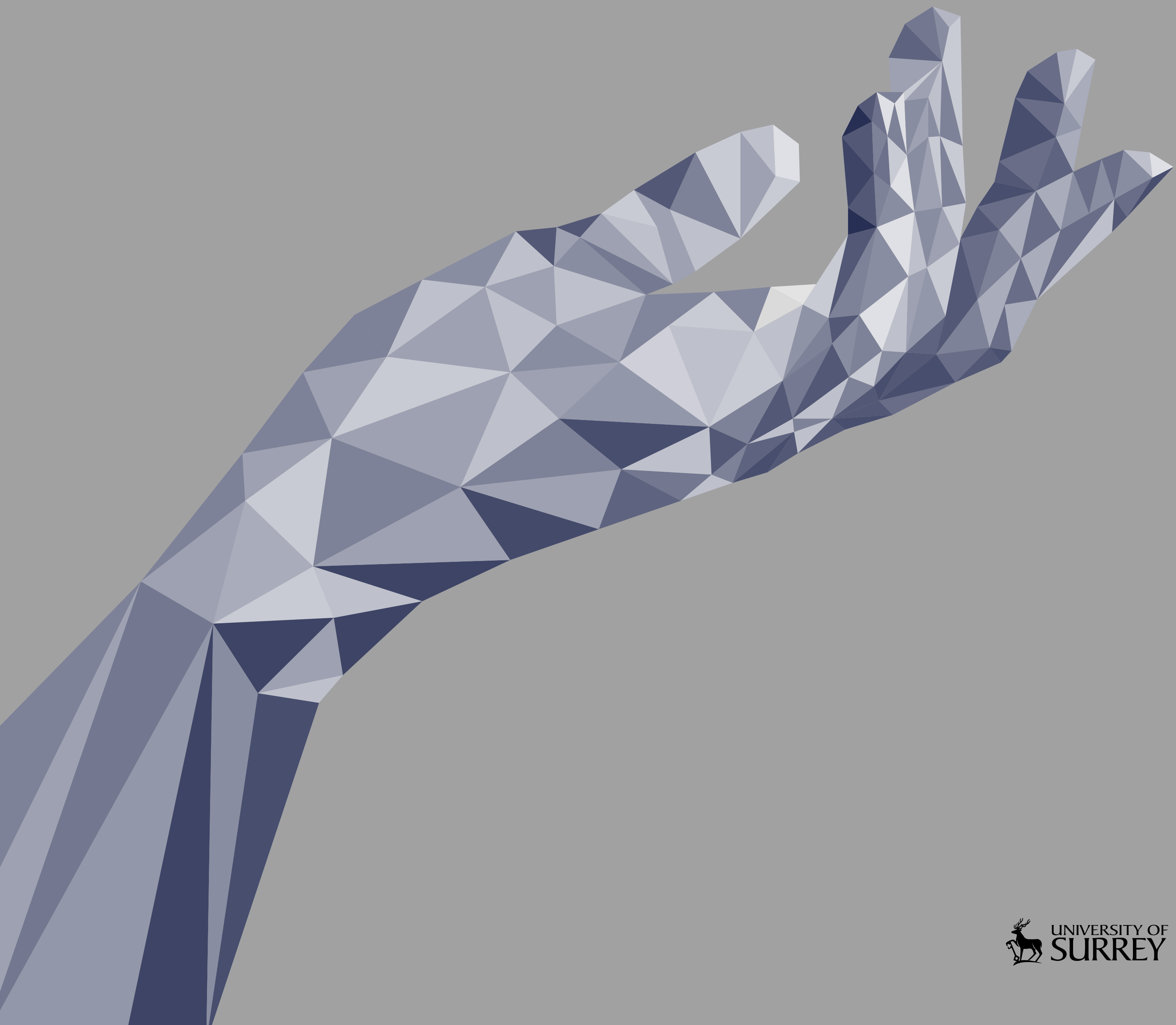
LLOYD'S

Emerging Risk Report 2019

Technology

Taking control
Robots and risk



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Contents

Executive summary

This report focuses on the rapidly emerging development of cobots - devices that help humans by extending their physical capabilities - and its implications for the insurance industry. Cobots are a fast-developing segment of the robotics market and are becoming increasingly popular as they are cheaper, smaller and smarter than regular robots (Gurman, 2018). As a result, they are increasingly moving out of factories and being used in sectors such as agriculture, healthcare and retail where they interact with humans or help them to do jobs that are dirty, dangerous, repetitive and difficult. As the focus of this report excludes software bots, we define robot as 'a machine situated in the world that senses, thinks and acts' (Bekey, 2011).

The cobots market is growing fast

Whilst cobots currently account for only 3% of the total robotics market, this figure is expected to reach 34% by 2025 (Smith, 2018) with the total value of sales set to reach US$9-12 billion by then (Murphy, 2017). The top cobot exporters include Japan, Germany, Italy and France (Trade Map, 2018), while 75% of imports are made by China, the Republic of Korea, Japan, the United States and Germany (IFR, 2018c).

At the moment, manufacturing remains the principal market for cobots. However, there are also clear emerging markets for industrial cobots (CB Insights, 2018) in new set of industries (IFR, 2018b) where jobs are:

- Dirty (e.g. construction and demolition: 1,100 units sold in 2018);
- Dangerous (e.g. defence: 12,000 units bought in 2017);
- Difficult (e.g. surgery: US$1.9 million worth sold in 2018); and
- Repetitive (e.g. farming: 7,200 units sold in 2018).

The logistics and healthcare sectors are also adopting cobots, particularly in countries with labour shortages and ageing populations. This has resulted in large facilities processing up to 200,000 orders per day with only four human workers present (LeVine, 2018) and hospitals adopting robots for a variety of jobs including surgery, cleaning and rehabilitation. Recent figures suggest that since 1990, robot prices have halved whilst labour costs have more than doubled. In short, the economic case for robot and cobot adoption is becoming increasingly compelling.

Since cobots are a relatively new and emerging technology it is hard to predict how quickly they will be adopted. However, it is highly likely that cobots will play a significant role in transforming many industries, sectors and regions across the world in the next few years.

Measuring the impacts on society

Robot use has several implications for society, including determining the responsibilities and rights of the machines, and where liability lies between owners, designers, programmers and other collaborators. Introducing cobots into a public environment is much more than a technological challenge. Possibly the biggest limit on the use of cobots is their compatibility with health and safety regulations and public attitudes, although recent research points to increasing acceptance as people become more accustomed to seeing robots in use.

While there is consensus that robots are already displacing jobs and will continue to do so, robots, particularly cobots, rarely replace workers; they replace tasks. They often help workers through decision-making, or physical handling rather than replacing them. However, as with any other tool, on aggregate robots will impact employment.

The shift towards automation will also create new jobs, as predicted by PwC's 2018 UK Economic Outlook.

Taking safety into account

A total of 38 robot-related accidents was reported to the US Occupational Safety and Health Administration (United States Department of Labor, 2019) in the 33 years between 1984 and 2017. Twenty-seven of those led to the death of a worker (Nichols, 2017). In comparison, the total number of workplace fatalities in the US in 2013 alone was 4,585 (Bureau of Labor Statistics, 2015). In Germany, severe industrial accidents (i.e. those resulting in fatality or loss of limbs) are very rare, ranging from three to 15 annually between 2005 and 2012 (DGUV, 2015). Murashov et al (2016) pointed out that there are few reports detailing accidents involving industrial robots, and that such incidents are rare worldwide.

The reliability of robots and cobots depends greatly on their design application and where they are used. Use of cobots typically involves multiple parties that include not just the organisation where the cobot is installed, but also its installation team, systems integrator, consultants/advisors and maintenance team, possibly telecommunications and cloud service providers as well as the cobot's designer and manufacturer. While most cobots are not necessarily considered dangerous, given their relatively low payload, it is nonetheless important that firms ensure there is oversight from a health and safety human expert and that their cobots operate in compliance with international standards for robot safety standards. The design, manufacture and operation of robots and cobots fall within the scope of several layers of ISO Standards and Technical Specifications.

Even though cobots are not necessarily considered dangerous, one of the challenges for the insurance industry is that "there are simply not enough cobots in the market to get accident statistics" as stated by Interviewee #1 (see page 23). Given the low numbers of robot-related accidents and the fact that only around 3% of installed robots were cobots in 2015, it is not surprising the data on cobot-specific accidents is not yet available.

A dedicated risk assessment will be crucial, as are additional measures to reduce risk based on real-world performance data (Platbrood & Görnemann, 2018).

Reacting to the new risk landscape

Widespread cobot use will create new risks, change existing risks and reduce others. To develop a more compelling picture of the cobots landscape, the report looks at four sectors (industrial environments, agriculture, healthcare and retail) in which the use of cobots is currently constrained by concerns about the risks highlighted below. By helping insureds identify the risks and by offering ways to mitigate them, insurance could help increase and speed up cobot adoption.

Reducing the risks

Robots can make a huge difference to how companies operate. They can prevent people from having to work in hazardous environments and inaccessible places. They increase productivity because they can operate continuously and reduce human errors in warehouses. The use of robotics in surgery has been found to shorten lengths of hospital stay, decrease complication rates and allow surgeons to perform finer tasks. Robotics in agriculture could potentially reduce environmental impact. Robotic devices executing precision tasks and operating either alone or in clusters can be less damaging than combine harvesters with their significant weight and load-bearing footprint. The gains are not limited to productivity. Lower waste is also a major environmental gain. In manufacturing and logistics, robots that work over a 24-hour period can enable fully automated environment with no human presence on-site and products to be built in small units that enable localised manufacture. In agriculture, cobots picking at night reduces the need to cool the produce. In short, cobots play an important role in meeting the objectives of the triple bottom line (people, planet, profit).

