general, as the main driver of reshoring manufacturing activities to Europe. This process could be driven not only by the importance of proximity between supply and demand described above, but also by the increased importance of being able to access skilled talent. In these skills, Europe is among the leaders in the world. At the same time, AIR is likely to reduce the need for less qualified and lower-cost human capital. Their tasks, such as manual tasks and basic, routine operational tasks can be performed by robots and automated process management systems. The real impact of AIR on reshoring is however difficult to estimate, and evidence illustrating the existence of this phenomenon is limited. Eurofound’s European Reshoring Monitor is one of the relevant sources for recent cases of reshoring.<sup>5</sup>

The introduction of AIR into the production line will also impact upon the operating hours of the manufacturing facility itself. Increased capacity of robotics to work, responding to changes in the environment and coordinating with other robots within the production line facilitates manufacturing plants operating for extending hours, potentially even 24/7 (McKinsey Global Institute, 2013).

#### *Changing configuration of value chains*

A higher degree of value chain integration is expected to take place as a result of AIR for manufacturing activities but also because of advanced professional service robotics (for logistics, warehousing, cleaning, repairing, maintenance, etc.). These service robots make it possible for example to integrate production machinery, warehousing systems and production facilities into single cyber-physical systems. The traditional frontier between the production and logistical tasks of manufacturing can be expected to become more blurred. AIR may also allow producers to expand the range of tasks they can conduct, to include for instance, packaging, logistics and direct sales to consumers.

Value chains are also affected by the agility and diversification that is enabled by AIR. Traditional manufacturing value chains are characterised by the high level of specialisation of respective players

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<sup>5</sup> <https://reshoring.eurofound.europa.eu/>

along the chain, for example producing one type of material, component or product for one type of client, generally within one value chain. Agility increases the capacity, through small-batch production and customisation, to produce a broader set of products within a single production facility. It is worth noting however some experiences which have proven customisation is still better-off in the hands of humans, given the time and effort still required to re-programme some AIR each time a new custom product needs to be produced.

While agility and customisation this provides companies the possibility to diversify and enter new markets, it also means that the level of competition increases. Certain manufacturing incumbents may see competition emerge from players generally considered to be outside of their respective markets. New generations of robots are also lowering the barriers to entry for smaller companies that lacked the capital and skills to procure, calibrate and implement traditional industrial robots (PwC, 2014).

There are examples where the demand for and level of customisation of a product exceed the capacities of robots. One such example is the production of the Mercedes-Benz S-Class saloon, which has too many customisable elements and options to be automated, and as such the company has reverted to employing skilled human to man the production line (The Guardian, 2016). Notably however, in this case, the shift towards human workers is complemented by the company's shift towards increased productivity by equipping workers with smaller, lighter machines to work in collaboration with workers, also known as cobots.

As AIR can allow businesses to diversify their markets (for example, AIR may allow a textile producer traditionally working for the construction industry, to move into the transport sector), this implies changes in business models they will utilise. This mostly concerns the business models of established manufacturing companies that can use AIR to become flexible and diversified. AIR combined with the Industrial internet of things can also change business models in terms of forward and backward integration, such as managing logistics to clients and having increased control over the production processes of suppliers.

### *Changes in the robotics value chain itself*

One additional change expected to take place as a result of increased AIR adoption concerns the robotics production value chain itself. The typical business model of established suppliers of industrial robots is to work closely together with system integrators, who enable the integration of robots in the context of the existing firm and production lines. This way, robot manufacturers focus on the technology of the robot manipulator and controller, while the application-related know-how resides mostly with smaller companies doing the integration work. This division of tasks works well across many markets, ranging from food and beverage to automotive and aerospace. However, the transition to AIR implies more IT, more data collection, data analysis and intelligence. This means that collaboration with the final client/user becomes more important for AIR original equipment manufacturers. Therefore, robot manufacturers may intensify their partnerships with system integrators or even acquire these companies. This allows them to intensify the customer relation, using commercial models such as leasing/rental agreements and pay-on-production (EURobotics, 2014). This also implies a potential shift in ownership – and potentially liability – from the user of the robot who may only be leasing or paying for the use of the robot as a service, to the producer of the robot who may retain ownership over the machine.

The deployment and maintenance of advanced robotics will bring about an increased need for specialists in automation and programming, robotic systems integrators and robot maintenance. While these tasks can be conducted internally (this is particularly the case in larger companies) these support services are generally outsourced to service providers. This implies closer proximity and increased collaboration between manufacturing firms and specialised robotics support service providers. It also means a higher degree of dependency of these external firms when it comes to trouble-shooting, installation and maintenance of robots.

