IFR International Federation of Robotics

Positioning Paper

Robots and the Workplace of the Future

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INTRODUCTION AND PURPOSE OF THIS PAPER

This paper looks at how robots, as one segment of automation technologies, are impacting work and the workplace. It also considers what companies and educational institutes are doing and must do to close an existing skills gap that will worsen without active adjustments to systems to prepare existing and future workers with the skills for which there is demand. It draws on input from academic institutions, industry associations, consultancies and think tanks, as well as from IFR members who are manufacturers of industrial and service robots.

Automation is changing the way we work and, to an increasing extent, the way we live. Automation improves productivity and enables companies, and nations, to remain or become competitive. It enables new business models focused on providing new goods and services and helps companies improve the efficiency and flexibility of supplying those goods and services. Economists agree that increased productivity is key to improving Gross Domestic Product, the value of goods and services produced in a country, and in turn, jobs and wages.

Societies have been automating the process of making and providing goods and services for centuries, from the plough, to the printing press, to the steam engine, and these changes have driven increases in per capita earnings, living standards[1] and life expectancy[2]. Each time a new wave of automation technologies is rolled out, there are fears that swathes of professions will become extinct with employees unable to find alternative work. In some cases, professions have indeed become extinct[3]. In other cases, job profiles adapt – the skills of switchboard operators and typists were absorbed into the personal assistant profile, for example. In other cases, automation replaced specific tasks but created greater demand for the job profile. Cash machines increased the demand for bank tellers and the automation of 98% of the labour involved in weaving cloth led to a four-fold increase in the number of factory weavers in the 70 years after its introduction (J. Bessen 2015).

Automation has a long history of positive impact on job quality and remuneration which we discuss in depth in our paper The Impact of Robots on Productivity, Employment and Jobs. There is no historical evidence of technology being detrimental to aggregate employment levels. Yet each wave of technological change brings with it the fear of whether this time will be different. Will automation destroy more jobs than it creates? These fears are evident in the current discourse in many Western economies on automation and robots. This time, fears focus not only on job replacement but on the possibility of super-intelligent robots out-smarting or even controlling humans.

It is notable that public attitudes to robots and automation differ between countries – not only between developed and developing economies, but also within developed economies. Developed economies such as Japan and China have a generally positive public discourse on robots. Some of this is cultural – for example, the positive attitude to robots in Japan is often explained by the cultural heritage of animism which accords non-human objects a

[1] For example, the average hourly compensation of American employees increased by 85 percent between 1973 and 2014 (Heritage Foundation 2015).
[2] Average life expectancy has gone from 50 years for babies born in 1900 to over 80 in many countries (National Institute on Aging 2011).
[3] Examples of extinct jobs include; lamplighter, rat catcher, ice-cutter, switch operator, log driver and typesetter.

spiritual essence. However, much of it is economic. Many societies are confronting increasing income inequality, political polarisation and social unrest. Automation makes an easy scapegoat for concerns about jobs and income security. Furthermore, robots literally embody our fears about the fragility of our long-uncontested role as overlords of planet Earth.

No-one can accurately predict today where technology will take us in 50 or 100 years. What we can say, however, is how automation – and specifically robots - are being employed today. We can forecast with some degree of accuracy how the ongoing uptake of robots will affect industries, business models, jobs and workers over the next 10 years. It is a positive picture, one in which the quality of work, and remuneration for it, improves, new job types are created, and many more types of work are available to people whose access to the job market has been limited by physical disability or by declining physical strength in old age. It is a picture in which small-to-medium-sized companies (SMEs), which account for over 90% of businesses in most economies, are better able to compete, and to assume new roles in global supply chains. It is also a future for which most societies are currently unprepared. Shrinking workforces due to ageing populations in developed economies are compounded by skills shortages in the existing workforce in many industry sectors.

THE IFR'S POSITION IN SUMMARY

- **Automation is driving job creation**. Despite fears reflected in media articles, there is no concrete evidence that automation is different in its impact on employment from the previous waves of technology-driven change over the centuries which led to a mix of job displacement, job creation, and changing job profiles. What may be different this time is the pace of change in job profiles and skills requirements which seems to be faster than in the past, as evidenced by the fact that, according to recruitment company Manpower, 65% of the jobs that today's children will perform do not exist yet. This aggressive pace of change combines with the effects of globalisation - particularly the outsourcing of jobs to cheaper countries and to temporary labour, with an ensuing decline in job security and downward pressure on wages in many job types – to create insecurity.
- **Human labour will remain competitive.** The fact that tasks can be automated in theory by no means implies they will be in practice – the decision to do this will be influenced by many factors, including the size of company and geography as well as the cost and payback period of investing in automation technologies. Most experts believe humans will remain central to successful automation strategies. Research by the OECD shows that companies that employ technology effectively are ten times more productive than those that do not. Companies must assess where technology can bring highest returns, as well as where human experience, even in routine tasks, provides competitive advantage.
- **Most experts in the three industries covered in this report – manufacturing, logistics and healthcare - predict a future in which humans and machines will work together**. Productivity increases and competitive advantage will increasingly depend on a company's ability to design and implement processes in which humans and machines work together.
- **Automation can create rewarding (in terms of both job satisfaction and salary) job profiles for workers** in the three industries covered in this report. A higher variety of tasks, work in multi-disciplinary teams, de-centralised management structures, and

worker autonomy in task and process planning and decision-making are all attributes of the job profiles that will result from a focus on effective human-cyber-physical systems.

- **Robots make work safer and less physically demanding.** Robots already carry out a variety of dangerous tasks. New developments in collaborative robots and exoskeletons will reduce chronic health complaints associated with unergonomic tasks, particularly heavy lifting.
- **A shortage of qualified employees is holding back growth.** Whilst levels of employment are regaining pre-recession levels in most countries, significant skills gaps already exist in our three focus industries (among others) that will increase unless corrective action is taken.
- **Process expertise is as, or more important than pure IT skills in manufacturing and logistics.** Whilst almost all industries are calling for a greater supply of digital skills, manufacturers find process knowledge takes far longer to acquire.
- **Experts call for tighter collaboration between industry, government and educational institutions** to equip the coming and existing workforce with both the soft skills needed for new job profiles as well as practical expertise and applied technical skills. More sector-specific, public-private sector education initiatives are needed to ensure SMEs, many of which can’t afford to invest in training, can benefit. The question of who will fund these initiatives remains open.
- **Governments will need to develop policy incentives to encourage corporate investment in training, and /or step up their funding of education.** They should continue a trend in many countries of focusing, through dialogue with the private sector, on training for skills for which demand is forecast and in industries in which the country or region demonstrates competitive advantage.

1. ROBOTS AND AUTOMATION

Rapid advances in software programming techniques combined with new vision and motion technologies are rapidly expanding the scope of robot applications. Robots are coming out of their cages to work alongside humans. This has significant implications for how work, and organisations, will be structured in the future.

The most rapid advances in automation are driven by software programming techniques that enable applications to analyse, find patterns in and make predictions from vast quantities of data. These broad techniques are being applied in almost every industry to improve the accuracy, quality and speed of specific processes. Software can diagnose illnesses without help from a human (Financial Times 2017) (Your.MD 2016), check that patients are taking medications (The Medical Futurist n.d.), price insurance risk more accurately (Digital Insurance News 2017), support lawyers in resolving property disputes by checking title deed registrations (Financial Times 2017) predict equipment failures before they happen, cut energy use in data centres (The Guardian 2016), (Dr Jay Perret 2017), identify the best places to drill for oil (IBM Center for Applied Insights 2016), and power search engine responses and recommendation engines.

The programming techniques that are enabling particularly swift advances in automation functionality are generally termed artificial intelligence - software programmes that categorise and analyse data and reach conclusions or make predictions in less time and more accurately than humans. These programmes, or algorithms, are often able to find correlations in data that humans could not, leading to greater efficiencies and new insights[4].

In robotics, these software developments are combined with improvements in hardware such as grippers and sensors to expand the scope of robot applications, most notably in enabling robots to work alongside humans rather than separately in cages.

[4] For example, genetic algorithms, a machine learning technique, enabled Facebook to reduce costs in the IP layer of its data centre by 25% and enabled Solara Diagnostics to discover a link between oestrogen cycle and susceptibility to deep vein thrombosis that would have been impossible for humans to find given the huge number of variables in the DNA and lifestyle data (Dr Jay Perret 2017).