The report finds:

- The widespread adoption of autonomous mobile robots in retail and agriculture is likely to reduce employees' accidents and failures caused by fatigue.
- The use of robots in dangerous environments, such as nuclear decommissioning, mining, space and construction, can help improve safety.
- For insurers, increasing adoption of robots in dangerous environments would reduce number of employee injury claims by automating processes.

Changing risks

- The risk profile of employers' liability and public liability could change as liability could be pushed back onto the robot product manufacturer/designer.
- There is the potential for large-scale insurance losses resulting from business interruption in supply chains that use cobots that could need replacing and redesign due to a cyber failure or faults.
- Cobots weighing less than 100kg are more vulnerable to natural catastrophe events, which creates the potential for risk aggregation and therefore higher losses (e.g. 20 agricultural robots are more vulnerable to windstorm damage compared to a 20-tonne tractor).

  The ensuing property damage and business interruption losses covered could be large.
- Cobots require vast data storage facilities which could be vulnerable to cyber-attacks.
- Robot use in the healthcare sector can complicate liability. Medical clinicians using robots without the necessary training, or incorrectly operating may amount to medical malpractice; a robot may be defective and covered under product liability policies. The difficulty lies when robots are not fully autonomous and there is not a consensus whether the clinician is negligent, the robot is defective or both.

New risks

- Faulty cobots have the potential to cause damage to property (e.g. a moving robot might drive into a supplier's vehicle) and to other workers or people around as they start working in increasingly autonomous ways.
- In healthcare and homecare, there are risks associated with working directly on people. Interviewee #7 (see page 24) notes that safety tests with cobots tend to be done with adult male subjects, which indicates that they may not necessarily be safe for environments with more vulnerable persons such as older people or children.
- Interviewee #2 points to a future for agriculture where farms and fields will be worked by robots and drones together with tractors, but with high levels of artificial intelligence. This scenario introduces new risks, e.g. the consequential losses to crops from hacking or design faults, and increased losses from theft of valuable technology.
- Unscrupulous manufacturers might insert unethical behaviours into the robots' code.
- Robots that have user-adjustable ethics settings (e.g. choice between maximising length of life or quality of life) may have their settings somehow set outside an "ethical envelope".
- There is likely to be an ongoing struggle around the ownership of data between the intelligence functions, the cobot manufacturer, the internet of things (IoT) provider, the product manufacturer and, in some cases, the consumer. Whilst cobots in an industrial environment collect large amounts of factory and supply chain data, those interacting with humans in the home or in a retail environment gather highly-sensitive personal data. Security breaches in these domains could lead to large losses and slow cobot adoption.

Artificial intelligence and robotics

Artificial Intelligence (AI) is a core technology in the future development of robotics. Indeed, all interviewees in the report said that the future of robotics is dependent on the future of AI. Developments in AI and their potential impacts on the insurance industry are discussed in further detail in Lloyd's report *Taking control: artificial intelligence and insurance.*

Much of research in AI, such as deep learning for vision, speech recognition in interface design and the transition from supervised to unsupervised learning, are central to the future application of cobots. Challenges around designing an interface to minimise safety concerns where speech may be misheard or misunderstood and could lead to potentially life-threatening situations. A second problem is making the interface engaging and entertaining so that people will continue to interact with the device. Future developments in robotics are closely linked to those in AI.

Conversational AI has immediate application where robots are already fulfilling informational rather than physical needs. For example, in healthcare there is research into and development of text and speech conversational bots for mental health therapy and for health information provision. There is also research on physical robots in hospitals and care homes which can guide patients to locations or encourage them to do rehabilitation exercises. The use of cobots for healthcare in the home puts the emphasis on their interaction with humans so developments in technologies such as conversational AI will be central to their adoption.

Questions around new intellectual property (IP) ownership will arise from AI-enabled cobots in unsupervised learning within a factory or home.

Does the IP belong to the firm, the owner, the systems integrator or even the robot itself? There are also security and privacy concerns for firms whose IP is in manufacturing where the theft of the IP and ideas by disgruntled employees with good understanding of the systems can be a risk.

Cyber-risks, including hacking and data theft from systems as well as when devices are communicating with each other are another concern. Processes could be hacked or systemic defect introduced, and factories and workspaces could be held to ransom. For example, cyber criminals could threaten to shut down robots on a farm during peak picking season and threaten leaving the crops to rot.

There is also the potential for deliberate unethical "training" of a cobot, although it would be the responsibility of the robot installer/systems integrator to minimise the likelihood of this occurring.

Business opportunities for insurers

Growth

- With an estimated compound annual growth rate of about 60%, cobots represent a substantial new emerging market that offers considerable opportunities insurers to provide products and services to cobot developers and adopters.
- These markets are likely to be international, but as the pressure for onshoring and responsive manufacturing grows, opportunities in Western economies are also expected to grow rapidly.
- The development of Robot as a Service business models will also expand opportunities with SMEs, which may previously have been priced out of the robot market.

Insurance products

- Increasing adoption of cobots in environments that work closely with humans will expand the need for insurance products including: product liability, product recall, cyber, property, (contingent) business interruption and medical malpractice, all of which could be marketed as comprehensive insurance solutions for the robotics sector.

Partnerships

- There is an opportunity for the insurance industry to work directly with manufacturers to identify the risks associated with cobots deployment. This may well help to address health and safety concerns and therefore speed up adoption.

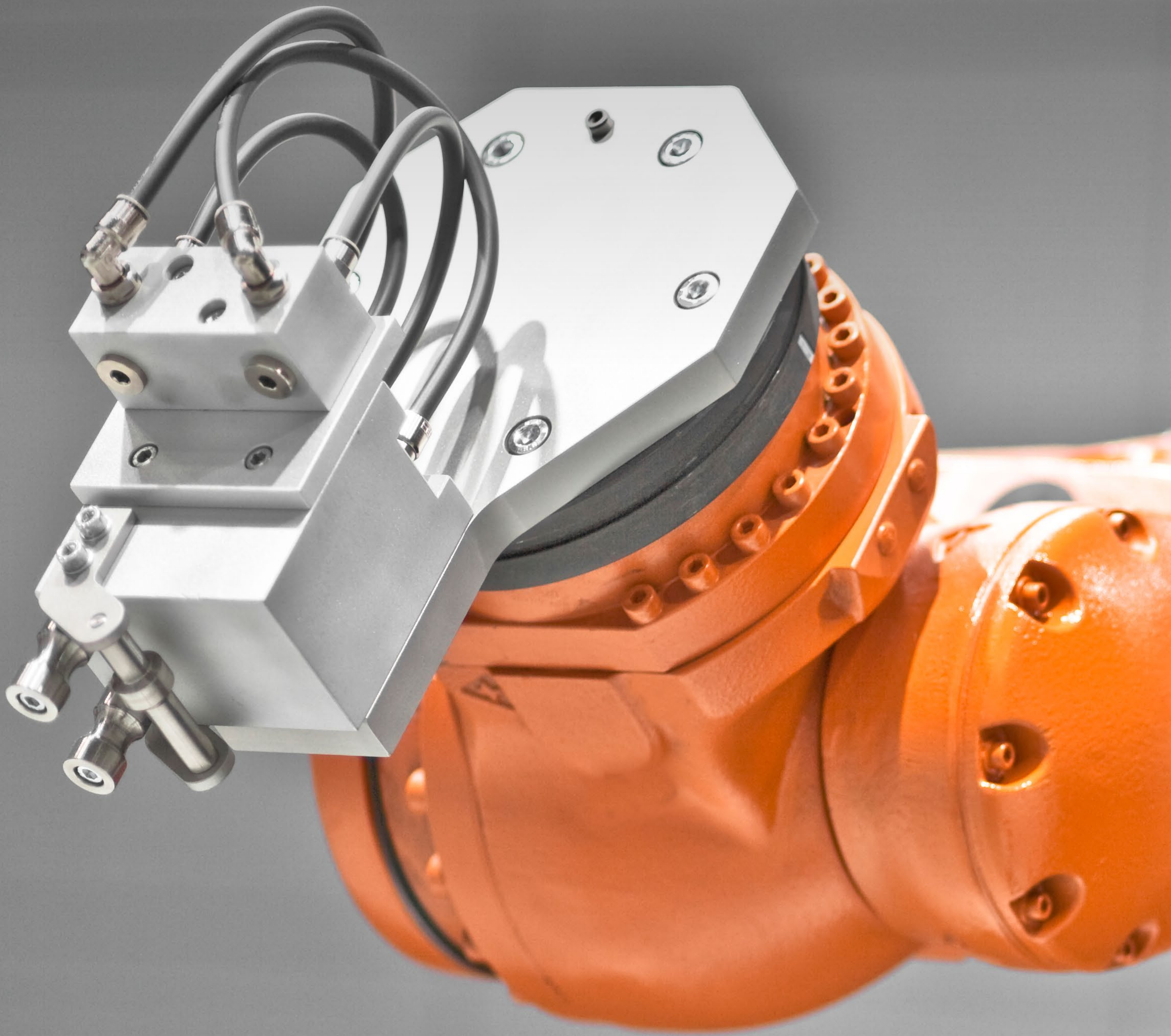
Data

- Data from cobots enables a much greater understanding of risk and offers opportunities for improved risks and pricing models. There are also opportunities to collaborate with clients to share risks relevant data to create better products. For example, in "precision farming", sensor data from fields could be combined with external climate and weather data to allow developers to develop algorithms that help the farmer make best use of their land this in turn might allow insurers to create bespoke and more accurately-priced crop insurance.