In some cases, it is not specialised robotics service providers who provide support to AIR users, but the AIR producers themselves. Robotics manufacturers are widely considered as an important source

for technical know-how and training, on how to operate AIR. Companies turn to their AIR suppliers for information and capacity building in order to program, operate and provide maintenance to their machines. In some cases, AIR producers provide a certain amount of hours of training along with the purchase of their robots.

### **A driver for lower material intensity in manufacturing**

As described in section 0, one of the main drivers for the uptake of advanced robotics is the desire to increase the efficiency of production processes. Higher efficiencies are generally achieved due to more 'lean' production processes (i.e. adapting the level of effort to the task at hand). For instance, higher precision robotics can reduce the level of waste generated as well as reduce the necessary inputs for production, and make less mistakes. As a result, advanced robotics is increasingly considered as one of the building blocks of the 'Factory of the Future' that is not only more productive, efficient and competitive; but more environmentally friendly too.

AIR also allows for using new materials such as carbon-composites and bio-based materials. This requires reprogramming of robots and fine-tuning of other activities and machines in production processes (International Federation of Robotics, 2015). Advanced robotics will, without a doubt, facilitate the introduction and use of lighter, more complex and smarter materials into production processes, as a result of their ability to conduct more precise tasks, predict unexpected behaviours, and reduce error in the handling of these materials. The exact material efficiency gains are difficult to estimate, and will differ between industries and products.

### **The impact of AIR on work processes: automation, automation and automation**

Some of the main effects of AIR on work processes include: meshing of production, packaging and logistical tasks (and respective divisions or companies); extending the operating hours of industries (for instance, operating 24/7 thanks to increased autonomy of robots); and increased flexibility in order to adapt and respond to different assignments in a non-routine fashion.

Yet main impact of the uptake of AIR on work processes is the increased level of automation. This implies that an increasing number of tasks will be performed by robots instead of humans. As a result, the impact of AIR on work processes is not radically different than the impact of 'standard' or 'non-advanced' robotics. However, the types and level of complexity of tasks that can be automated thanks to AIR is constantly increasing, and may include non-routine activities that require a certain degree of autonomy in terms of decision making.

In line with the literature review, the experts that we consulted predicted that the upstream stage of value chains and production processes (materials and components, for example) will be increasingly automated by means of AIR. This is partly due to the large-scale and routine nature of these activities. Still, process operators, quality managers and maintenance/repair staff will conduct important tasks. Assembly, being at the heart of many production processes, is another stage with increased automation. The transition from 'normal' robotics to AIR will imply that downstream or final stages of production processes will also be susceptible to automation. For example, robots and humans can collaborate in complex assembly tasks, such as those using soft materials, quality control of products, logistics and client interaction. Hazardous tasks involving for example, handling of heavy equipment or dangerous materials, will also become increasingly conducted by robots.

As such, the traditional dichotomy between automated vs. non-automated task is likely to become blurred. New generations of robots which can be placed 'outside of a cage' are likely to lead to work processes and tasks in which humans and robots collaborate. One of many examples provided by interviewees is car assembly, with robots conducting the 'heavy lifting' parts of the task, while human workers provide oversight and assist the assembly of very subtle, fragile components.

Advanced robotics is also expected to significantly improve quality management/control within production facilities (and value chains). Advanced robots are generally better able to conduct quality checks as they are more precise and able to collect more data. One example of this is the application of

AIR by the Spanish food processor, El Dulze, to quality checking lettuce. The robot gently handles the lettuce, tests the density and rejects those of lower quality. The introduction of the robot has decreased the reject rate (from 20% to 5%) and improved hygiene standards (McKinsey Global Institute, 2013). Data and information about machine conditions as well as materials, components and products, can be used to fine-tune the production process in terms such as resource intensity and production scheduling (Jay, Kao, & Shanhu, 2014). Quality control is bound not only to become an increasingly important function, but also one which is increasingly embedded into other management activities.

The very nature of management is bound to change as the human component becomes smaller, while robots and human-robot interaction become more important. Therefore, the task of managing human resources will undergo a substantial modification, particularly as robots increasingly replace humans in charge of conducting simple and routine manufacturing operations.

### **How the impact of AIR on work processes could evolve**

In a limited number of industries and companies, the above-mentioned changes and impacts are already tangible, but to predict the impact of AIR on manufacturing industries still requires a certain level of speculation. The scale and scope of AIR uptake is too limited to make any type of detailed assessment of its impact on work processes and, especially, individual workers and the labour force in general.