A note on artificial intelligence and autonomy

Much of the debate around potential job losses revolves around rapid advances in artificial intelligence. Though there **is no commonly agreed definition of artificial intelligence** the term is often highly emotive, as it implies a parallel version of – and potentially superior substitute for - human intelligence, for which there is equally no agreed definition. Complicating the issue further is the fact that the term artificial intelligence is often used to refer to what computer scientists define as general artificial intelligence. This is the ability of a software programme, or collection of programmes, to apply insights, predictions and conclusions from one set of data or tasks to a wide range of data and circumstances – a capability currently unique to humans. General artificial intelligence does not exist today and predictions as to when and whether it will ever exist – as well as whether it should be encouraged – vary widely. All the current capabilities in the field of artificial intelligence relate to what is defined as specific (or narrow) artificial intelligence. This describes the ability of a software programme to perform specific tasks within narrow parameters.

Similar confusion and emotive associations exist around the **term autonomous**. Artificial intelligence capabilities are often associated with giving software and robots autonomy - that is the freedom to act independently or to self-govern. This conjures up images of software - generally personified in a robot - that has free will and can take unpredictable, unstoppable and unexplainable actions. **A more accurate description of the current capabilities enabled by artificial intelligence would be automated. This describes the ability of a software programme to carry out steps in a process without human intervention, yet within parameters and towards an end goal specified by the programmer. Advances in artificial intelligence mean that programmers can set those parameters more broadly than in the past, leading to a far higher potential for unintended consequences and giving the appearance of autonomy.** As a theoretical example, a robot programmed to clean up a room may throw out valuable objects left lying around in addition to sandwich wrappers that have fallen on the floor unless it is programmed to recognise objects that match a taxonomy of 'valuable objects' or programmed to only remove objects fitting a taxonomy of 'rubbish'. It may navigate the room using a pathway that the programmer could not predict. Yet the robot still does not have autonomy. Its goal of tidying the room was programmed, as were the parameters governing its actions to achieve that goal (Amodei, et al. 2016). Whilst its exact pathway in this example has not been programmed, its actions on that pathway (avoid wet surfaces, move around objects that display certain characteristics, etc.) have. This also applies in the case of reinforcement learning, where the software programme discovers which actions lead to a desired result by trial and error. It also applies in inverse reinforcement learning, where the software's end goal is to work out the goal or intention behind a series of actions (human or otherwise). The end goal is still specified by the programmer, not by the algorithm.

Humans set the parameters within which artificial intelligence algorithms operate. They are guided by legal requirements and safety standards as well as by an assessment of commercial risk. This will vary between sectors. In the industries covered in this paper, robust safety standards and regulations together with customer requirements for extremely high reliability and precision mean these parameters are likely to remain tightly set in robot applications to ensure predictability.

2. ROBOTS AT WORK

The robot market is growing rapidly but adoption of robots and other automation technologies remains low in many industries. There is significant potential for productivity improvements and for business model innovation. This applies particularly to SMEs for whom robots have traditionally been too expensive.

In this section, we look at the current state of robot implementation in three core industry sectors - manufacturing, logistics and healthcare. We describe the changes industry experts and IFR members expect automation and robot adoption to bring about in these industries over the next 5-10 years.

Robot adoption continues to increase globally. Over 1.8 million industrial robots were in operation globally at the end of 2016 and the IFR expects this figure to grow to over 3 million by the end of 2020, representing an average annual growth rate of 14% between 2017 and 2020 (IFR 2017). About 6.8 million service robots were sold in 2016 and this figure is expected to reach over 51 million in the period between 2017 and 2020 (IFR 2017).

ROBOTS IN MANUFACTURING

Customer demand for greater product variety is driving an increase in low-volume, high-mix manufacturing. Robots are key to improving productivity in this challenging environment. Adaptive factories, in which production facilities can be rapidly repurposed, will increase. Smart factories, in which machines are digitally linked, can shorten product development time, reduce product defects and cut machine downtime. Advances in collaborative robots and assistive technologies such as exoskeletons expand the scope of tasks robots can perform in support of worker productivity. 'Cloud robotics' - where data from robots is aggregated and analysed for optimisation and predictive maintenance - is a rising trend. Digitally-connected robots enable new business models such as 'Robots as a Service'. Robots are becoming cheaper, easy to repurpose and increasingly easy to re-programme, reducing the total cost of ownership. These trends are predicted to increase the uptake of robots among SMEs.

Robot adoption in the manufacturing industry increased by an annual global average of 12% between 2011 and 2016, concentrated heavily in the automotive and electronic / electrical manufacturing sectors, which accounted for over 66% of new sales in 2016 and just under 60% of total global operational stock (IFR 2017). Historically, only large companies have employed robots, due to the high capital cost and the time and expertise required to programme these robots to perform specific tasks. Both factors have resulted in a low adoption rate by SME manufacturers, which account for almost 70% of manufacturers globally (Tobe 2015). This is starting to change as the cost of installing and running an industrial robot (which includes robot hardware, peripherals and systems integration) falls[5].

[5] Robot prices have fallen by roughly half between 2010 and 2016 according to economists at Barclays Capital (Barclays Investment Bank 2017). The price of industrial robots is estimated to have

Falling component prices, improvements in vision, gripping and mobility technologies combined with advances in artificial intelligence are leading to a growing market for collaborative robots[6] that work alongside humans rather than being housed in cages. These robots are equipped with sensors and software that detect and respond to unexpected forces. Some collaborative robots, though not caged, remain fixed. Others are mobile, many with omni-directional wheels so they can move in any direction without having to turn. If a worker accidently bumps into a collaborative robot, it will either stop completely or move its actuator (a robot arm, or gripper for example) away. A mobile robot that moves around a factory or warehouse might be programmed to stop if its sensors detect a moving object within a certain radius. Importantly for SMEs, these robots can be programmed easily, often by guiding the robot manually through the action required. The combination of falling costs for robots and increasing adaptability enables SMEs to achieve productivity improvements without sacrificing the flexibility to work short production runs.

Factories are becoming highly adaptive, able to switch production lines very quickly, enabling manufacturers to respond to customer demand for increased product variety and specialisation. The factory might be large, such as GE's "multi-modal" factory which opened in 2015 in India. This factory can switch between production for GE's oil & gas, aviation, transportation, and distributed power businesses as well as building products for a range of other industries. Conversely, many experts predict the dis-aggregation of manufacturing plants into small, highly versatile units that can be easily located close to demand. Manufacturing equipment will be modularised in units the size of containers, each containing a smart, internet-connected piece of manufacturing equipment, assembly robots, and test equipment. These units can assemble a variety of product orders from different customers who transfer product designs to licensed partners (Sol n.d.). A move to smaller manufacturing units could have a profound impact on the manufacturing market. In Europe, for example, large manufacturers dominate - about 1% of the internationalised, high-performing manufacturing firms in Europe produce more than 75% of output or foreign sales (Bruegel 2016) – and a move to smaller units could offer substantial opportunities for SMEs. The factory may be able to operate multiple product lines, or it may focus on one specific raw material, employing designers and sales staff and a small team of production planners, programmers and maintenance technicians who configure the factory in near-real-time for different orders based on that material (euRobotics aisbl 2014).

European Trade Union IndustriALL believes a new 'dis-assembly' business model could create jobs and reduce waste. The dis-assembly model takes advantage of product tagging that is being used to steer and track products through the manufacturing life-cycle and uses

dropped more than 25 percent since 2014 according to IEEE GlobalSpec's Engineering360 (Engineering 360 2017). BCG estimates that a combination of falling prices for robots, systems engineering and peripherals with increased performance translate into an annual 8% cost improvement for a typical application like spot welding (BCG Perspectives 2015).

[6] Market analysts forecast a rapid growth (between 50 and 60% CAGR) in the adoption of collaborative robots over the next 5 years – see (Research and Markets 2017), (MarketsandMarkets 2016), (Reuters 2016). The IFR is currently producing more definitive statistics for the uptake of collaborative robots and expects that market adoption may proceed at a somewhat slower pace over this timeframe.

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this information to identify reusable components and strategic raw materials (IndustriALL 2015).

Factory equipment will become increasingly digitised. In the smart factory model (also referred to as Industry 4.0), data is collected at each stage in the production process from sensors attached to machines or from existing digital interfaces. Data can then be aggregated and analysed in order to optimise the process. In many cases, process optimisation can be automated. For example, the trajectory of a robot arm, or its gripping force, can be adjusted automatically, with no human intervention, if the software determines this is necessary to minimise risk of damage, or speed up the production process. If a part from a sub-supplier is delayed, this information is automatically routed through to all of the other systems - from production planning to logistics - allowing for the necessary adjustments to be made at each stage. Inventory can be reduced through sensors on shelves and bins that send data on inventory status to inventory management systems. These systems can be set to trigger automatic orders of new stock if figures fall below set parameters.