Conclusions

- The market for cobots is a fast-growing sector in the global economy and presents potential for specialty insurers. The large traditional robot – challenging to design, make and maintain – is being replaced with cobots that have voice recognition, are linked to industrial IoT, can be set up in half a day, use open-sourced code and can optimise around libraries of algorithms with learning capabilities and in many cases, are more mobile and agile.
- The adoption of cobots is opening up a new world of commercial possibility for developers, suppliers, users and insurers, at the same time as creating new risks, some of which may be unknown today. Other risks will reduce and change. This will necessitate innovation in both existing and new lines of business.
- Safety is the main concern and number one barrier to adoption, followed by issues of trust and acceptance (which are closely related to safety). These will require research into safety technologies, but also engagement and upskilling of stakeholders as lack of knowledge is the main barrier to uptake of automation, followed by the bespoke nature of products and concerns about the length of time to get a return on investment. This also relates to the issue about who has responsibility – it is not just safety technology that is required, but knowledge and training of users.
- The report shows how the adoption of cobots is currently constrained by safety, security, liability and physical risks. By helping insureds identify the risks and by setting out ways to mitigate them, insurance could help increase and speed up cobot adoption.
- The report suggests robotics designers and manufacturers, systems integrators and users should work with the insurance industry to mitigate and transfer the risks associated with robotics more fully. By leading in this space, the insurance sector will acquire the necessary knowledge to provide insureds with guidance on cobots best practices, thereby shaping the ecosystem in which they operate and the product offering.
- To conclude, predicting how rapidly robot and AI technology will be adopted and implemented will occur is difficult, but it is highly likely cobots will play a significant role in transforming many industries, sectors and regions across the world in the next 5 years and beyond. Insurers can facilitate this growth by working with sectors to develop the products and services they need.

Background



1. Background

The widespread adoption and use of robotics have given rise to emerging opportunities and risks, which we will examine and discuss in this report. Broadly, there are three categories of robots[a] (although it is important to note that many would not include software bots and RPA as robots):

1. The traditional industrial robot that typically operates in a caged environment, working with high payloads and/or speeds. It is relatively well-understood in terms of its strengths, opportunities, research challenges and growth potential.
2. Cobots or collaborative/cooperative robots which typically interact closely with humans and have much lower payloads[b]. They can be fixed or mobile.
3. Software bots have few if any physical characteristics, but can respond to a variety of inputs such as automated queries. This category more generally includes developments in Robotic Process Automation (RPA). Software constitute a rapidly expanding market which has its own challenges, principally around the development of Artificial Intelligence (AI) (Gurman, 2018).

This report focuses on the rapidly-emerging development of cobots; devices that help humans by amplifying their cognitive processes, interacting with both customers and employees and extending human physical capabilities (Wilson and Daugherty, 2018). A fast-developing segment of the robotics market, cobots are becoming increasingly popular as they are cheaper, smaller and smarter (Gurman, 2018). Unlike traditional robots, they do not need to operate in a protective cage. They are cheaper to maintain and can often carry out a wider range of tasks.

Typically, programming a cobot is also easier; this is sometimes done through 3D visualisation or by moving a robot arm through waypoints for faster set-up.

The disadvantages of cobots are that they typically handle a payload of around 20kg only (although Fanuc recently launched a 35kg cobot (Corbin, 2016); they have limited reach; and their operating speeds are considerably lower than traditional robots. This however has not affected their popularity. Collaborative robots are increasingly moving out of factories and applied in sectors such as agriculture, health and welfare, retail and entertainment where they are in contact with both trained and lay operators. The leading robot and cobot experts we interviewed for this report expect speed and payload to increase each year as technology continues to develop.

Definition

Carnegie Mellon University's Robotics Institute defines a robot as 'a machine that senses, thinks and acts'. Robots therefore include:

- Sensors, which provides vision and/or force sensing;
- 'Thinking'; they process information either locally or remotely and make judgements; and
- Acting; the application of a robot that includes welding, assembling and now, interacting with a customer.

As the focus of this report excludes software bots, we add a sense of physicality to our definition of a robot:

'a machine situated in the world that senses, thinks and acts' (Bekey, 2011).

[a] A Glossary of Terms for robots used in this report can be found in Appendix B

[b] There are inconsistencies in the use of this term. Interviewee #9 stated that in his experience, 'cobot' is used to refer to the small industrial robot arms marketed for collaborative use, and 'collaborative robot' used for more general robots designed to work with/alongside people.

An important debate is whether all the functions of 'sense, think, act' must be in a single box. This seems unduly restrictive in today's world of cloud computing, unlike the early days of robots where vision/tactile systems were frequently found in separate devices. Today's concept of a robot is also becoming increasingly blurred, overlapping strongly with many similar definitions of digital technology as we head towards recognising anything with a microprocessor as a robot.

The perception or 'robotness' may also be context-dependant. For example, a comparatively simple 'pick and place' device in a factory is called a robot whilst a sophisticated washing machine in the home is not. Devices that society frequently label as 'robot' tend to have their sensors and actuators outward-facing, while inward-facing devices like ovens and fridges manipulate a controlled internal environment and are therefore categorised as appliances.

Despite these challenges, we consider the addition of the term 'machine situated in the world' to the standard 'sense, think and act' definition as a good basis for this analysis. Much of this report considers devices that exhibit increasingly sophisticated examples of 'sense, think and act'.

History

Robots were first used in car manufacturing by General Motors in the early 1960s, but it was not until the 1980s when widespread application and research saw them being employed for processes such as welding, paint spraying, assemblies and inspection. By then, robots were also used in electronics through pick and place machines for printed circuit boards, as the application of robots became an essential part of Computer Integrated Manufacturing (CIM) and the factory of the future.

However, the business case for robotics implementation was often problematic, as humans were cheaper and more agile. In car manufacturing for instance, productivity from the application of the Toyota Production System (TPS) was found to be much higher than from automation, and the mantra became 'lean first then automate'. Closely associated with the techniques of lean production, TPS includes a range of process improvement techniques aimed at reducing waste and focusing on the social and procedural aspects of the process flow rather than the technology[c].

In the period following the widespread adoption of 'lean' across industry, sales of industrial robots remained relatively static at around 100,000 units per annum. However, since 2010 when ISIXSIGMA reported that 70% of companies were using lean principles (Woods, 2010), there has been a substantial increase in worldwide sales of industrial robots; 387,000 units recorded in 2017 (Statista, 2018).

Value chain

The following framework is useful for understanding the value chain of robotics, which comprises of three main elements:

1. Brains. The intelligence that is the machine learning, natural language processing and artificial intelligence aspects of the robot. As 'intelligence' providers build a platform of data they will be able to increase a robot's understanding of its environment. This gives rise to opportunities to build a platform that hosts data from multiple robots, learns from many examples and provides 'intelligence' as a service. This is discussed further in Lloyd's report *Taking control: AI and insurance.*
2. Manufacture and assembly. Robot manufacturers are classified into industrial robots, medical robots, consumer robots and drones[d].
3. Components. Includes specialist component manufacturers, many of whom have been engaged in the robotics industry for long periods providing basic mechanisms such as motors gears and actuators. There are also specialist software providers who enable users to tailor their robots to specific environments. Finally, there is the long supply chain of basic component parts such as semiconductors.

On the supply side, the advent and adoption of digital technology has been a major enabler in the growth of cobots. This includes the prevalence of computer chips supporting machine learning and deep learning, 3D cameras and drones, which along with other sensors enable the capture of large volumes of data. All of this is supported by the scalability of cloud-based computing resources. Taken together, they contribute to a huge upsurge in possibilities that are now being recognised by technology developers as well as entrepreneurs and venture capitalists (VCs).

[c] TPS was widely researched by a team at Massachusetts Institute of Technology (MIT) which found that engaging employees through process improvement led to much higher productivity than technology adoption: an echo of previous extensive socio-technical systems research. MIT's research resulted in the book *The Machine That Changed The World* (1990) which provided substantial evidence that TPS techniques led to lower defects, higher productivity and higher levels of worker engagement (Adler, 1993).

[d] This report does not cover drones, which are discussed in Lloyd's report Drones take flight: Key issues for insurance

Adoption

Technology adoption is often non-linear and tends to follow an S-curve. Five key factors determine the adoption of new products (Rogers, 2010):

1. The relative advantage of the new technology over previous technologies. The greater the advantage, the faster the adoption;
2. Compatibility with existing values and practices;
3. Simplicity and ease of use;
4. Trialability; and
5. Observable results.

Each of these factors is important when considering the speed of cobot adoption. Possibly the biggest limitation for cobot adoption however, is its compatibility with health and safety regulations. We will discuss this further in Section 3 on Laws and Regulations.

Despite the widespread application of the Rogers model (Rogers, 2010), a smooth linear growth trajectory for cobots is unlikely. For example, as sales increase, production unit price fall and accessories such as grippers become cheaper, software and ancillary services become more available. Predicting when this inflection point will occur is notoriously difficult (Robotics Business Review, 2017; Clements, 2018) but despite these caveats around timings and trajectories, it is highly likely that cobots will play a significant role in transforming many industries, sectors and regions across the world. This will result in societal and technological changes that will provide the insurance industry with a similar range of opportunities and challenges. The speed of adoption is likely to differ across sectors. For example, its use in manufacturing could pick up when unit prices fall, changing the economic trade-offs, but in healthcare, adoption is likely to be limited by the need to train professional support workers and in the home, through the development of appropriate interfaces.