Changes will be incremental, partly due to substantial investments needed to adopt AIR. Timing will differ between industries, types of companies, countries and regions (for example, regions with or without easy access to capital, skilled labour and process engineering services). According to the Robotics Roadmap, human-robot collaboration will evolve as follows (Robotics VO, 2013):

- 5 years: Broad implementation of easily programmable, adaptable, and safety-rated soft-axis guarding for fixed or mobile assembly robots on the factory floor;
- 10 years: Systems that automatically detect and respond appropriately to conforming/non-conforming human behaviours in the workplace, while maintaining consistent performance; and
- 15 years: Systems that can recognise, work with, and adapt to human or other robot behaviours in an unstructured environment (e.g. construction zones or newly configured manufacturing cells).

The era in which human-to-human conflict management is replaced by human-to-robot conflict management is not bound to make its appearance overnight. As such, human resources within manufacturing organisations will undertake an “awkward period” of change as robots are increasingly introduced into the workplace. Indeed, human resources will not only have to negotiate greater human-robot collaboration, but the implications of robots taking the place of human workers, also known as ‘botsourcing’ (PwC, 2014).

## Impact on work

### AIR: job-creator or job killer?

Before discussing the impact of a widespread uptake of AIR on manufacturing tasks, occupations and skills, this section touches on the potential impact of AIR on job creation or suppression. Although this is not the focus of our study, the debate about replacing humans by machines must be acknowledged, and robots are an important theme in this debate.

Jobs in manufacturing are identified as being in the line of fire, as opposed to occupations in, for example, education, engineering, health and personal services. Over the past few decades, industrial robots have already taken on a variety of manufacturing tasks, usually manual tasks with a high level of routine and tasks that are difficult, dangerous, or impractical for humans such as welding, spray-painting and handling heavy materials (McKinsey Global Institute, 2013). One of the major concerns around the use of AIR, as opposed to other technologies in manufacturing, is their effects on job creation/suppression, given the capacity of robots to automate non-routine and intellectual tasks. The answer to the question whether AIR is likely to kill more jobs than it creates is far from straightforward. The information collected by means of this study, particularly through expert interviews, paints a much nuanced picture. Still, some experts are optimistic; others are pessimistic about the added value of human workers.

In principle, the introduction of more AIR will mean that the manufacturing process will require fewer jobs as several tasks (or even entire occupations) will be automated. This holds especially for jobs such as those requiring physical, manual work, with low or moderate degrees of intellectual and social tasks. The job-killing aspect of all types of robotics, including AIR, is of particular concern to labour unions. It is interesting to note however, that in one company covered by our case study, opposition to the purchase of a robot came from upper management, while factory employees were favourable to this investment. They considered the reduction of physical strain and mental stress as well as opportunities to diversify their job. Taking a broader perspective, direct job losses resulting from automation of certain tasks and occupations can be offset by the creation of additional jobs due to increased production volumes. In other words, increased production capacity is generally considered as a driver of growth, which will indirectly result in the creation of additional jobs.

Moreover, the uptake of AIR vs. job losses does not appear to be a zero-sum game. While in some cases jobs are made redundant due to the purchase of a robot; in other cases, the implications on the existence of those jobs appear to be more nuanced. Automation by means of AIR can lead to the re-distribution of tasks and jobs internally, across different production line sections and different departments of the company. As such, rather than killing a job, the use of AIR is more likely to change occupations through increased multi-tasking, problem-solving, client-interaction, and interacting with a robot. This may or may not lead to the actual departure of the person holding that job.

While more automated and flexible manufacturing systems will result in fewer jobs in some departments, it can lead to more jobs in other departments within a manufacturing company such as those within R&D, design/development, marketing, sales, leasing, predictive maintenance (cf. servitisation). Interviewees also mentioned that manufacturing can require many jobs outside of the manufacturing company. This includes, for instance, suppliers of enabling services such as software development, manufacturing and repairing of robots, system integrators, cloud computing, and (micro) logistics. For instance, the International Robotics Federation estimates that for every 10 robots in use in a factory, there is a need for one skilled technician for robot management and maintenance (Metra Martech, 2013).

Reshoring could prevent job losses due to AIR, at least in Europe and other high-income regions that try to (re)attract manufacturing activities. However, the effects of reshoring on the number of jobs will be limited. This is mainly because most of the tasks that are relocated are bound to be highly automated (McKinsey Global Institute, 2013).