The data generated by linking machines to manufacturing systems can also be used to detect product defects and predict machine faults. For example, German manufacturer Daimler reduced the defect rate in cylinder head production by 50% in 16 weeks, leading to a productivity increase of 25% (IBM 2014). Predictive maintenance enables manufacturers to fix problems with machines before they occur. Previously, the equipment supplier would be alerted by the manufacturer only when the part was either due for a routine service (which it might not need), or was failing, resulting in machine downtime and production delays. Consultancy McKinsey estimates that predictive maintenance could save companies over $600 billion per year by 2025 (McKinsey 2015). Market research company IOT Analytics forecasts a compound annual growth rate (CAGR) for predictive maintenance of 39% over the time frame of 2016-2022, with annual technology spending on predictive maintenance reaching US$ 10.96 billion by 2022 (IOT Analytics 2017).

Most manufacturers are investing in or acquiring companies that provide tools for collecting and analysing data[7]. Meanwhile, there is a growing market of Internet of Things software companies[8], many offering services such as predictive maintenance, competing with equipment manufacturers doing the same.

These developments in data capture, storage and analysis are generating new business models in manufacturing. The ‘servitisation’[9] of parts of the manufacturing process that were previously performed in-house will, in future, extend to robots and potentially to entire manufacturing facilities (EFFRA 2016). Robot manufacturers are developing and commercialising service models based on data collected by sensors attached to robots. A number of robot manufacturers are working on ‘cloud robotics’ offerings which promise the

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[7] 38% of manufacturers surveyed by the Economist Intelligence Unit in 2016 said they are investing in or acquiring technology companies (Economist Intelligence Unit 2016). See also (Financial Times 2017).

[8] According to market research company IOT Analytics, there are now 450 internet of things platform companies (IOT Analytics n.d.).

[9] Servitisation refers to the bundling of services with products. Products may be offered ‘as a service’ meaning customers lease the product rather than purchase it, with services such as maintenance and upgrades included in the leasing fee.

automatic optimisation of robot performance by the robot supplier without intervention by the manufacturer. Data from robots at one or multiple customer sites can be aggregated and analysed to optimise a specific process. The robot programme can be adjusted and automatically downloaded back to one or all of the robots operating in the production step. The advantage of this ‘big data’ approach is that the more data optimisation algorithms are fed, the better their results. Research house IDC predicts that ‘by 2020, 60% of robots will depend on cloud-based software’ with 200% efficiency gains in being linked to a ‘mesh of shared intelligence’ (IDC 2016). Market research companies predict annual average growth in the cloud robotics market of around 30%, reaching between $ 22 and $ 36 billion by 2025 (Transparency Market Research 2017), (Research and Markets 2017).

Some robot manufacturers are considering leasing rather than selling the robot, in a ‘Robot as a Service (RaaS)’ model. Customers pay for a continuously optimised robot that is programmed to meet their production requirements. This has clear advantages for SMEs; no initial capital outlay, fixed costs, automatic upgrades and no requirement for robot operators. IDC predicts that by 2019, 30% of commercial service robotic applications will be leased (IDC 2016).

The advent of big data in manufacturing could redefine industry lines between equipment makers and manufacturers. For example, one Chinese robot supplier is becoming a manufacturer, setting up central robot manufacturing facilities in a number of provinces in China that will offer complete production services for a number of small manufacturing companies for articles such as furniture, sanitary ware and door handles. This model is being supported by a number of regional governments in China because it improves factory health and safety and enables easier and more accurate monitoring of emissions, reducing the load of monitoring thousands of small manufacturers to monitoring one that has better capital resources for addressing emissions.

The impact of automation and robot adoption in manufacturing will be different in different economies. In ASEAN countries, which comprise over 600 million people, many of them manufacturing workers, automation is likely to lead to job or task displacement in some manufacturing sectors such as textiles, according to the International Labour Organisation. However, in electrical and electronics (E&E) manufacturing, one of ASEAN’s most prominent sectors and a mainstay of economic growth[10] the trend is towards collaborative robots which support rather than displace workers. Because ASEAN’s E&E sector and subsectors possess a formidable and established nexus of producers and suppliers, the world’s high demand for IoT devices and components presents a significant growth opportunity (International Labour Organisation 2016).

For all the promise of and hype around smart factories and Industry 4.0, progress is as yet relatively slow. Surveys by various management consultancies show adoption rates by manufacturers of robotics and automation of 15 – 37%, predicted to grow to around 50% over the next three years (PwC 2017), (MHI 2017). One issue hindering faster adoption is that large manufacturers run a huge number of different software systems, most of which are not compatible. Software systems of manufacturers, suppliers, and customers are rarely

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[10] .ASEAN’s E&E exports almost tripled over the past decade, reaching US $382.1 billion in 2014 according to the ILO.

closely linked. Nor are systems within internal departments such as engineering, production, and service integrated. Consultancy McKinsey estimates that more than half of the potential issues that can be identified by predictive analysis require data from multiple IoT systems that have not typically been required to share data and are frequently incompatible. (McKinsey 2015). Add to this the huge amount of data coming from sensors and it is not hard to imagine the complicated undertaking that implementing a connected factory model represents. Artificial intelligence programmes may help manufacturers address data incompatibility by enabling them to develop semantic maps – definitions of the information that is required by one system from another system. This would enable manufacturers to automate the extraction and conversion of that data throughout the factory (Manufacturing Business Technology 2017). Another issue, which we discuss in Section 3., is the fact that most manufacturers are still working out where it makes economic sense to automate. For SMEs, the economic viability of robot adoption is dependent on the ease of programming and operating the robot, not just on the initial capital outlay. The cost of software and systems integration accounts for between 60 to 75% of the total cost of robot ownership (BCG Perspectives 2015) (IFR 2017). Robot manufacturers and researchers are focusing on developing intuitive programming interfaces modelled on consumer electronics. Some experts envisage a future of open robot applications platforms from which manufacturers can select applicable programmes (Fraunhofer IPA 2016).

ROBOTS IN LOGISTICS

Automation in logistics has traditionally focused on highly standardised processes such as ‘goods-to-picker’ models that work with standard pallet sizes and marked routes. Advances in vision and gripping technologies are now expanding the application of robots into non-standard environments. These include picking individual items and loading trucks with parcels of different weight, shape and robustness. Robots will increasingly assume unergonomic, ‘heavy-lifting’ tasks within logistics, freeing humans to focus on managing operations. ‘Last-mile’ deliveries from the last logistics centre to the end customer are being automated though autonomous terrestrial delivery robots which are being tested in a number of countries. Legal hurdles with drone delivery may be overcome at sea sooner than on land.

Logistics is a huge[11], capital intensive and highly competitive market yet aside from notable exceptions such as amazon, the extent of automation is still low[12]. While robots have been used for some time in warehouses to load pallets of goods on and off trucks and move them within factories, their use has largely been limited to standard shapes and routes. Goods-to-

[11] Estimates of the size of the logistics market vary between $ 2.7 and $ 8.1 trillion (Transparency Market Research 2016).

[12] For example, supply chain consultancy St Onge estimates that 80% of warehouses are manually operated with no supporting automation (DHL Trend Research March 2016) while a survey conducted for Modern Materials Handling found that only 20% of over 200 companies surveyed used robots for palletizing or picking, and only 10% used mobile robotic storage and retrieval systems (Modern Materials Handling 2017).

picker models in which robots to bring shelves to workers who are assembling orders – rather than the worker walking miles each day to collect them – can save up to 50% of warehouse picking labour. However, goods-to-picker systems are currently highly capital intensive. They also still require a significant labour force to pick the items off the shelves and assemble the order – a monotonous task that can lead to repetitive strain injury (DHL Trend Research March 2016).

Combined advances in vision and gripping technologies together with artificial intelligence mean that robots are increasingly able to work in non-standard environments, automating monotonous and physically demanding processes that previously had to be carried out by humans. Bin-picking, for example, requires a robot to be able to identify and pick a single part out of a bin of either similar or dissimilar parts. The target part may be entirely or partially covered by others. Once the part has been found, the robot's software processes data to determine how to reach it, calculating the proper orientation for the effector (hand or other gripping mechanism). Sensors in the gripper feed data to the robot's software that sends code back to the robot to enable it to pick up the object without damaging it by either exerting too much pressure, or too little so that the object slips. Given the complexity of these functions, it's not surprising that Amazon made bin picking the subject of Amazon's annual Robotics Challenge competition for three years in a row. Many IFR members provide bin-picking solutions, often working with specialist vision technology providers and systems integrators. The same technologies enable robots to load and unload goods on trucks that are not stored on pallets. These trucks typically take several hours to unload manually.