From the demand side, robotics technology is no longer limited to industrial use, but is being implemented in many areas from factories and hospital theatres to vineyards, care homes and theme parks. We are also beginning to see more devices in the home, such as vacuum robots that can now be integrated with Artificial Intelligence (AI) interfaces like Amazon's Alexa (Song, 2018). The growing number of devices available for the domestic environment will have ramifications for the insurance market as well as wider societal impacts. Looking longer term for example, mini gardening robots could enable personal food production at home which could help reduce food waste and purchasing.

This in turn has implications for employment and tax revenue of the traditional food value chain.

Box 1: New business models

Across industry, new business models are emerging that focus on the provision of an asset 'as a service'. Probably the most famous example is with large equipment suppliers such as Rolls-Royce who offer 'Power-by-the-Hour' to airlines, such that the airline no longer needs to buy the engine outright but pays a usage fee for every mile flown. This shift to 'outcome-based contracting' is also occurring in robotics where the user firm can contract for a Robot as a Service (RaaS).

RaaS offers the robot user many advantages, e.g. no capital outlay, so it is OPEX (operating expense) not CAPEX (capital expenditure). It also provides more predictable monthly expenses,costs and lower maintenance and repair costs. For the robot provider, it reduces the sales barrier and provides recurrent revenue. However, there are some challenges that arise e.g. around negotiating priorities where a cobot is shared across facilities or setting expectations around conditions of use and any damage that may ensue.

Cobots from Universal Robots can now be hired for as little as £65 per day (Bots.co.uk, 2018), a cost very close to the 2019 UK's National Living Wage. As cobot business models develop, we can expect to see, for example, pricing models based on hourly usage or even the productivity gains achieved by the robot.

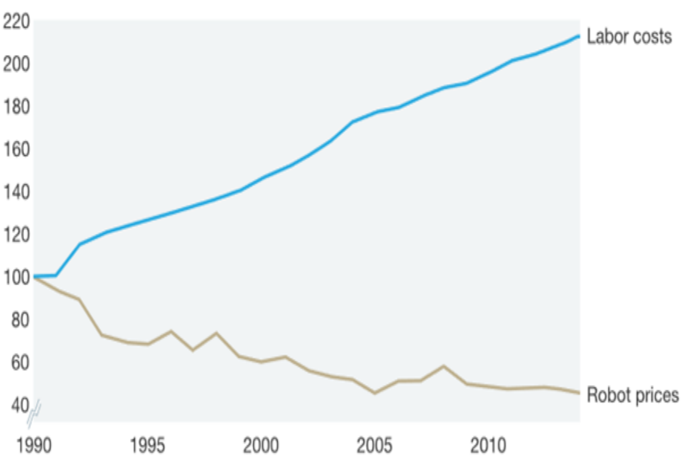
Economics of robotics adoption

There is no denying that robots can make a huge difference to how firms operate. They protect people from operating in hazardous environments (noise, temperature, chemicals, etc) and inaccessible places. They also offer substantial productivity gains by operating continuously and in warehouses through reductions in shrinkage (damage, theft, admin error, etc).

Due to their ability to carry out repetitive tasks accurately, robots allow for much lower defect levels in manufacturing products. As part of an integrated system in a factory, the home, the farm or the warehouse, robots can warn other devices of variations and therefore allow them to adapt accordingly. As part of a fully-integrated network system they can also provide data for optimising logistics and resource allocation. Recent figures suggest that since 1990, robot prices have halved whilst labour costs have more than doubled (see Figure 1). In short, the economic case for robot adoption is becoming increasingly compelling.

The gains are not limited to productivity. Lower waste is also a major environmental gain. In manufacturing and logistics, robots that work over a 24-hour period can enable a fully automated and unmanned environment and products to be built in small units that enable localised manufacture. In agriculture, cobots picking at night reduces the need to cool the produce. In short, cobots play an important role in meeting the objectives of the triple bottom line (people, planet, profit).

Figure 1: Robot prices have fallen in comparison with labour costs



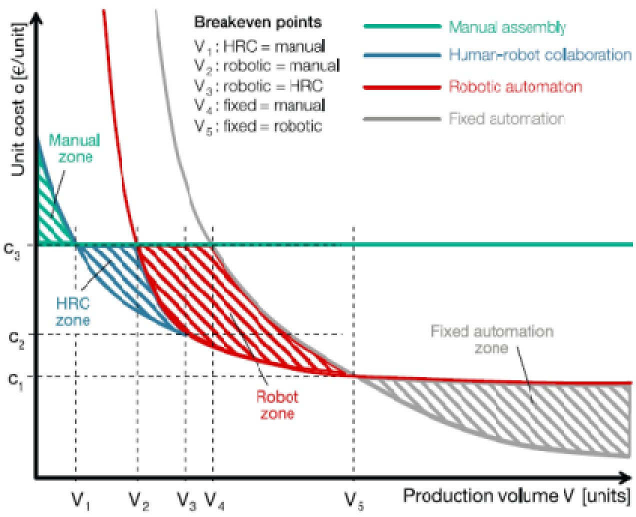
Note: Index of average robot prices and labour compensation in manufacturing in United States, 1990=100%

Source: Tilley, 2017

In his analysis of the economics of cobots, Schmidt (2018) outlined a number of main drivers for cobot integration: improvement, innovation ergonomics, new assembly processes, quality improvement and monotony reduction. All these factors alter the traditional cost-benefit analysis of technology adoption, prompting Schmidt to develop an economic comparison of alternative production systems.

Figure 2 shows that the range of economic usefulness for Human-Robot Collaboration (HRC) is quite narrow. At low production volumes, manual labour is used, and at high volumes full automation is economic. In the space between these extremes, traditional robots are economical at slightly lower volumes than full automation, and HRC has taken a place at slightly higher volumes than manual labour. There are of course many products and industries that fit this description including, for example, most small batch production in the food industry (according to Interviewee #2).

Figure 2: Cobot integration and economic comparison of alternative production systems



Source: Schmidt, 2018

This model has implications across all four of the sectors included in the report. In industrial, agricultural and retail contexts, the model indicates the economics of replacing labour. It may indeed underestimate the effect by not emphasising the benefits of 24-hour working, the increasingly low costs and sophistication of devices as well as the benefits for process flow and quality control. Indeed, as cobot use increases, production of cobots acquires scale economies, unit costs of sale and installation will decrease, giving rise to further opportunities for their adoption.

Modified framework – focus on process types

Schmidt's adoption model however has some potentially confounding effects. For example, it does not adequately reflect the increased personalisation of products and services. Digital technology is driving the emergence of a 'market of one', where consumers are demanding increased product personalisation and service environments, higher levels of personalised care. These demands drive variety into product and service delivery and require robots to operate on a greater range of tasks. This is one of the main drivers of the 'S' curve.

The lower the variety and greater the repeatability in the task, the more applicable is the traditional robot and its implementation will depend on a classic cost-benefit analysis around processing times, volumes, costs of acquisition/contract terms (see Figure 2).
In environments where it is important or necessary to interact closely with a human, the traditional heavy/fast robot is unusable. Many of these contexts have much higher potential variety.

This focus on the nature of the task rather than the sector enables us to develop a modified adoption framework that is applicable across sectors. This modified framework has four process types:

- Repetitive. Standard processes which are carried out frequently, are highly predictable, consistent and usually efficient. These are tasks where traditional caged robots are useful. At very high volumes, dedicated automation is used.
- Repeaters. Processes which are still predictable but less frequent in occurrence. The type of robot applied will depend on the cost-benefit analysis.
- Strangers. Processes which are highly customised, rarely occurring and often requiring a high level of specialised resource. These are likely to be environments where cobots are used if the variety does not overwhelm the analytic capability (e.g. in vision systems).
- Aliens. Things that have not been seen before and will therefore be outside the robot/cobot's area of expertise. Robots/cobots are unlikely to be used in these contexts until much more sophisticated data analytics and learning have been developed.

This provides a useful framework to consider multiple types of robots and their risk implications. For those highly-repetitive contexts requiring very limited human interaction, robots are being widely applied. Those robots that have a high degree of autonomy are designed to work in stranger/alien environments and are heavily dependent on sensors, control systems, AI and software design.

The challenge facing widespread firm adoption of cobots is the classic Innovator's Dilemma; the incumbent has few incentives to change its business model from its existing economies of scale. The speed of adoption will therefore be closely aligned to how persuasive their economic arguments are.