## The impact of advanced robotics on working tasks and skills

AIR mostly affects tasks that are likely to become automated, either fully or partially. This mainly involves routine, physical tasks requiring no or limited decision making capacities, and/or analysis of multiple variables. In the context of manufacturing, this mainly concerns production tasks (as opposed to supervision tasks) which are generally found on the production floor, at assembly lines and stand-alone machines. Other types of tasks are likely to be performed by robots in collaboration with humans, which will also fundamentally change the nature of the task itself.

However, given the cross-cutting nature of AIR, it's likely that a widespread uptake of this technology in manufacturing will result in at least some degree of impact on the majority of production tasks. This involves production, logistics, supervision and management, administrative and human resource-related tasks. Robotics could also impact commercial and support tasks through for example, the use of chat bots instead of sales staff and helpdesk attendants.

As such, the range of skill sets to be affected by the gradual uptake of AIR is very broad. The following table illustrates some of the main types of skills and relative impacts stemming from the use of AIR.

*Table 3: Impact of AIR on industrial manufacturing skills (non-exhaustive)*

<b>Skills</b>	<b>Impact stemming from AIR</b>
<b>Engineering skills</b>	Skills in advanced mechatronics and component design (sensors, actuators, power management, etc.); Skills in advanced robot dynamics and kinematics; and Skills in sensor development and integration.
<b>Data and mathematics skills</b>	Skills to analyse data being collected by robots (big data); Skills to analyse and develop safer and more efficient robot trajectories and movements; and Skills in machine learning, including deep learning.
<b>Material/resource specific skills</b>	Skills in materials' science and real-time simulation of material behaviour (e.g. so that robots are prepared to work with soft materials).
<b>Equipment and machinery operation skills</b>	Skills for programming robots and robot maintenance; Increased need for skills in automation and programming, robotic systems integrators, and robot maintenance; and Human-robot collaborative skills for workers.
<b>Packing related skills</b>	Human-robot collaborative skills for workers.
<b>ICT related skills</b>	Skills for programming robots and robot maintenance; Skills in deploying and securing industrial communication networks; and Skills in VR and virtual prototyping of production processes (together with engineers).
<b>Communication skills</b>	Skills for the design of human machine interactions and interfaces; Skills in data science and cognitive computing, to ensure robots can; and communicate with workers in natural language.
<b>Organisational skills</b>	Skills in industrial organisation that consider the role of AIR into the productive process.
<b>HR skills</b>	Integrating the presence and use of robots in HR practices (e.g. using robotics as a key recruitment selling point).
<b>Legal skills</b>	Skills allowing understanding and mitigating the legal implications of using AIR in a manufacturing setting (e.g. privacy, work-related accidents).

Skills	Impact stemming from AIR
<b>Thinking skills and competences</b>	Skills in systems thinking and systems design; and As advanced robots automate more and more task, attention and thinking capacity of workers will be freed to work on higher value activities.
<b>Social skills and competences</b>	Human-robot collaborative skills for workers; and Skills allowing to assess the social impact (and the impact on worker’s lives) of advanced robots in the productive environment.

Source: Technopolis Group

Skills needs related to the adoption of AIR will also concern new materials such as bio-based materials, carbon fibre, composites and various inputs for Additive manufacturing (3D printing). Workers will need to understand these materials and understand how they perform because they are increasingly integrated into new products and technologies made by AIR, as well affecting the form and function of the AIR themselves. These developments will have subsequent impacts upon the skills required in manufacturing, for example the skills related to mechatronics will be required within the car manufacturing process. The importance of such skills was highlighted by several interviewees.

### Occupations in manufacturing affected by the changes brought about by AIR

The incremental uptake of AIR solutions in manufacturing is expected to lead to the suppression or transformation of several existing occupations, as well as to the creation of new ones (as discussed in section 0). While some of these changes will be industry-specific, others appear to be common and relevant to all manufacturing industries. For example, a shift is expected to take place away from low-qualified manufacturing jobs and occupations (i.e. plant and machine operators), which will be gradually replaced by robots. This section discussed several specific occupations.

Interviewees and workshop participants provided examples of AIR leading to changes in certain occupations and the tasks clustered within these occupations. Workers can become more focused on supervising the work of robots that perform tasks and in collaborating with these robots. Occupations such as production line supervisor and operators, production or specialised services managers, or forklift operators are expected to undergo drastic changes and will require upskilling, mostly through on-the-job training. Occupations that still require manual labour such as stationary plant and machine operators, assemblers and labourers in manufacturing will become more complex, and the ability of local workforces to master new skills will become more critical (The Boston Consulting Group, 2015).