Logistics provider DHL envisions a future in which sorting and distribution centres will work around the clock, enabling faster service and improved capital efficiency. Robots will unload trucks and transport goods to loading areas, sequenced with the activities of other robots. Parcels will then be loaded by robotic arms into the trucks that will take them to the next sorting centre in the network. Drones or mobile parcel robots will then deliver them to their recipient, or the recipient may send their self-driving vehicle to the sorting centre to pick up the delivery. These and other tasks will be supervised by employees working in a robot-control centre who will manage workflows, make key operational decisions and handle exceptions such as parcels that require repacking, relabelling, or a customs check (DHL Trend Research March 2016).

Shipping and transport company Maersk predicts that massive container ships will not dock in the future. Instead, drones will transport containers to shore. The containers will be made of a super-strength, lightweight plastic that was 3D-printed at the port to fit the cargo dimensions. The drones will then load the vessel with new cargo which will be slotted into place by an army of on-board robots, before the unmanned ship continues its journey (Maersk 2016). These are visions of the future that the IFR believes will take many years to be realised. Despite rapid progress in the vision, machine learning and gripper technologies necessary for the sorting of non-standard shapes and object placement, many tasks in logistics and manufacturing require a dexterity that only humans can offer.

The stage of the supply chain between the last node in the logistic company's delivery chain and the customer is also being addressed by a host of robotic start-up companies. A number of them are testing and bringing to market 'autonomous terrestrial delivery robots' - small mobile robots that can be used to deliver packages within a narrow radius of a few miles from the starting point, operating at a maximum speed of 10 miles per hour. These robots are designed to make so-called 'last-mile deliveries' in cities that are cost-inefficient for trucks and vans. The robots move autonomously, but a human controller is available to step in if they get stuck. The goods can be unlocked by the recipient by phone. The use of these robots has already been approved in Idaho and Virginia with legislation pending in other US states (The Guardian 2017), (Wired 2017).

ROBOTS IN HEALTHCARE

Robots are used across the healthcare supply chain, from drug testing and manufacturing, to logistics and finally to patient treatment and care. The healthcare sector is experiencing huge productivity pressure across these areas. The move to precision- and personalised medicines bring the same high-mix, low volume challenges faced by manufacturers. Robots improve productivity in drug production by performing repetitive tasks requiring high precision in drug testing and medical analysis. Hospitals run huge logistics operations and will benefit from many of the developments in the logistics sector automating the transport and delivery of goods. The application of robots in patient treatment, particularly surgery, continues to expand. Ageing populations will put healthcare services under massive strain. Robots will increasingly be used to assist healthcare workers in hospitals in tasks ranging from lifting, to rehabilitation and daily tasks such as dressing. Robot assistants will help elderly people live independently, supporting telepresence interaction with physicians and caregivers and providing information, reminder and emergency monitoring services.

The use of robots in the healthcare sector is increasing across the whole healthcare supply chain, from drug discovery to patient and elderly care. Productivity improvements are vital in this sector to cope effectively with the rapid growth in ageing populations – not only are there more older people due to demographics, we also now live longer due to advances in healthcare. According to IFR data, sales of medical robots increased by 23% in 2016 compared to 2015 to over 1,600 units, accounting for a share of 2.7% of the total unit sales of professional service robots. The IFR estimates that sales of medical robots (covering surgical, diagnostic, rehabilitation and 'other') will reach $1.8 billion in 2018 and $7.7 billion in the period between 2018 and 2020 (IFR 2017).

Pharmaceutical companies are increasingly turning to personalised, or precision, medicines targeting specific symptoms or genetic profiles, in contrast to the broad-spectrum drugs we have been used to. In many respects this mirrors the broader trend in manufacturing from high-volume, low mix to low-volume, high-mix production. In the pharmaceutical industry, low-volume can literally mean suitable only for one person[13]. Productivity improvements are

[13] For example, a new type of cancer treatment, known as chimeric antigen receptor cell therapy or Car-T, involves extracting a person's white blood cells and engineering them in a laboratory over several weeks so they can identify and attack cancer. Currently, the treatment costs an estimated $150,000 per person. Logistics costs are also high - Car-T treatments must be transported within highly controlled temperatures. They cannot be repurposed if sent to the wrong hospital. (Financial Times 2017).

vital to lowering the cost of, and ensuring high levels of accuracy in, developing, producing and delivering these treatments.

Healthcare Facts

By 2050 the contingent of seniors in the USA is expected to double from 13.3% of the population or 40 million to 80 million. About 85.6 million Americans are living with some form of cardiovascular disease or the after-effects of stroke. Direct and indirect costs of cardiovascular diseases and stroke total more than $316.6 billion (American Heart Association n.d.).

Healthcare spending reached $ 3.2 billion in 2015, just short of $10,000 per person, and representing just under 18% of GDP (Centers for Disease Control 2017).

In the EU, healthcare spending in 2015 accounted for nearly 10% of GDP - just under €3000 per capita. More than 75% of this is publicly funded (OECD and EC 2016).

Demographic developments are expected to push public spending on health care up by 1.9% percentage points of GDP on average in most EU Member States between 2007 and 2060. (European Commission 2010).

Despite huge healthcare spending totals, healthcare systems remain inefficient – the OECD estimates that more than 1.2 million deaths could be avoided through better public health and prevention policies or more effective and timely health care (OECD and EC 2016).

All developed economies are predicting a shortfall in nurses and carers. This is particularly acute in Japan. Despite tripling the number of nursing care workers since 2000, Japan will still need 2.53 million nursing care workers in 2025, 800,000 more than in 2015 (Japan Times 2015). The Japanese government has put an explicit focus on supporting the development of healthcare robots, with a focus on mobility, toilet and bath aids, and monitoring systems (METR 2015).

Robots are already in widespread use in pharmaceutical development, testing, and manufacturing. They offer accuracy without downtime in tedious, repetitive tasks that require a great deal of precision, such as preparing blood samples. For example, Copenhagen University Hospital in Gentofte can deliver 90% of blood sample results within one hour, saving patients a return trip to the hospital, by employing robots to handle and sort blood samples for analysis. This is despite a 20% increase in samples. The robots handle approx. 3,000 samples per day, 7-8 tubes per minute (Case Studies - Gentofte Hospital n.d.).

Robots are also well established in patient treatment. Over 1,200 robots for surgery and therapy were sold in 2016, 12% more than in 2015 (IFR 2017). The da Vinci robot-assisted surgery robot has been used to treat over 3 million patients in 64 countries worldwide (Da Vinci Surgical System n.d.). Robots are also being developed for cutting bones which they can do more accurately and with faster healing rates than humans (Robotic Industry Association 2015). Magnetic microbots are used in various operations, such as removing plaque from a patient's arteries or helping with ocular conditions and disease screenings (Information Week 2012).

Robotics is predicted to have a huge impact in patient care and assisted living. Between 2015 and 2050, the proportion of the world's population aged over 60 years will nearly double from 12% to 22%. By 2020 the number of people aged 60 years and older will outnumber children younger than 5 years (World Health Organisation 2015). The growth in ageing populations is driving an increased incidence of age-related maladies and disease that are expensive and time-intensive to treat. Increased productivity is a key priority in the healthcare sector and robots will play several roles.

Many of the advances in robotics in the logistics sector are directly applicable to hospital environments, which have huge logistics operations. Experts estimate that a 1% efficiency improvement in healthcare could save over $ 60 billion over a fifteen-year period (Annunziata 2015).

Singapore's Hospital of the Future

At the Centre for Healthcare Assistive and Robotics Technology (CHART) at Changi General Hospital (CGH) in Singapore, a robot called HOSPI delivers items such as medicine, medical specimens and patient case files within the hospital. It is able to move around and even use the lifts on its own. The items HOSPI carries can only be accessed with ID cards. The robot has trays for medical staff to put items on. It communicates and relays information on its whereabouts to the control centre, enabling its location to be monitored at all times. HOSPI is also equipped with security features to prevent tampering, theft and damage during delivery. It is equipped with sensors and programmed with the hospital's map data to avoid obstacles such as patients in wheelchairs. New hospital routes can also be programmed in advance. Use of the robot helps to save manpower and boosts the hospital's productivity by up to 30 per cent. Other projects at the hospital include an interactive robot that can entertain patients while they wait for their appointments and children during vaccinations and a system to sort out surgery instruments. The latter task is usually done by a nurse's assistant and automating the process will eliminate human error leading to a 50% productivity increase for the assistant (Channel News Asia 2015).