Data and statistics

Emerging Risk Report 2019
Technology

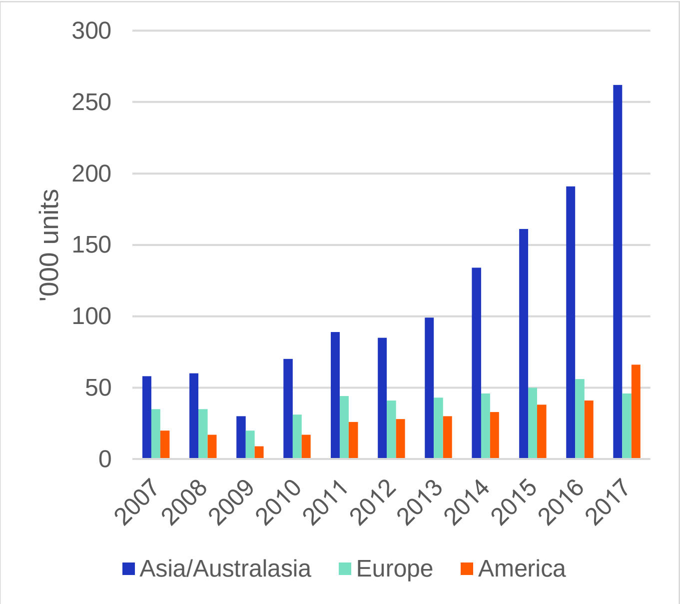
2. Data and statistics

Growth

The main adopters of robotics technology have been industrial firms; in manufacturing, extraction industries and industrial service applications. 98% of the 253,748 robots delivered in 2015 were traditional robot systems (Murphy, 2017). These are typically in caged environments working with heavy payloads at fast speeds, costing around US$100,000 each including the physical device and software. The International Federation of Robotics (IFR) has charted a sharply-rising curve for industrial robot sales in the decade to 2017 (see Figure 3) while Loup Ventures estimates that this market will grow by 11.8% annually to a value of over US$33 billion by 2025 (Murphy, 2017).

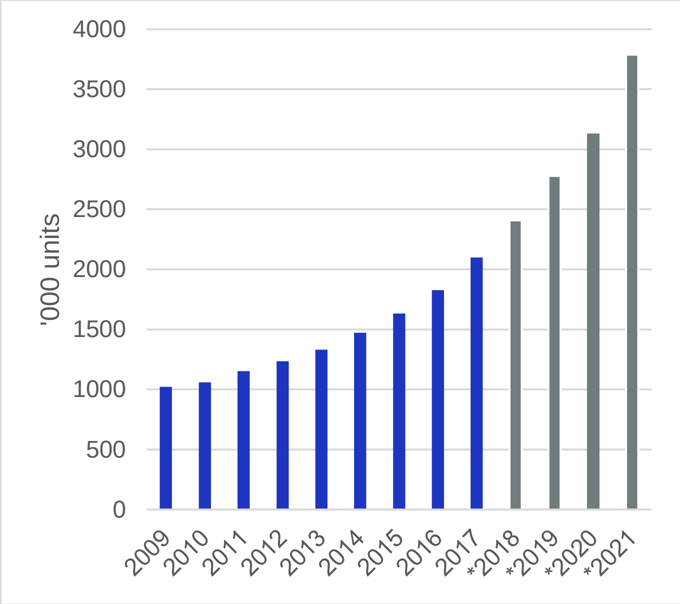
Figure 4 shows the projected growth in operational stock of industrial robots, estimated at 16% per year.

Figure 3: Estimated worldwide annual shipments of industrial robots by regions



Source: IFR World Robotics, 2018

Figure 4: Estimated worldwide operational stock of industrial robots 2016-2017 and forecast for 2018 through 2021



Source: IFR World Robotics, 2018

Cobots

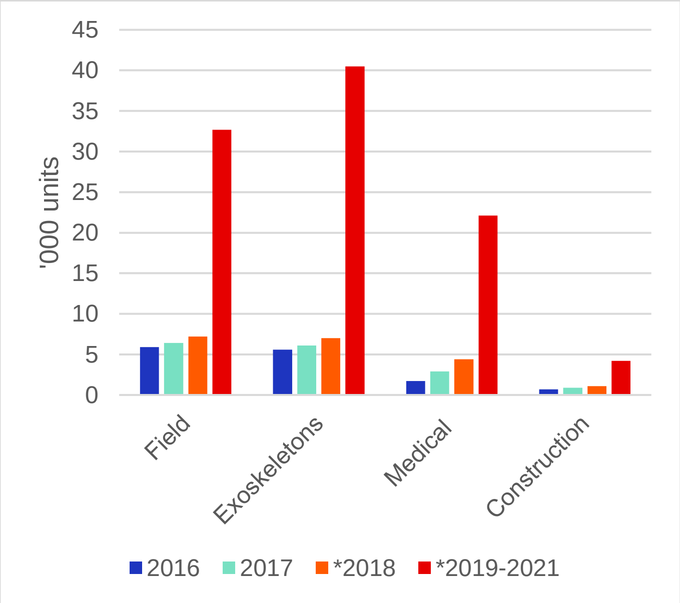
A substantial acceleration in sales will occur in cobots. Loup Ventures estimates that the numbers shipped will increase from 8,950 in 2016 to 434,404 in 2025 at a compound annual growth rate (CAGR) of 61.2%; a total value of around US$9 billion (Murphy, 2017). Other reports predict similar growth; MarketsAndMarkets.com (2018) estimates a market worth US$12 billion by 2025 and a growth rate of 50% CAGR. BIS Research predicts the market's value to be US$5.5 billion by 2023 with a CAGR of 64% while Jürgen von Hollen, president of Universal Robots, expects market growth of between 50-70% over the next five years (Demaitre, 2018)[e].

Whilst cobots currently account for only 3% of the total robotics market, this figure is expected to reach 34% by 2025 (Smith, 2018).

Service robots

The IFR predicts that the market for service robots will grow by a 21% CAGR over the next three years (see Figure 5).

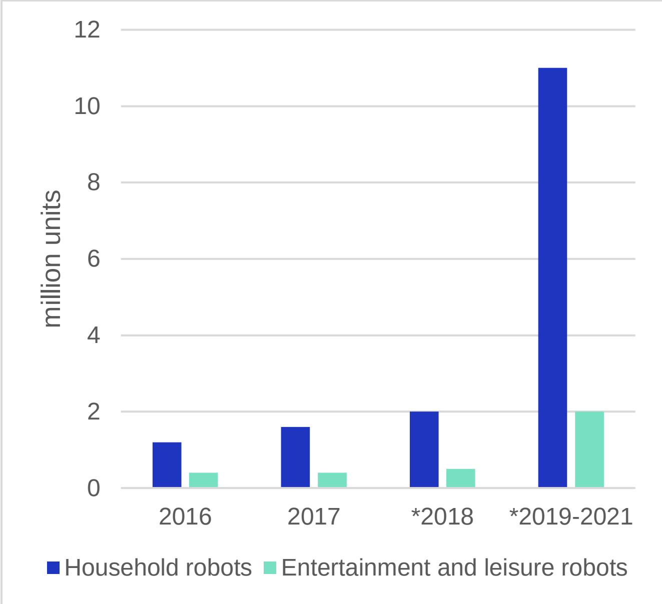
Figure 5: Service robots for professional use. Unit sales 2016 and 2017, forecast 2018 and 2019-2021



Source: IFR World Robotics, 2018

The IFR also examines robots for personal/domestic use separately, as their unit value is generally only a fraction of many types of service robots for professional use, particularly medical robots (IFR, 2018a). Even so, the use of household and entertainment robots is forecast to rise sharply in the next five years (see Figure 6).

Figure 6: Service robots for personal/domestic use. Unit sales 2016 and 2017, forecast 2018 and 2019-2021



Source: IFR World Robotics, 2018

[e]The difference in estimates are due to varying baseline figures, economic assumptions and methodologies employed.

Robot producers

Who are they?

The world's three largest industrial manufacturers of industrial robots are:

1. Fanuc with a strong automotive installed base (totalling 400,000);
2. Yaskawa which has a business built on its expertise with servo motors (installed base of 360,000);
3. ABB which is integrating robotics within its industrial Internet of Things (IoT) solution ability (installed base of 300,000).

As stated previously, the immediate future for industrial robot sales looks buoyant (Francis, 2018a) with established manufacturers expanding their range and many start-ups emerging with new technologies and materials, such as Grabit and its electroadhesion devices capable of lifting all kinds of different objects.

ABB, Fanuc, Yaskawa and Kawasaki are considered the leading manufacturers of cobots, with Asia Pacific as the fastest-growing region, according to Inkwood Research (2018). Yaskawa, Fanuc and ABB are also developing smaller profile, lighter-weight cobots, but emerging players in this space include Omron, Universal Robots and Robotiq, whose lighter, cheaper and more easily programmable devices are fundamentally changing the market.