The deployment and maintenance of advanced robotics solutions shall also bring about an increased need for certain types of occupations such as specialists in automation and programming, robotic systems integrators and robot maintenance. While these occupations are not entirely new, they are fairly distinctive given the fact that they integrate a range of different skillsets and competences into a single occupational profile. This makes finding individuals with the right skill sets hard to come by in labour markets. Several interviewed company representatives, mentioned difficulties in filling certain positions requiring a mix of skills in engineering, ICT and programming, and in data and mathematics skills.

One occupation often overlooked in the context of industrial manufacturing and AIR, is that of researchers and developers. Especially large companies invest in in-house R&D, conducted by their own staff. These researchers and developers are an important linking pin towards external organisations (universities, research institutes, companies, etc.) that experiment with new technologies and applications. As such, these in-house experts need to be continuously updated on the state of the art of AIR technologies, and how they can be used in the setting of their host companies. Given that the development and implementation of advanced robotics is characterised by the integration of a wide range of different technologies, including materials science, electronics, communications, digital media, artificial intelligence (AI) and software engineering, this requires being able to assemble multi-disciplinary R&D teams, as well as broadening the fields of competence of individual researchers.



Interviewees also mentioned that the reduction in manual tasks implies a greater emphasis on the importance of creativity for process operators and jobs at earlier stages in the manufacturing process. This including occupations dealing with design of products, development of robots, prototyping and programming of production systems.

Lastly, AIR is bound to modify, though to a lesser extent, occupations such as chief executives, senior officials, business administration managers/professionals and human resources managers. This will be particularly true in small companies where the level of specialisation of roles and responsibilities, and the exposure to the effects of AIR are more widespread among staff and personnel. Senior management will have to learn how to manage the purchase and technically integrate AIR into their companies. At the same time, senior management must mitigate the challenges and risks of AIR, such as changes in tasks, occupations, employment levels and production configurations. In the case of textiles in northern France, one of the key components to the successful purchase of robotics was the dialogue between the company management and the staff and worker representatives. In this case, senior management of the company took it upon themselves to discuss with the staff and union representatives, what the implications of the purchase of the robot would. They specifically indicated their intention to be transparent about both the advantages and potential drawbacks linked to this investment, in order to mitigate concerns and opposition from workers. Human resource managers are also affected by the migration to AIR. Recruiters need to be increasingly aware of the types of skills necessary to fill vacancies which are in direct contact with robotics. Moreover, training will become more important. One interviewee also mentioned that the presence of advanced robotics in a company can be used as a selling point for recruitment. More in general, robotics could increase the appeal of manufacturing jobs.

## **Changes to working conditions**

### *Job quality*

As mentioned above, automation of manufacturing will result in fewer jobs requiring physical, manual labour. Notably, there will still be manual jobs, though these will instead shift away from more physically laborious tasks such as moulding and welding, towards those of assembly and visual inspection. This shift away from physical, manual jobs is complemented by the improved ergonomics of the machinery that workers interact with. The means through which this is achieved varies. For example, AIR may involve technologies and software that allow for improved communication between robots and people. The reduction of manual labour is highlighted throughout the literature and by most of the interviewees, who additionally noted the importance of robotics' ergonomics.

While some interviewees indicate that jobs become more routine and 'boring' as processes become more standardised and automated, other interviewees predict that jobs may actually become more interesting given their need for higher levels of creativity, problem-solving and decision making. In a mid-to-long term perspective, there is likely to be very few jobs that involve high levels of routine tasks as production systems and tasks change continuously.

### *Health and safety*

The integration of AIR into manufacturing processes has the potential to positively impact workers' health and safety. For example, devices may provide assistance to workers in charge of performing physically intensive jobs, making them less burdensome and reducing the likelihood of injury. In other cases, robots may conduct inherently hazardous jobs, such as those involving handling of toxic residues, or dangerous tasks, such as underwater welding.