Robots are being used in hospitals to transport equipment and medicines. In a typical 200-bed hospital, equipment and waste is transported just under 400 miles per week. It is estimated that the use of robots reduces the cost per delivery by 50-80% (Aethon n.d.), and reduces the average distance of 3-4 miles that a nurse walks each day (Nursing Times 2016).

Robots can be used to transport medication directly from the pharmacy to the nurses' station. According to one estimate, 36,500 doses of medication go missing each year in the average 400-bed hospital, costing between US$ 300,000 and US$ 700,000. Robots can also be used to transport urine and blood samples, using RFID codes and PIN security systems to track delivery and ensure only authorised personnel gain access (Aethon n.d.). As in other industries, robots can be used to work in contaminated environments, from research and testing on highly infectious diseases in laboratories to cleaning contaminated rooms and ducts in hospitals.

Robots are also being developed to lift patients from beds to wheelchairs and operating theatre beds[14]– heavy work that, in the U.S,, causes a rate of musculoskeletal disorders in nurses, aides and orderlies that is seven times higher than the average for all industries, and

[14] And a bed that can transform into a wheelchair has been certified for use in hospitals (Panasonic 2016).

costs at least $20 billion annually (US Department of Labour n.d.)[15] Research is also underway into robot-assisted dressing, the most commonly required assistance for older adults among all activities of daily living other than bathing/showering. Dressing assistance is needed by over 80% of people in skilled nursing facilities (Yu, et al. 2016).

A large and promising field of research and testing is in the use of robots for patient rehabilitation, assistance for patients with chronic conditions, and support for elderly people living independently. Rehabilitation robots comprise exoskeletons and orthotics[16]. Exoskeletons that enable patients with spinal cord injuries to walk are already commercially available, as are rehabilitation robots that assist patients in carrying out specific exercises. These robots are predicted to reduce the huge healthcare burden of dealing with conditions such as stroke[17] . There is some evidence that patients using rehabilitation robots have better levels of recovery than those undergoing human-only methods (Krebs and Volpe 2015).

Research is also being devoted to technologies to enable elderly people to live at home independently for longer. For example, there are a number of robots aimed at enabling doctors and carers to have an effective virtual presence in the homes of patients and the elderly. These robots can be directed to move around the room by the carer from a standard computer, allowing them to see the patient's surroundings. The patient sees the carer on the robot's screen (Giraff n.d.), (Anybots n.d.). A social healthcare robot named Zacharias, funded through the EU's Robots in assisted living environments programme, is currently being tested. The robot can detect diseases such as dementia or Parkinson's disease as they develop by noting changes in patterns of physical movement. Any unusual data is automatically sent to the family or the person's doctor to alert them (European Union 2017). The use of robots in at-home elderly care needs careful design however. They can be used to promote and facilitate human-human interaction by increasing mobility in the elderly. Equally, they could reduce human interaction, for example by eliminating the need to go shopping. Some academics (Turkle 2012) raise concern about the ethics of the use of social robots with the elderly, who may be open to manipulation. User acceptance of robots that assist humans in highly personal tasks also requires sophisticated robot interfaces. The EU and Japan are funding a £2m project to develop versatile, 'culturally-aware' robots that are re-configurable to match national culture and customs to help look after older people in care homes or sheltered accommodation (BBC 2017).

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[15] A study in the Netherlands found that lifting weights of 25 kg increases lower back injuries by 3.7 per 100 employees per year (Gezondheidsraad 2012).

[16] Passive or powered external devices for the neck, upper limb, trunk, and lower limb that are designed to guide motion, bear weight, align body structures, protect joints, or correct deformities.

[17] In the U.S. alone, there are 795 000 patients with new strokes every year with over 6 million survivors (Krebs and Volpe 2015). Performing many repetitive exercises is an effective way of getting the brain to learn to control muscle groups paralysed as a result of stroke – something that robots can be programmed to do (What is Patient at Home).

3. ROBOTS, AUTOMATION AND THE WORKPLACE OF THE FUTURE

Automation is changing job profiles. This section focuses on the skills requirements for new job profiles. We discuss the consequences for organisational and management structures, and skills requirements.

Robots, as part of broader automation strategies, are set to have a substantial impact on productivity, business models and even traditional industry boundaries and, as a result, on work. Much of the narrative on the impact of automation on employment and jobs focuses on scenarios in which entire job profiles and professions – including white collar professions - disappear. In our paper The Impact of Robots on Productivity, Employment and Jobs we reviewed current evidence and thinking on the impact of automation on employment and jobs. Most research by academics and consultants concludes that automation does not lead to net job destruction, and that very few (less than 10%) of jobs will be replaced through automation in the foreseeable future. Rather, it will be tasks that are automated, with workers taking on new tasks that result in higher-skilled, higher-paid job profiles.

JOB PROFILES AND SKILLS REQUIREMENTS

Digitalisation and automation are changing job profiles and skills requirements. Robots will take on an expanding range of routine, repetitive tasks, many of them sources of chronic injury. In general, workers will increasingly focus on unstructured tasks such as managing production flows, resolving exceptions and bottlenecks and dealing with customers or patients. New job profiles will generally be higher-skilled, better paid and give workers more autonomy. However, workers will also continue to perform routine tasks, either because it is not economically viable to automate them, or because automation has created new routine tasks that require human skills. Employers will place increased emphasis on 'soft' skills such as problem-solving, decision-making under pressure and communication. Digital skills will be key in all industry sectors. New job profiles are likely to contain a strong digital element. However, process expertise will remain highly prized and takes longer to acquire than digital skills. Manufacturers may find it easier to train production specialists in IT than vice versa. Assistive systems, including virtual reality, will support workers in learning and performing tasks. Robots and assistive systems will increasingly be used to support healthcare workers in patient rehabilitation and elderly care. Wearable robots including exoskeletons will be used across a range of industries to prevent chronic injuries and support workers and patients with restricted mobility.

Increasing adoption of robots, as part of broader automation strategies, will change job profiles and skills requirements. The European Factories of the Future Research Association, for example, predicts that manufacturing workers will no longer perform routine tasks. Instead they will have to perform varied and mostly unstructured tasks, depending on the needs of the dynamically changing production process (EFFRA 2016). Workers will be tasked with controlling, and sometimes programming, robots and other automated processes, and managing production flows, stepping in manually when there are exceptions to a planned process. The same task and skills-set applies to logistics (DHL Trend Research March 2016). In most cases, workers will be part of multi-disciplinary project teams, making good communications skills a pre-requisite. They will need to be adaptable and apply a wider range of skills in their roles. Skills requirements will not be static, rather each worker will need to evolve their skills to fit a range of projects. The impact on skills requirements in healthcare will be less dramatic. The main use of robots in this field will be to reduce heavy, monotonous and fetching-and-carrying tasks for nurses and carers, freeing them to spend more time on patient interaction. Nevertheless, new skills in operating robots will be required, and will be more demanding in areas such as rehabilitation where the robot or robotic device must be programmed to the needs of the individual patient. Carers will also need to adapt to the use of virtual (telepresence) robots to interact with patients.

Digital skills will be key in all industry sectors. Approximately 50% of automotive respondents in a study by Boston Consulting Group (BCG) of more than 750 production managers from companies in the automotive, engineered products, and process industries, said that they expect to employ more workers with IT skills, and approximately 25% expect the number of IT employees will increase by more than 10% (BCG 2016). The European Trade Union Institute predicts the increase of jobs such as data analysts, miners and architects, software and application developers, specialists in networking and artificial intelligence, designers of robots, 3D printers and other ‘intelligent’ machines, as well as digital marketing and e-commerce specialists (European Trade Union Association 2016). All of LinkedIn’s top 20 ‘hottest skills of 2015’ were digital (European Political Strategy Centre 2016).

The focus on digital skills is leading to a variety of new jobs types, at all levels, from robot programmers and mechatronic engineers to Chief Digital and Chief Robotics Officers[18].