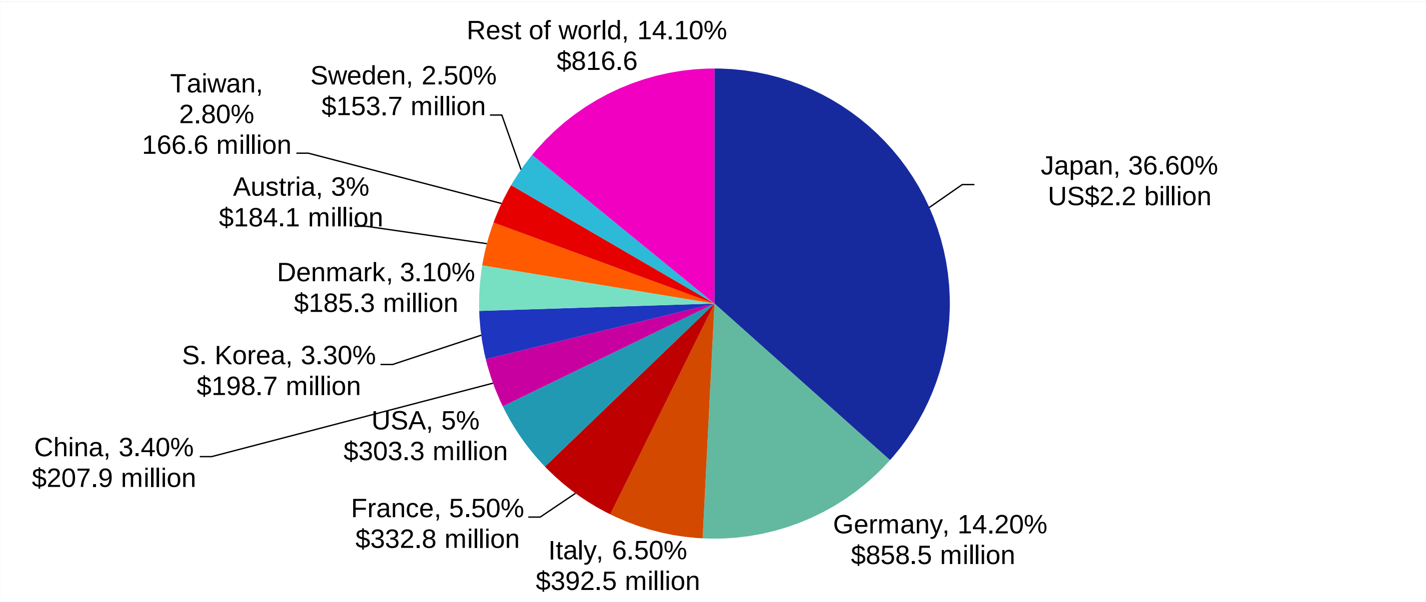
We are arguably at an inflection point for cobots (Clements, 2018; Robotics Business Review, 2017) and the sector is moving into a new phase; from being a market with heavy barriers to entry including expensive research and development (R & D) and marketing costs and expensive programming (Market Research Engine, 2017) to one that is rapidly opening with many new suppliers and technologies. The large traditional robot – challenging to design, make and maintain – is being replaced with cobots that have voice recognition, are linked to industrial IoT, can be set up in half a day, use open-sourced code and can optimise around libraries of algorithms with learning capabilities and in many cases, are more mobile and agile (as noted by Interviewee #1).

Where are producers located?

In 2017, worldwide sales from the export of industrial robots by country totalled US$6 billion (Workman, 2018), with the top 11 countries contributing 86% of the world's exports in robots (see Figure 7). The 11 countries each exported over US$2 billion during 2017 (figures compounded from Trade Map, 2018). However, the world production of robots is larger than this, as within-country sales are not accounted for.

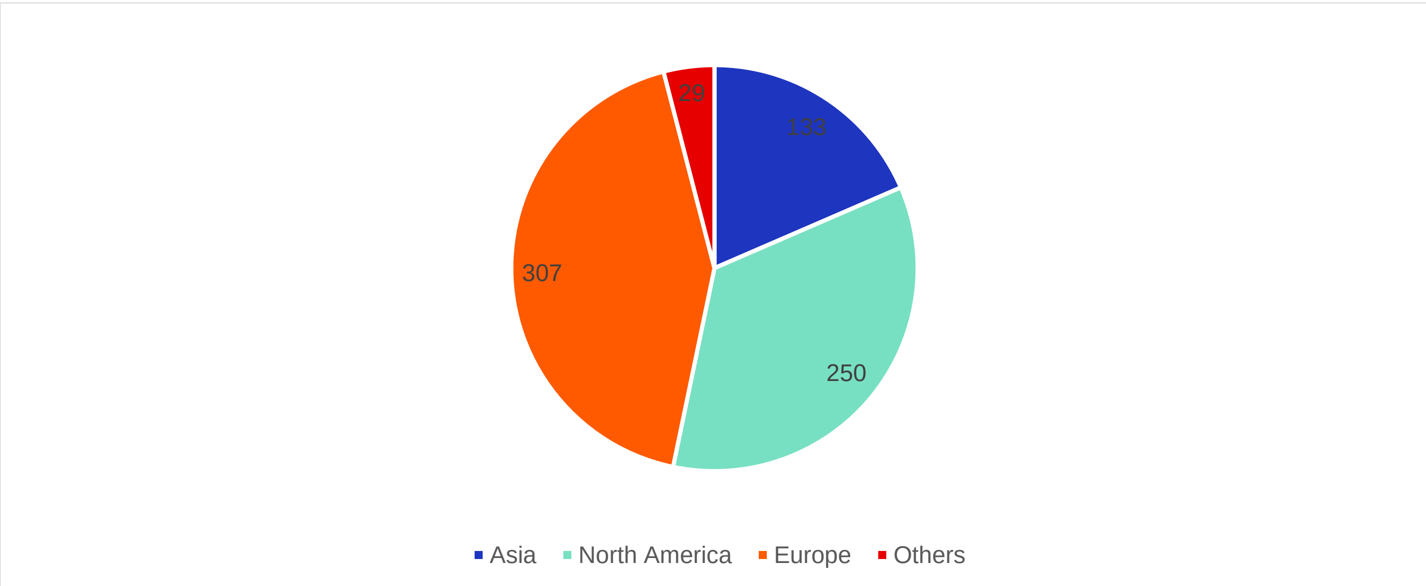
Figure 8 indicates that North America and Europe have a predominance of smaller manufacturers of service robots while Asia is dominated by a few larger companies.

Figure 7: Largest exporters of robots in 2017



Source: Trade Map, 2018

Figure 8: Origins of over 700 robot companies



Source: IFR World Robotics, 2018

Sectors

For the present and immediate future, robots are mainly used in manufacturing (IFR, 2018b) particularly in industries like automotive and electronics where jobs are:

- dirty (e.g. metals and machinery: 44,500 units sold in 2017);
- dangerous (e.g. plastics and chemicals: about 20,000 units sold in 2017|);
- difficult (e.g. electronics; 121,300 units in 2017); and
- repetitive (e.g. automotive industry: over 130,000 units sold in 2017).

Typically, these jobs would be handled by large industrial traditional, caged robots.

All aspects of manufacturing will remain the principal market for cobots, but there is evidence of growth in service robots for home and domestic use (Jacobs and Virk, 2014).There are also clear emerging markets for industrial cobots (CB Insights, 2018) that contribute to lowering labour costs and enabling strategies such as the reshoring of manufacturing, in the same type of contexts but a new set of industries (IFR, 2018b):

- dirty (e.g. construction and demolition: 1,100 units sold in 2018);
- dangerous (e.g. defence: 12,000 units bought in 2017);
- difficult (e.g. surgery: US$1.9 million worth sold in 2018); and
- repetitive (e.g. farming: 7,200 units sold in 2018).

Internationally, 75% of total robot sales go to five countries: China, the Republic of Korea, Japan, the United States and Germany (IFR, 2018c).

There are also extensive and growing robotics markets in logistics and warehouses, particularly in countries that experience labour shortages. For example, in the US, Amazon’s Jobs Day in August 2017 saw only 20,000 applications for 50,000 job openings (Morris, 2017). Major start-ups in this robotics space include Kiva (acquired by Amazon in 2016), Seegrid, Clearpath and Fetch. Cobots are also being used by DHL within its life sciences division for picking (i-SCOOP, 2017). In high-volume contexts there is evidence that jobs will be displaced; Chinese e-commerce giant JD.com has a 100,000 sq. ft. facility in Shanghai processing up to 200,000 orders per day but only four human workers (LeVine, 2018). This raises the issue of changing property risks with concentration of high-value equipment and limited human supervision.

Agriculture is also seeing considerable interest in robots following John Deere’s acquisition of the ‘see and spray’ robotic start-up Blue River Technology for US$305 million. Cobots are being used in the RASberry project at the University of Lincoln, where human strawberry pickers are supported by mobile robots acting as transporters (Duckett et al, 2018). Finally, the growing application of cobots in the health and social care sector is expected to be driven by significant demand for labour as the UK is forecast to be short of around 400,000 care workers by 2026 (Matthews-King, 2018).

Laws and regulations

3. Laws and regulations

Attitudes on regulating industrial automation have been found to vary from country to country. For instance, worker safety and job security are important considerations in framing industrial regulations and robot law in the US, while in China where industrial automation is a mean of growing its economy, there is an added focus on patents from robot laws (Prakash, 2017). South Korea is developing a Robot Ethics Charter, a code of conduct established for people involved in the development, manufacture and use of intelligent robots to prevent harmful or adverse effects that may arise, such as the destruction of social order, and to ensure intelligent robots contribute to enhancing the quality of human life (Statutes of the Republic of Korea, 2019). The EU report *Guidelines on Regulating Robots* (2014) stated that stringent product-safety rules should not stifle innovation.

In the UK, health inspectors have been found to be more risk averse than their EU counterparts to the risks of installing cobots in UK factories, often insisting that all robots should be fully guarded (Interviewees #7 and #9). The Health and Safety Executive (HSE) magazine cites a number of people who have gone through the process of putting a cobot into their factory and then being told by a health and safety inspector: ‘That’s not safe, stop.’ (Warburton, 2017). When the appropriate regulations have been followed at all stages of design and implementation, with robust mitigation procedures and training in place, then it can be shown that the cobot will probably not be considered ‘dangerous’ (Warburton, 2017).

Safety

In 2015, a technician died in an accident with a robot at a Volkswagen plant in Germany, sparking a flurry of discussion about robot safety (Financial Times, 2015). A total of 38 robot-related accidents was reported to the US Occupational Safety and Health Administration (United States Department of Labor, 2019) in the 33 years between 1984 – when the first human was killed by a robot at Ford’s Flat Rock plant in Michigan – and 2017. Twenty-seven of those led to the death of a worker (Nichols, 2017). In comparison, the total number of workplace fatalities in the US in 2013 alone was 4,585 (Bureau of Labor Statistics, 2015). In Germany, severe industrial accidents (i.e. those resulting in fatality or loss of limbs) are very rare, ranging from three to 15 annually between 2005 and 2012 (DGUV, 2015). Murashov et al (2016) pointed out that there are few reports detailing accidents involving industrial robots, and that such incidents are rare worldwide.