Furthermore, assisting workers with manual tasks will be particularly valuable in responding to the needs of the aging workforce in many developed countries. For example, some automotive assembly-line work currently requires heavy lifting and entails awkward physical positions. A robotic device could be used to relieve a line worker from physically demanding tasks as well as to improve ergonomics. For example, a robot could lift a car's interior-finishing elements, such as a roof lining,

into the chassis and, after manual alignment by a worker, automatically affix the part to the chassis (The Boston Consulting Group, 2015). Reducing the physical burden of some jobs and occupations is also likely to lead to a decrease in work-related injuries and illnesses (i.e. carpal tunnel syndrome, back injuries, burns, and inhalations of noxious gases). This implies cost savings for companies and health systems. Health and safety implications are mentioned throughout the literature and were noted in many of the expert interviews. These interviews further highlighted the potential to equip workers with monitoring tools such as wearables to monitor air quality or the health of the worker, thus offering additional protection from potential harm.

However, the increased use of AIR in the workplace can bring about certain occupational risks that did not exist before. As has always been the case with technological upgrading, particularly in the field of robotics, the use of new machines creates conditions that require the right, new sets of skills and knowledge in order to avoid accidents from taking place. One specific mentioned is that ‘robots break out of their cage’ and now work alongside humans. While these observations predominantly stem from the literature review, it was additionally echoed within the expert interviews.

Theoretically, the increased use of advanced robots should inherently reduce the number of work-related accidents due to increased reliability and precision (compared to human counterparts). However, issues of liability around accidents caused by devices are not completely clear, particularly since the owner/operator split in the field of AIR becomes increasingly blurred. There is a recognised need for investment into the safety of processes in situations where robots and other machines co-work with humans (e.g. emergency break buttons, visual and auditory sensors, using natural language to interact with robots and other machines). To address this issue, the use of remote operating/oversight of robots could offer a safer option than having both robots and humans on the work floor. This issue was highlighted by the literature review and mentioned by several experts.

### *Contractual arrangements*

Contractual arrangements may be impacted by two emerging issues: liability issues linked to potential accidents stemming from human robot-interactions and privacy issues stemming from robots that collect data about human behaviour and performance. Concerns, particularly from a legal viewpoint, have been identified around legitimacy and privacy of human workers working with robots, with implications for employees’ privacy rights. Due to robots’ enormous capacity for gathering and recording data, intensive monitoring with cameras and sensors can capture human behaviour and movements and store it for future reference. This potentially represents a significant invasion of privacy, in a way that working with another human does not. Recording capacities of advanced robots could give employers a great deal of information about how their employees perform, and could thus result in staff being constantly monitored and placed under surveillance (Robolaw, 2014). This view was highlighted not only within the literature but also by interviewees. It was mentioned that data might also be used for performance reviews, insurance cases and law suits. Note that legal and ethical aspects associated with more intensive use of advanced robotics are an emerging research field.

### *Work life balance*

It has been argued that one potential impact of robotisation might be upon the work life balance of employees, allowing for greater ‘re-laxation’ thanks to shorter working weeks or increased use of part-time working. A related possibility is the greater use of working by telepresence, which would allow both remote and flexible working (Robolaw, 2014). This view, stemming from the literature, is hardly mentioned by interviewees. Instead, experts stressed various ways in which greater automation may result in *less* flexibility. It was speculated that smaller teams would leave less flexibility to manage staffing and planning issues, or in the case of production systems operating 24/7 where overnight orders or machine failure require workers to be called in.

### Work organisation

Increased levels of automation within manufacturing firms can reduce team sizes and the number of activities that require team work. In addition to the greater potential for remote working comes the potential for more communication and collaboration with off-site colleagues and business partners. As a result, the working environment may become less social, a perspective noted by several interviewees.

Further to this, as more responsibility and tasks are attributed to AIR, there is a potential for workers to have less autonomy, and possibly less motivation. This may occur when AIR takes over many planning, management, quality control and problem solving tasks, while also monitoring behaviour of workers. This may not apply to process operators and workers involved in the early or final stages of manufacturing (e.g. design or quality control).

### Actions and strategies

This study, particularly the expert interviews, provided insights into the actions and strategies of social partners, triggered by AIR and automation in general. The following table summarises current and planned actions and strategies, coordinated by five types of stakeholders. This concerns a non-representative set of examples. Note that actions and strategies are likely to differ between countries, regions, companies, industries and stakeholders, given the different contexts and interests.