IT skills alone will not meet the requirements of smart factories and warehouses, however, or be enough to optimise processes in hospitals. One quarter of managers in the BCG study expect to need people with production planning and logistics skills. The focus on job profiles combining digital with production, process and operations planning skills is reflected in a number of other studies (Dutch Ministry of Economic Affairs et al. 2014), (VDMA 2016), (BCG 2015). And although IT skills are in short supply (as we’ll discuss in Section 4.), in-depth process knowledge may be ultimately more valuable in many companies. A number of companies interviewed for a study by the German Mechanical Engineering Industry Association preferred to train their production specialists in IT skills than to train their IT specialists in production processes, reflecting the importance of tacit knowledge that comes from process experience on the job. As one interviewee put it, ‘Big Data works perfectly if you have a complete understanding of the underlying processes, but if you don’t know what effect you are trying to observe, you won’t have your sensors in the right places and you won’t be able to collect the data you would need to analyse that effect correctly’ (VDMA 2016). The importance of technical expertise is not limited to advanced economies. In a survey of 4000 companies in the ASEAN region by the International Labour Organisation,

[18] Recruitment agency Russell Reynolds Associates says that in Europe, the number of search requests for a Chief Digital Officer has risen by almost a third in the last 24 months. The United States has seen the same growth in half that time (Russell Reynolds 2017). IDC predicts that by 2019, 30% of leading organizations will implement a chief robotics officer role and/or define a robotics-specific function within the business (IDC 2016).

technical knowledge was considered the most valuable skill, followed by teamwork and communications skills (International Labour Organisation 2016). In their drive to establish leadership as producers of IoT devices and components, ASEAN's electronics manufacturers will seek higher skilled talent with R&D competencies, ranging from analytical experts to autonomous driving engineers and sustainability integration experts.

Some tasks will be carried out by workers remotely rather than directly. For example, crane drivers at shipping and transport company Maersk's Maasvlakte II terminal in Rotterdam now work as 'remote operators', moving the cranes from inside a control room using six screens showing multiple camera angles with the ability to zoom in anywhere for a closer look (Maersk 2015).

Robots will continue to take on routine tasks that are either hazardous, or unergonomic, leading to chronic physical complaints. Welding, for example, is extremely hazardous to the human body[19]. Robots are also being used for routine cleaning tasks in hospitals and government buildings that may have hazardous or contaminated environments[20].

Workers will increasingly use digital tools for training and support in executing tasks. For example, maintenance technicians who previously carried a phone and a computer with a limited technical database will in future be equipped with cameras, geolocation systems and online access to a full database of technical data. The technician can take photos that are processed by algorithms that identify the photographed part and provide access to relevant information. The technician can see a full maintenance history of the part and can place an order for replacement components. He or she can send an estimate for the repair directly to the client, who can sign off digitally, triggering the automatic generation of an invoice (European Trade Union Institute 2016).

EFFRA and other experts predict the increased use of augmented reality technologies for carrying out tasks and for training. For example, maintenance workers may receive repair instructions on how to replace a particular part as they are looking at the actual system needing repair. This information may be displayed directly in workers' field of sight using devices such as augmented-reality glasses. Large industrial companies are already using virtual reality simulation to train plant personnel to handle emergencies (BCG 2015). EFFRA predicts the increased use of wearable embedded equipment connected wirelessly to the surrounding manufacturing environment to alert workers to potential safety or ergonomic hazards (EFFRA 2016). E-learning courses, addressing specific issues faced by workers on the job, will also be increasingly available (Fraunhofer IGCV 2017).

All the literature on skills requirements of the future shows a clear trend in manufacturing and logistics away from routine tasks towards work that is more varied, more satisfying and

[19] Dangerous fumes from metals and coatings can lead to serious illnesses. Some products contain lead or asbestos, and the exposure can lead to emphysema, lung disease and even kidney failure. Along with the fumes, manual welding produces a lot of noise and intense heat. The loud environment can cause hearing loss of stress in the welder, and the heat can cause burns or heat exhaustion. The ultraviolet light from the welding torch can cause Ultraviolet Keratitis, also known as "welder's flash".

[20] For more examples of the dangerous tasks that robots perform, see https://www.robotics.org/blog-article.cfm/Dangerous-Robot-Jobs/15 and http://www.webdesignschoolsguide.com/library/10-things-we-couldnt-do-without-robots.html.

generally higher paid. In caring professions robots and automation do not require as many new skills but place a greater emphasis on human interaction. Whilst there are predictions of increased wages for nurses and carers, this is driven by supply shortages due to demographics rather than an upgrading of skills[21].

Figures on the likelihood of various routine tasks being automated are frequently taken to imply certainty that these tasks will indeed be automated. The reality is less simple. Automation must be economically viable for a company to adopt it. This varies from company to company. Many routine manufacturing tasks require deep process knowledge that cannot be generated or replaced by software. In 2014, for example, Toyota announced, to much media fanfare, that it was replacing automated machines in some factories in Japan and creating heavily manual production lines staffed with humans. The company told news agency Bloomberg that it wanted to make sure that workers truly understand the work they're doing instead of feeding parts into machines and being helpless when one breaks down (Quartz 2014).

In some cases, advances in automation displace some routine tasks, but create others. For example, humans are needed to prepare training data that enables machine learning algorithms to distinguish one type of thing (from a cat to a spam email) from another. Google, Amazon, Facebook and YouTube employ large numbers of these 'micro workers'[22]. People are particularly important in processing cultural data – such as deciding whether something classes as hate speech[23].

When automation leads – as it ideally should – to increased demand, more routine jobs may be created. For example, economist Michael Mandel estimates that the ecommerce sector has created 355,00 new jobs in the U.S. since 2008, compared to 50,000 lost in retail. The UK's Royal Society estimates that warehousing jobs in the UK have increased by 115,000 since 2010, compared to 7,000 job losses in retail (Mandel 2017) [24]. As we argued in our paper The Impact of Robots on Productivity, Employment and Jobs, it is critical to consider the net impact of robots and automation on job and task creation – taking into account not only jobs and tasks that are replaced by automation, but also jobs and tasks that are created within the automating sector and within other sectors as a result of requirements for new, or more, components or services.

[21] For example, a leading medical staffing firm in the US has hired 79% more nurse recruiters in 2016 than it did at the end of 2013, just to keep up with the market (Fortune 2016).

[22] Amazon's Mechanical Turk platform, for example, registered over 350,000 available 'Human Intelligence Tasks' in July 2017.

[23] Facebook recently announced around 3000 new hires to deal with this issue (Reuters 2017).

[24] And Amazon, a leader in logistics automation, has more than doubled its permanent headcount over the last three years despite increasing the number of robots working in its warehouses from 1,400 to 45,000 (Quartz 2017).

ORGANISING WORK: HUMANS IN THE LOOP

Robots will not replace humans. Indeed, people are central to successful automation strategies, particularly in the challenging environments described in Section 2. Increasing adoption of collaborative robots is changing the nature of human-machine interaction. Companies must focus on designing processes to use people, machines and IT most effectively. This will become a source of competitive advantage.

‘Will human workers in the smart factories be turned into tools of tasks decided by robots and their algorithms? Or are the machines the workers’ partners? Will we see an ‘emancipation’ of workers from routine and repetitive tasks? Or a restriction of workers’ room for manoeuvre or even free will?’ asks the European Trade Union Institute (European Trade Union Association 2016).

Trade unions in Europe are generally positive about the potential of automation for higher-skilled, higher paid and more satisfying jobs, but all stress the need for workers to be involved in process design and the importance of continuous training and up-skilling (European Trade Union Association 2016), (Trades Union Congress 2017). Most experts believe humans will remain central to work processes in the industries we have discussed in Section 2.[25]. As Acatech, the German national academy of science and engineering, points out, ‘Systems can be set up to impose restrictive control over every minute detail of a person’s work, or they can be configured as an open source of information that employees use as a basis for taking their own decisions. (…) the quality of people’s work will not be determined by the technology or by any technological constraints but rather by the scientists and managers who model and implement smart factories’ (Acatech 2013).

Studies indicate that workers in productive smart factories and warehouses could enjoy more, not less, autonomy as a result of automation – but companies must design processes with this goal in mind. For example, a German manufacturer that introduced advanced machining systems to manufacture components ensured workers retained autonomy by giving them product specifications and allowing them to decide how to best use automated systems (European Trade Union Institute 2016).

In low-volume, high-mix production environments, companies must be able to rapidly switch between different types of product run. Most experts believe this will result in a move to decentralised management structures in which project teams are given a high degree of autonomy to make decisions in real-time based on changing project requirements and conditions (EFFRA 2016), (Technische Universität Dortmund 2016). Teams will assemble ‘on the fly’ to provide the required skills for a given project and then re-configure for the next one. These teams are likely to be multi-disciplinary and combine workers of different age-groups and experience levels who will work together remotely as well as in person.

[25] For example, more than three-quarters of respondents in a survey by SCM World with MESA International believed that people will be at the centre of the automated factory of the future, because they provide the degree of flexibility and decision-making capabilities required to deal with demanding customers (SCM World 2014).

Meet the new co-worker

Some workers in smart factories and warehouses, and in hospitals and care facilities, will be responsible for robot operations and the effective integration of robots into processes and workflows. Others will be working directly with robot co-workers. Logistics provider DHL, for example, sees a future in which robots and humans work together in a co-packing area to assemble basic products or components into new items customized for individual orders (DHL Trend Research March 2016).