In the medical field, a 2016 US study by Alemzadeh et al (2016) found that 144 people had died during or after robot-assisted surgery in the US between 2000 and 2013. With over 1.75 million robotic-assisted procedures performed over this period, the number of deaths per robotic procedure is very small and has in fact decreased as the number of robotic procedures has gone up.

The reliability of robots depends greatly on their design application and use environment. Modern Fanuc industrial robots are said to have a Mean Time between Failures (MBTF) of between 80,000 to 100,000 hours (Motion Controls Robotics, 2019). In comparison, ST Robotics (2018) quotes a MTBF of 15,000 hours for its R12 cobot arm in a workshop situation. A 2004 reliability analysis of mobile robots in a hostile environment found an average MTBF of 24 hours, an improvement from the eight hours reported in 2002 (Carlson et al, 2004). Mobile robots are lighter-built, with less mechanical redundancy than static industrial robots, which means they have lower reliability. The mobile robots tested were however not operating in optimised conditions in a factory with low-variety tasks and loads. Instead, they were simulating military operations in urban terrain and urban search-and-rescue operations, hence in varied and hostile environments, and with a high variety of loadings.

Given the low numbers of robot-related accidents and the fact that only around 3% of the installed robot base were cobots in 2015, it is hardly surprising that data on cobot-specific accidents is not yet available. As Interviewee #1 stated: “There are simply not enough cobots in the market to get accident statistics”.

Usage of cobots typically involves multiple parties that include not just the organisation where the cobot is installed but also its installation team, systems integrator, consultants/advisors and maintenance team, possibly telecommunications and cloud service providers as well as the cobot's designer and manufacturer. When considering risks of cobots coming in contact with so many humans, the question that arises is, can cobots damage humans? Interviewee #7 has noted that safety tests with cobots tend to be done with adult male subjects, which indicates that they may not necessarily be safe for environments with more vulnerable persons such as older people or children. While most cobots are not necessarily considered dangerous, given their relatively low payload, it is nonetheless important that firms ensure there is oversight from a health and safety human expert and that their cobots operate in compliance with international standards for robot safety standards (see Section 3 on Laws and Regulations). A dedicated risk assessment is crucial, as are additional measures to reduce risk based on experience (Platbrood & Görnemann, 2018).

As home robots and RaaS becomes increasingly popular, even the ownership of the device becomes problematic. Interviewee #9 noted that in RaaS, the service provider will harbour the bulk of the responsibility, subject to users following established guidelines and manufacturers providing equipment that comply with standards and ratings. Methods for recording and analysing incidents to help identify what caused them are currently in development.

Standards

The design, manufacture and operation of robots and cobots fall within the scope of several layers of ISO Standards and Technical Specifications. Cooperative robots are specifically addressed in ISO 10218-1:2011, which provides for four modes of safe working.

Published in 2016, ISO/TS 15066 only applies to cobots in industrial environments, although its principles are relevant in other sectors. This Technical Specification aims to provide a comprehensive risk assessment guide of all the motions, interactions and operations a robot should perform in environments where humans are present. For instance, its pressure and force limit specifications can help prevent injury if there is incidental contact between a human worker and a robot (Robotiq, 2018). For example, in the case of a packaging application where a robot's points of human contact are already limited to workers occasionally supplying one bin and occasionally removing the other.

Personal care robots are governed by the ISO 13482:2014, which provides guidance on safe design, construction, installation and use in three categories: mobile service, physical assistant robots and person carrier robots (BSI, 2014). Its publication in 2014 was welcomed by the CLAWAR (Climbing and Walking Robots Association) for providing much-needed clarity. Previously, whenever there was an accident involving a new robot product, its manufacturer could easily be sued for potentially large damages as the manufacturer would have faced great difficulty in proving that all necessary steps had been taken to ensure that a new robot was 'safe' and therefore not at fault (CLAWAR, 2014).

Although the regulations for determining whether a device qualifies as a medical device in markets such as the EU, USA, Canada, Brazil, Australia and Japan are broadly comparable, regulators can exercise a significant amount of discretion in assessing whether a given system or device meets those criteria. Such variations however make it difficult to state with certainty whether a specific robotic device used in a medical application will be classified as a medical device, and is therefore subject to regulatory oversight, review or clearance (UL, 2017). This then affects the insurance status of any given device, which may vary from country to country.

See Appendix B for further details about ISO standards.

Ethics in robot design

It is clear that health and safety considerations should be implicit in the design of a robot, especially those that may come into contact with humans and more particularly, lay people. With the use of a professional service robot, some shortcomings may be mitigated by its operator receiving adequate training. However, where the operator is a lay person physically interacting with a personal service robot, safety is a major and primary concern (Röhrbein et al, 2013), as 'naïve users' do not have a good understanding of how a robot moves (Rodrigues et al, 2016).

The Engineering and Physical Sciences Research Council pointed out that Asimov's laws of robotics are inappropriate because they insist that robots behave in certain ways, as if they are people (EPSRC, 2010). In real life however, it is the people who design and use the robots who must be the actual subjects of any law. Hence, the Council has developed five "rules" for the designers, builders and users of robots:

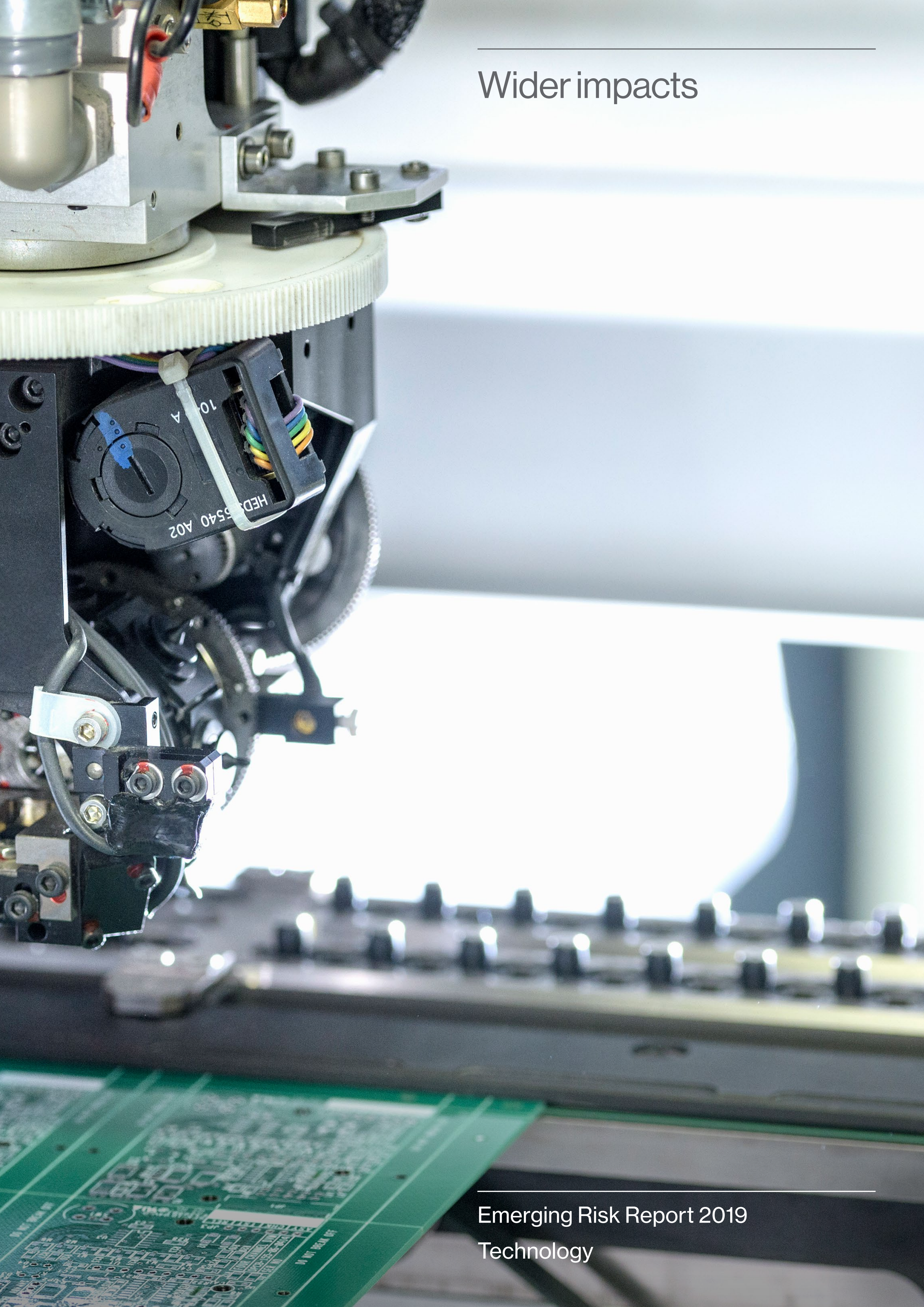
1. Restricting the design of robots as weapons only for national security purposes;
2. Robot design and operation should conform to existing law, including privacy;
3. Robots should be designed to be safe and secure;

4. The machine nature of robots should be transparent, and illusion of emotions not used to exploit vulnerable users; and
5. It should be possible to find the person responsible for a given robot.