*Table 4: Impact of AIR on industrial manufacturing skills (non-exhaustive)*

Stakeholder type	Actions and strategies
<b>Trade unions</b>	Some degree of push-back to the idea of increasing the use of AIR and automation in general. AIR is seen as a potential threat to existing jobs given the shift away from human intervention. Concerns over the liability and privacy dimensions of AIR in the workplace. However, there are favourable views when it comes to increasing worker health and safety.
<b>Governments</b>	Widespread support for the use and development of AIR in industry. AIR is seen as a key component of the 'Factory of the Future' which is a hot topic on many national and regional economic and industrial development policy agendas. For instance, the <i>Hauts de France</i> Region in northern France is providing financial support for the purchase of advanced industrial robots.
<b>Employers and individual companies</b>	Positions towards and inclination to acquire increased robotics capacities vary greatly. Large companies are setting the pace when it comes to the use of AIR. SMEs appear to be somewhat more hesitant, given the fairly drastic implications (e.g. financial and technical) of the purchase of AIR systems, combined with a certain degree of fear of technology and fear of change. The northern France case study on the textile sector illustrates the stark differences in the level of uptake of robotics across seemingly comparable companies. For example, robots are not ready yet for the complexity of jacquard weaving.
<b>Vocational training and lifelong learning providers</b>	AIR technologies do not appear to be fully integrated in existing curricula. Private providers and particularly robotics suppliers are still considered to be the main source of training for companies acquiring AIR systems. This is also reflected by the recurring perception of the significant skills gap in labour markets when it comes to the necessary skills to run and operate AIR in an industrial setting. The focus of existing training programmes is on safety issues related to automation, yet this is not necessarily linked to robotics.

	<p>As regard the skills requirements to implement, operate and maintain AIR, it seems there is some reluctance among employers to support training activities, because well-trained employees may leave a company, because companies are reluctant to invest in not so well-trained employees (will there be jobs for them?) or because (older) employees don't want training (or don't want to move to other jobs). Vocational training and lifelong learning providers are thus expected to play a key role in filling existing skills gaps. Good examples of this are only found in a few countries such as Germany, Austria, Italy and the US.</p> <p>Further to the issue of skills, there is a recognition of the need for social partners to collaborate (more) to make sure that changes in the curricula of education and vocational training institutions meet (emerging) skills demands of employers. This involves actions such as specific T-profiles and combinations of STEM and transversal skills (including 'learning skills') at different education levels. Further to this, education and training for manufacturing sectors is additionally hindered by expensive facilities for manufacturing process training, whether they be virtual or physical.</p>
<p><b>Higher education institutions, also including those that conduct R&amp;D</b></p>	<p>Some HEI appear to be increasing the attention for AIR in their education and research programmes. A number of HEI-hosted laboratories are focusing on Factory of the Future-related work, including the use of AIR. This work is embedded into educational curricula as well as the work of for instance PhD students. The Agile Factory platform hosted by the Art et Métiers university of Lille is one example of this (see <a href="https://tv.arts-et-metiers.fr/lusine-agile-campus-de-lille/">https://tv.arts-et-metiers.fr/lusine-agile-campus-de-lille/</a>)</p>

Source: Technopolis Group

## Concluding remarks

Advanced industrial robotics certainly is a cluster of technologies that is sending ripples across manufacturing industries. The added value of AIR, as compared to ‘normal’ robotics, lies in tougher and less structured environments; in adapting to exogenous factors; cooperating with workers; and ultimately potentially replacing human intervention for manual tasks, as well as some tasks requiring a certain level of decision-making capacities in non-routine tasks.

AIR is considered an opportunity to enhance productivity, growth and competitiveness across a variety of industries and value chains. The possibilities to create disruptive change, already led to adoption in selected industries and experiments in many others. Yet, it is important to keep in mind that despite the disruptive nature of some AIR functionalities, the changes brought about by this are fully in line with the automation phenomenon which has been around for several decades (or centuries, if one considers the parallels with mechanisation and the introduction of steam power and electricity). As such, there is the need to acknowledge the disruptive nature of AIR but the level of disruptiveness compared to other innovations in the field of automation is still relatively limited.

There are still many questions regarding the pace at which AIR will be taken up within industrial value chains, and whether or not this technology will become increasingly accessible to smaller and ‘low-tech’ manufacturing companies. Taking an objective, strict definition of advanced robotics (with an emphasis on intelligence, flexibility and close collaboration with humans) the question arises whether the additional costs are justified in mass production settings (‘basic products’). Uptake of advanced robotics is likely to be higher in the production of customised products. Taking a subjective definition of advanced robotics, the potential for disruption is substantial in small and medium-sized companies with low levels of automation. Still, or the time being AIR is adopted mostly by large firms. To a large extent, this reflects the medium to high technological maturity of AIR systems, and the substantial investments needed to procure, implement and operate AIR systems. The size, scope and skills of large companies also allow them to manage the potential drawbacks and limitations: technical, social, financial and legal. This is not to say that start-ups and other small companies can’t use AIR to develop and provide new products (such as customised products) and fight their way into markets and existing and new value chains.