Collaborative robots, that can sense their environment and either stop or move away when humans approach, will perform a wide range of tasks in factories and warehouses. They can work with humans to lift heavy weights from one position to another, for workers to then process; fetch and carry parts needed by a worker in a process; and perform high-precision tasks in an assembly process that is driven by the worker. Collaborative robots can glue, weld, solder, mark and label products and perform quality control by recognising non-standard items.

The International Standards Organisation identifies four types of human-robot collaboration. These range from coexistence, where a human and a robot work alongside each other but do not share a workspace, to collaboration, where a human worker and a robot work simultaneously on the same product or component. The Fraunhofer Institute found in a study of 25 German manufacturers that the coexistence model prevails, with genuine collaborative applications virtually non-existent currently in production facilities.

Considerable research is going into collaborative applications in which robots interpret and respond to human voice, gesture and movement. For example, if a robot and a human are to successfully carry an object together, the robot has to adapt its motion to compensate for the pushing and pulling forces exerted by the human via the carried object (Berger, Vogt and Haji-Ghassemi 2013). Artificial intelligence will allow robots to anticipate and react to the specific requirements of individual workers – for example, identifying if they are left or right-handed and adjusting the path of the actuator accordingly (EFFRA 2016). One research project in medical applications, which require particularly accurate motor coordination, looked at the optimal selection, picking and handover of surgical instruments from a speech- and gesture-based robotic nurse to a surgeon in an operating theatre (Jacob 2013).

In some cases, workers will not just be working with a robot, they will be wearing one. Exoskeletons will be used to enable workers to deal with heavy loads without injury. Exoskeletons can reduce the incidence of chronic back conditions due to long periods of being in one position. 'Wearable seats' - lower-limb exoskeletons that enable factory workers to assume a sitting or semi-sitting position when required – are being tested by a number of car manufacturers to reduce lower-back strain (SPARC 2016).

Researchers at MIT are working on an exoskeleton that attaches to the hips and provides additional arms or legs, depending on the wearer's requirements. These exoskeletons improve productivity* and mean workers do not have to assume unergonomic positions to complete tasks (RoboHub n.d.).

* The impetus for the development of the MIT exoskeleton was an observation that for some tasks in aircraft assembly, two or three workers collaborated on the same task, but only one of the two or three was doing the important task - for example drilling – with the other two carrying out boring and tiring tasks like lifting parts or following the first worker with a vacuum cleaner.

Research indicates that implementing de-centralised organisational and management structures is challenging. For example, one-quarter of the 2200 executives surveyed by consultancy PwC said they use external resources even when they have skilled workers in-house, because it is too difficult or too slow to work with internal teams (PwC 2017). Designing effective human-machine interaction is not trivial either. Models for cyber-physical-human-systems (CPHS)[26] need to take into account the different ways in which people and computers observe, process, and act on information. For example, computers process information and act upon it in a highly predictable fashion, whereas people do not. They may lose focus in the middle of a task or choose not to follow instructions. Conversely, humans are better able to adapt to changing situations and can develop solutions to problems building on intuition that machines do not possess. Successful process design balances the relative strengths of humans and machines, and the interplay between them (S. Sowe 2016).

4. CLOSING THE SKILLS GAP

Lack of qualified employees is holding back growth, not lack of jobs. Educational curricula often do not provide the skills in demand, particularly for technical professions. Apprenticeships and other vocational schemes combining theoretical and 'on-the-job' training are on the rise. Closing the skills gap will require tighter linkages between companies and educational institutes to match supply to demand. SMEs that lack the resources to develop their own training programmes will benefit from industry-specific, regional alliances between groups of employers and colleges. Efforts to standardise skills and credentials would enable better communication between companies and higher education institutes.

Despite concern that automation will reduce jobs, the current and foreseeable reality is one in which companies are unable to fill vacancies due to lack of appropriate skills. In the U.S., the number of job openings steadily over 2017 to just under 6.0 million at the end of the year (U.S. Bureau of Labour Statistics 2017) and the job vacancy rate in the EU-28 was 2 % in the third quarter of 2017, double the rate in the wake of the financial crisis. The European jobs and mobility portal (EURES), which was set-up with the aim of providing job seekers in the EU with the opportunity to consult all job vacancies publicised in each of the member state's employment services, registered almost 2.4 million vacant posts (Eurostat 2017). Of the more than 42,000 employers surveyed in 2016 by recruitment company Manpower, 40% were experiencing difficulties filling roles - the highest level since 2007 (Manpower Group n.d.). A study by recruitment company Hays found that skills mismatch was highest in the US, Portugal, Spain and Ireland, followed by Japan and the UK (Hays 2016). In China, companies are struggling to fill vacancies for skilled and high-skilled jobs. Although these workers currently only account for 19% of the workforce, they are in industries – mostly manufacturing sub-sectors – that experienced the fastest growth between 2003 and 2013 (J.P. Morgan 2016).

Of the reasons given in the Manpower survey for problems filling posts, lack of technical skills was cited most frequently, after a lack of candidates applying at all. IT skills were the

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[26] Engineered systems that are built from, and depend upon, the seamless integration of computational algorithms, physical components and humans.

second hardest category to source, jumping from seventh position over the previous year. In China, by contrast, firms are experiencing shortages in a wide range of skills, with international management topping the list for larger companies, but technical skills shortages were reported by manufacturing companies concentrated in Eastern provinces (J.P. Morgan 2016).

As we discussed in Section 3., digital skills will become a key component of education programmes in almost all disciplines. There is currently a shortfall in workers with these skills – the European Commission, for example, predicts that Europe could face a shortage of up to 900,000 skilled ICT workers by 2020. The Commission launched a Digital Skills and Jobs Coalition in 2016 as one of ten initiatives under its New Skills Agenda for Europe. Coalition members - businesses, organisations, education providers and social partners – pledge to carry out specific activities to increase digital skills in their constituencies (European Commission n.d.).

In general, there is a mismatch between the skills required and the systems in place to deliver them. The next generation workforce is caught between higher demand on the one hand for bachelor degree qualifications, and, on the other, the fact that many of these degrees do not qualify them for the jobs in which demand is strong. Many participants in the VDMA study, for example, reported in qualitative interviews that a bachelor qualification did not equip students with sufficient practical technical skills (VDMA 2016). This is echoed in China, where according to research by Fudan and Tsinghua Universities for J.P. Morgan, about 70% of companies believe that what students learn in school has little practical value. Similarly, a report by Accenture, Harvard Business School and Burning Glass find that in middle-skilled jobs in administration that are being upskilled through technology, employers require a bachelor's degree even when the new skills are not provided through a bachelor qualification and even though positions specifying a bachelor degree take longer to fill. (Accenture 2016)[27].

Many countries and companies have recognised the need for a greater focus on vocational education programmes that provide a mix of on-the job learning with theoretical instruction. In some countries, such as Germany, vocational models are already well established. Over 95% of German companies surveyed by the VDMA thought the 'Duales Studium' model, which combines theoretical education with one or more placements at companies, will become even more important to address the current gap in technical skills in Germany[28].

Apprenticeship schemes are making a come-back in the US, where the focus has increasingly been on completing four-year bachelor programmes. According to the Center for American Progress, 'apprenticeship offers a proven strategy to help workers gain in-demand

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[27] The study finds, for example, that whilst only 25% of existing administrative staff such as executive secretaries and insurance clerks hold a bachelor degree, 45% of job postings for the same roles require a bachelor qualification.

[28] Germany is also looking at how to assess the competencies of the large wave of immigrants who arrived between 2015 and 2017. Authors of a study by consultancy Economix, conducted for the German Ministry for Labour and Social Affairs, argue that there should be less focus on their formal qualifications, which can be difficult to match to the German system. Employers should instead focus on competencies, which could be tested in competence centres (Economix 2016).

skills and raise their wages. Workers who complete an apprenticeship see average lifetime compensation gains of more than $300,000 compared to their peers. Employers that sponsor apprenticeship programs—in some instances, with the help of tax credits or other subsidies—benefit by gaining access to a pipeline of skilled workers' (Center for American Progress 2017). President Trump passed an executive order in 2017 to redirect over $100 million of federal job training money to pay for the new apprenticeships, supplementing $90 million in funding for the existing program (New York Times 2017). Apprenticeship schemes are seen as particularly important in reducing youth unemployment. A study by the skills development organisation City & Guilds estimates, for example, that both in the UK and US, a 10-percentage point increase in the percent of upper secondary school pupils enrolled in vocational education would lead to a 1.5 percentage point reduction in youth unemployment rates (City & Guilds 2015).

Higher education institutes are also focusing on offering more practical, hands-on teaching in bachelor courses in engineering and manufacturing. Some, such as the Faculty of Science and Technology of the Free University of Bolzano and the University of Windsor, Canada, have established factories on campus to enable students to learn in a real-life production environment (Matt et.al. 2014). The Intelligent Manufacturing Systems (IMS) Centre in Windsor contains robotic assembly stations, inspection stations, automated retrieval and storage systems and material handling systems and can be reconfigured within one hour to simulate a new production environment (University of Windsor 2011).

In addition to technical skills, employees will also need broader analytical and communication skills to perform the tasks that will increasingly form part of job profiles in smart factories and warehouses. Many experts argue that science and engineering education must place greater emphasis on transferable skills such as business and project management (Acatech 2013).

Closing the skills gap at all levels will require better linkages between companies and educational institutes in order to identify and equip workers with the skills in most demand and provide better guidance to students on which courses offer most job potential[29]. Some experts recommend refining this focus further to hone in on skills-sets with high career development potential and jobs that are hardest to fill (Accenture 2016). The fast-moving development of new job profiles makes it a challenge for companies, as well as educational institutes, to reliably predict which skills they will need in the medium-to-long term. According to the Manpower Group, 65% of the jobs that today's children will perform do not exist yet (Manpower Group 2016). And the VDMA study found concrete details about exactly which competencies will be required in which areas of specialisation to be lacking. This reflects the fact that many companies are still assessing their automation strategies and are unclear exactly which skills will be needed, and how those requirements will develop in the future (VDMA 2016).

Despite numerous examples of large companies collaborating with higher educational institutes on vocational programmes, the Accenture et.al. study argues that many businesses still fail to properly specify skills clearly to the local colleges that are a source of workforce supply (Accenture 2016). Smaller companies lack resources to develop their own training

[29] Accenture research in the U.S. in 2013 showed that just 4% of jobseekers say that schools and universities are the best source of information on job opportunities (Accenture 2016)

schemes. Most experts see industry alliances, of which there are an increasing number, as the most effective path to address skills gaps on an industry-wide basis. Industry skills alliances mean educational institutes know their investment reflects the needs of an industry sector rather than one or two specific employers and enable small businesses to benefit (National Skills Coalition 2017). The U.S. has a number of these initiatives, some nationwide and some regional. On a nationwide level, the ARM Institute, a public-private partnership funded by the Department of Defence, develops education and certification programmes and supports semi-autonomous regional centres that collaborate with local manufacturers. A successful regional example is RAMTEC, formed in Marion, Ohio to supply skilled workers to local manufacturers. RAMTEC works with robot manufacturers to develop certification and associated training programmes that will enable students to find jobs more easily. In Europe, the Academy Cube, an initiative between international industrial companies and public institutions, specifically targets skilled workers from southern Europe, where unemployment rates are particularly high. The Academy Cube offers unemployed graduates in ICT and engineering the opportunity to obtain targeted, and certified qualifications and helps put them directly in touch with industrial enterprises (Acatech 2013). The World Economic Forum has launched a Closing the Skills Gap Initiative aimed at encouraging companies to commit to investments in skills training (World Economic Forum 2017).

Efforts to standardise skills and credentials would enable better communication between companies and higher education institutes. In ASEAN countries, where education systems are often based on outdated curricula and rote learning and where there is a lack of certification frameworks for technicians, manufacturers such as Mercedes-Benz are offering technical apprenticeships using a dual-education system to meet a need for engineers with specialized knowledge of automated process design and robotic programming. Mercedes-Benz partners with a vocational school accredited by the Ministry of Education in Thailand and has also established a training centre in Indonesia (International Labour Organisation 2016).

Increased public-private sector collaboration is important not only at the level of educational institutions, but also at government level in order to strengthen policy. An OECD review of vocational training programmes, for example, found that although Korea has a strong vocational education training (VET) programme system, weak industry links at government level meant that policies were not being developed to help the VET system adapt fast enough to changing labour market needs (OECD 2015).

FUNDING INVESTMENT IN HUMAN CAPITAL

Experts agree that more investment in human capital is needed to close the current skills gap and ensure that workers can benefit from advances in automation. The question is who will pay – government, employers, employees, or a combination of all three? Many companies invest substantially in human capital development, but between one third and one half do not. The increasing use of flexible work arrangements such as agency contractors and short-term employment contracts disincentives investment in human capital in sectors and companies that make heavy use of these arrangements. Research shows that companies that use technology effectively enjoy substantial competitive advantage. In the age of automation,

effective use of technology will increasingly depend on skilled workers with deep, company-specific process knowledge.

If investment in automation is to be effective, it must be accompanied by an investment in human capital. As we have discussed in Section 4., competitive advantage will come from the successful implementation of human-machine collaborative processes. In many industries, this requires workers who combine technical /digital skills with deep process knowledge, much of which is company-specific. Company-specific process knowledge not only improves return on capital spending, it is also shown to improve corporate innovation. One study found that 75% of innovations are new processes and products in traditional manufacturing (D'Acunto 2014). Another found that temporary contracts lead to reduced investment in research and development, particularly in companies that depend on a historically accumulated, company-specific knowledge base (Kleinknecht, van Schaik and Zhou 2014).

The question is who will pay - government, employers, employees, or a combination of all three? The European Political Strategy Centre (ESPC), the European Commission's in-house think-tank, argues that 'the increased likelihood of job changes, contractual and on-demand work, means that 'new arrangements will have to be crafted to effectively share the burden of training between individual workers, employers, and the state. Innovative public–private partnerships between schools, universities and private training providers, should be encouraged' (European Political Strategy Centre 2016). A study by Accenture, Harvard Business School and Burning Glass, on the other hand, argues this investment must come from companies, particularly for middle-skills requirements, though SMEs will require government support and incentives to fund training programmes. (Accenture 2016). The evidence on corporate investment in human capital is mixed. Whilst investment in corporate training appears to be static, or increasing, only half to two thirds of companies offer vocational training to employees[30]. Meanwhile, the percentage of employment accounted for by agency, temporary, part‐time and self‐employed workers - typically do not have access to corporate training programmes - is increasing[31].

Specific recommendations on how to fund skills training are beyond the scope of this paper. However, evidence would indicate that, whatever the role of the state and educational

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[30] Corporate spending on training has increased in the U.S over the last 6 years according to (Bersin by Deloitte 2015) and (Training magazine 2017). In EU 28 countries, spending on corporate vocational training remained constant between 2005 and 2010, when figures were last reported (Eurostat n.d.). However, whilst an estimated two thirds (66 %) of EU 28 companies provided continuous vocational training to their employees in 2010 – up from 60% in 2005 (Eurostat n.d.), a U.S survey by Accenture and Harvard Business School reports only 45% of companies offering internships or apprenticeships for middle-skills jobs (Accenture 2016).

[31] Temporary and part‐time work and self‐employment accounted for about a third of total employment in OECD countries in 2015 (OECD 2015). Economists Lawrence Katz and Alan Krueger claim all of the net employment growth in the U.S. economy from 2005 to 2015 – 9.4 million jobs – has been in alternative work arrangements (Katz and Krueger 2017). A survey by Harvard Business School of its alumni showed that 49% of respondents said their firms prefer to outsource work when possible rather than hire additional employees and, when hiring, are increasing their use of part-time workers (Accenture 2016).. One out of three workers in Japan – the traditional bastion of 'a-job-for-life'- are employed on fixed-term contracts according to one source (Japan Industry News 2016).

providers, companies need to step up investment in human capital, not only to close the skills gap, but also to drive innovation and productivity.

5. CONCLUSION

There is clear evidence that humans will remain central to effective automation strategies that are key to improving productivity and economic growth. As in the past, this wave of technological change will alter job profiles, requiring some workers to up- or re-skill either within their existing industry, or through a move to another sector. In the industries we have profiled in this paper, robot adoption can lead to more fulfilling, better-paid jobs – but it is down to the company to design cyber-physical-human-systems that give humans the autonomy central to job satisfaction.

The current problem is not disappearing jobs, but unfilled job openings due to lack of matching skills. Companies and educational institutes need to continue a trend of closer collaboration to ensure formal education is directed towards supplying specific skills in demand, as well as equipping workers with general analytical, communication and decision-making skills. Continuous, technology-based learning programmes are needed to ensure existing workers can continuously up-skill.

An open question is who will finance these programmes. Whilst some experts see the financial burden falling to the individual, others believe it is time for companies to reverse a trend of low investment in human capital – a move that could have a positive impact on productivity and innovation. Government has an important role to play in incentivising corporate investment and providing direct funding to educational institutions.

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