Especially the interviews and workshop provide indications that governments are still exploring whether and how to support the transition to AIR. Very few support schemes to encourage the use and uptake of AIR were mentioned, let alone assessed as effective. Programmes to mitigate the costs and financial burden of investing in AIR, or spreading it across several actors, appear to be a piece of the puzzle. However, the challenges and implications linked to the uptake of AIR go well beyond the simple financial dimension, and require finding solutions to a range of additional issues. These include changes in management, business models, value chains, work processes, etc.

AIR rarely functions in isolation, and may require links to other manufacturing technologies. The technology bundle included in the concept of AIR shows synergies with others, especially the Industrial internet of things. One could also speculate about the concept of intelligent assets that monetise themselves, possibly integrating mechanisms such as block chain for disintermediation, manufacturing as a service and supply chain transparency. The convergence of all these technologies and trends can have a far more reaching impact in manufacturing and manufacturing jobs than what we are able to understand from looking at these developments separately. Public support to encourage the use of AIR needs to be developed on a more ‘systemic’ basis rather than as simplified and isolated means to encourage the use and uptake of one new technology.

Perhaps one of the most visible challenges and gaps when it comes to the use of AIR, is the persistent need to ensure workers are equipped with the right types of skills. As such, supporting the development of skills and competences for AIR represents one of the low-hanging fruits for policy makers, companies and other social partners. This will not only alleviate certain bottlenecks in skills which currently exist, but will also mitigate the potential negative spill-overs linked to more intensive automation, particularly in terms of employment suppression and evolution of certain occupations. Skills upgrading is a key element in the successful transition towards more efficient and automated

production schemes. And while individual companies are taking it upon themselves to find ways to train their personnel, there is still a widespread perception of the need to ensure AIR is more fully integrated into mainstream higher education, vocational education and lifelong learning.

Several issues around the use and uptake of AIR would merit further analysis. Our literature review identified few studies (in the public domain) based on sound research about the impact of AIR on work.<sup>6</sup> Specifically, there are important knowledge gaps when it comes to the ethical, legal and regulatory implications of the use of advanced robotics in the workplace (e.g. privacy and liability) as well as the occupational risks linked to closer interaction between humans and robots. Closer proximity and more interaction between humans and robots implies a higher potential for accidents, despite AIR being equipped with advanced capabilities to prevent this from happening. However, it may also include dealing with non-physical negative side-effects such as those linked to growing social isolation in the workplace.

Finally, while this report addressed the impact of AIR on manufacturing industries, one must keep in mind that the robotics industry itself has enormous growth potential. The introduction of advanced robotics in a wider range of manufacturing industries (and service industries) increases demand in industries that produce robot, robot components, materials and the design and manufacturing of these products. As such, it is important to keep in mind that a vibrant and strong robotics industry in Europe will not only act as a source of job creation, but will also be a key determinant in the capacity of European industry to make use of this technology.

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<sup>6</sup> Studies that do address the impact of AIR on work include The Future of Jobs report (World Economic Forum, 2016) and Boston Consulting Group's report, Man and Machine in Industry 4.0 (2015).

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All Eurofound publications are available at [www.eurofound.europa.eu](http://www.eurofound.europa.eu)

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## Annex A: Research questions

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


## Annex B: Interviews

<b>Expert</b>	<b>Organisation</b>
Giovanni Crisona	SkillMAN
Aline Hoffman	European trade Union Institute, Head of Unit, Europeanisation of Industrial Relations and coordinator of the European Workers Participation Competence Centre EWPPC
Susanne Bieller	European Robotics Association (European Engineering Industries Association)
Professor Samia Nefti-Meziani	Professor of Artificial Intelligence and Robotics, University of Salford
Rich Walker	ShadowRobot
Gudrun Litzenberger	International Federation of Robotics (written comments only)

## Annex C: Workshop participants

<b>Expert</b>	<b>Organisation</b>
Jean-Marc Vienot, General Manger	Up-Textiles cluster
Stephan Verin, General Secretary	Up-Textiles cluster
Gregory Marchant, General Manager	Union Textile de Tourcoing (UTT)
Stanislas Malard, Apprentice engineer	Union Textile de Tourcoing (UTT)
Stephanie Verhaeghe, Project and Development Division Manager	OPCALIA
Damien Caelen, Technical & Project Manager	Sommer Needlepunch

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