Set out in 2010, these rules were intended as a living document and a basis for discussion and debate. Research however shows that it is hard to stop people from bonding with service robots and attributing volition to them (Knight, 2014). Also, it is not clear whether rule no. 5 applies to the Responsible Person of the Machinery Directive (HSE, 2011) or a person directly responsible at a given moment.

The UK's British Standards Institute (BSI) standard BS 8611:2016 provides guidelines for the identification of potential ethical harms (BSI, 2016a) as well as for the safe design and protective measures of industrial, personal care and medical robots (BSI, 2016b). The standard recognised that potential ethical hazards arise from the growing number of robots and autonomous systems being used in everyday life, highlighting that ethical hazards have a broader implication than physical hazards. However, claims of compliance with BS 8611:2016 cannot be made, as it is written as guidance and recommendations rather than a specification or code of practice. Hence it is important that different ethical harms and remedial considerations are duly considered.

Wider impacts



4. Wider impacts

Perceptions and acceptance

A 2012 study of public attitudes to robots by Eurobarometer (2012)[f] found that 70% of Europeans had a positive view of robots. A majority agreed that "robots are necessary as they can do jobs that are too hard or too dangerous for people" (88%) and that "robots are a good thing for society because they help people" (76%). They were however unhappy about having robots in their homes caring for children, elderly or the disabled; 60% of respondents thought they should be banned from such care activities. They also reported concern around their application in education (34%) and health care (27%).

However, we should recognise that most research into public attitudes on robots suffers from a methodological bias in that they are often using hypothetical examples. For example, Eurobarometer also reported that only 12% of EU citizens have used or are using a robot and their opinions may be exacerbated by perceived job displacement. Other research showed that 68% of respondents have a positive or approving attitude when they have been exposed to a robot as opposed to only 18% in hypothetical examples (Savela et al, 2017).

Unsurprisingly, these results suggest that when people have very little actual experience with robots, they are more likely to have negative attitudes; this may change as more people become exposed to robots in their daily lives. This is not untypical for innovations generally. In short, as a technology is perceived to be more useful and is easier to use, intention to use as well as usage behaviour rises (Savela et al, 2017).

Societal implications

The application of robots opens up a number of implications on society, including the responsibilities and rights of the robots and the lines of responsibilities between owners, designers, programmers and other collaborators. This in turn raises issues around the distribution of value between the supply chain partners and the potential for robot ownership to be located in tax havens free from the human complexities of domicile and residency (Ahmed, 2017).

Researchers have pointed out that tax policies currently encourage automation – even in cases where human workers are more efficient – because it enables firms to avoid the ongoing costs of employment such as wages and medical insurance contributions (Abbott & Bogenschneider, 2018). As robots displace workers, tax authorities are now considering their response. Recently the European Parliament voted down a proposed robot tax while South Korea has taken the opposite approach by limiting tax incentives for businesses applying automation. The implications for government policy are clearly at a very early stage.[g]

[f] Through a TNS Opinion and Social network poll conducted in 2012 through 26,571 face-to-face interviews

[g] Abbott and Bogenschneider's 2017 paper *Should Robots Pay Taxes? Tax Policy in the Age of Automation* provides more detailed consideration of this issue.

Box 2: Can robots replace the human touch?

ElliQ can respond to voice, gaze and touch, and suggest personalised activities at the right time to keep her companions sharp, active and engaged. But ElliQ is not human; she is an AI-driven social companion robot designed to help the elderly who live alone keep connected with their family, friends and the world around them (Elliq, 2019). Her creator, San Francisco-based Intuition Robotics, describes ElliQ as ‘the sidekick for happier ageing’.

According to human-robot interaction researcher Danielle Ishak, Intuition Robotics’ research has found that ElliQ’s human beta testers tend to form an attachment with the robot and are also more likely to open up to the robot, telling her when they’re depressed or lonely because they don’t feel they will be judged (Bloomberg, 2018). Despite this however, these is only so much ElliQ can do to cheer those who are severely depressed through loneliness and isolation; no source of AI robot will ever be able to replace human companionship or care, Ishak adds.

Robot ethics

Moor (2009) proposed that a robot may be four kinds of ethical agents:

1. Ethical impact agents whose actions have ethical consequences whether intended or not;
2. Implicit ethical agents which have ethical considerations built into (i.e. implicit in) their design (e.g. safety and security considerations);
3. Explicit ethical agents which can identify and process ethical information about a variety of situations and make sensitive determinations about what should be done; and
4. Full ethical agents which make ethical judgements about a wide variety of situations.

Robots and cobots can be generally classed as implicit ethical agents, in that they are specified and designed to operate safely in a given environment. It is however, possible that some cobots may soon be intended as explicit ethical agents (though there is some argument about the distinction between ‘ethical’ and ‘safe’, see for example Sharkey (2017)).

Winfield (2018) identified three risks associated with robots intended as explicit ethical agents:

1. Unscrupulous manufacturers might insert some unethical behaviours into the robots.
2. Robots that have user-adjustable ethics settings (e.g. choice between maximising length of life or quality of life) may have their settings somehow set outside an ‘ethical envelope’,
3. The rules may be vulnerable to malicious hacking. Winfield concluded that even with strong encryption, there is always a risk of hacking, so the responsibility for ethical behaviour must always lie with human beings.

Cave et al (2019) explored the risks beyond safety considerations and surmised that unless they can be properly managed, it is unwise to develop explicit ethical machines.

Robots as explicit ethical actors

There is no shortage of debate around the prospect of robots becoming explicit ethical agents, with such a possibility often expressed in the application of the 'trolley problem' with self-drive cars (Bonnefon et al, 2016). Put simply, the problem asks whether it is better to let an out-of-control trolley kill five people, or actively switch the tracks so it will kill one person. In practice, the answer is almost always to "slam on the brakes" rather than swerve into anything (Hern, 2016). Johansson and Nilsson (2016) point out there is little coverage of the trolley problem in driver instruction handbooks; instead, the focus is on avoiding accidents by constantly planning for surprising events. They suggest the design of robot AI should do likewise.

Roboticist Rodney Brooks (2019) called the problem "a made-up question that will have no practical impact on any automobile or person for the foreseeable future. Just as these questions never come up for human drivers they won't come up for self-driving cars." He compared the problem with Asimov's laws and the Turing test as thought experiments which have little or no impact on the way on the way robots are actually designed.

The 2017 European Parliament report also included a suggestion to grant self-learning robots "electronic personhood" status, enabling them to be insured and held liable if they caused damage to people or property. The report stated however, that "Asimov's Laws must be regarded as being directed at the designers, producers and operators of robots, including robots assigned with built-in autonomy and self-learning, since those laws cannot be converted into machine code" (European Parliament, 2017).

The European Commission strategy did not adopt the proposal of legal personhood for AI or robots, but it commits to ensure an appropriate ethical and legal framework since "artificial intelligence may raise new ethical and legal questions, related to liability or potentially biased decision-making" (European Commission, 2018).

Jobs and skills

The impact of automation – specifically, robots – on jobs is a complex debate with many different perspectives as well as statistics. In 2015, the Bank of England predicted that 15 million jobs would be taken over by increasingly sophisticated robots. According to McKinsey researchers, advanced robotics and AI could potentially automate 50% of work activities while in a highly-detailed analysis of tasks, Frey and Osborne (2017) considered 47% of total US employment to be at risk. A 2017 study by Nesta (co-authored by Osborne) estimated that 20% of the workforce are in jobs with shrinking demand but 10% are in occupations where demand will rise (Bakhshi, 2017). PwC's UK Economic Outlook predicted that although 20% of jobs would disappear due to AI, robotics and similar technologies over the next 20 years, a correspondingly similar amount of jobs would be created, with the health sector seeing the greatest number of new additions (PwC, 2018).

Despite these different headline numbers, there is a strong consensus that robots are already displacing jobs and will continue to do so. Analysing the effect of industrial robot use between 1990 and 2007 on the US labour market, Acemoglu and Restrepo (2017) estimated that one robot per thousand workers reduces wages by between 0.25-0.5% and employment by 360,000-670,000 jobs. More importantly, between 1.8 million and 3.5 million jobs will be lost should robot stock quadruple by 2025. Although these figures are based on some major assumptions and the effects may be slow, the researchers also pointed out that this may rapidly accelerate as robots deployed exceed the inflection point.

It is however not a straightforward transition from robots taking over tasks to job decreases. It is important to recognise that robots, particularly cobots, rarely replace workers. They replace tasks, sometimes by removing the need for employees but often augmenting workers through decision-making, or physical handling. Even in simple retail environments such fast-food chains, where the ordering transition and some aspects of the cooking can be automated, consumers may continue to expect and enjoy the human interaction and the implied safety that staff presence offers.

Introducing robots in a public environment is much more than a technological challenge. There is a need to involve user experience and industrial design specialists in the process. For example, Café X in San Francisco developed a public-facing robot barista programmed to display some human gestures including tilting the cup to present the beverage and then placing the cup with a flourish, whilst completing the task in less than 15 seconds.

The designers determined that choreographing the movement of the six-axis industrial robotic arm was more endearing to human consumers than adding facial features or superfluous speech (Budds, 2018).

The shift towards automation may displace jobs, but it will also create new ones, as predicted by PwC's 2018 UK Economic Outlook. Leading organisations are increasingly recognising that technologies such as AI and robotics are most effective when they complement, not replace, humans, notes Deloitte. Respondents to its *Global Human Capital Trends* survey foresee tremendous future demand for human skills such as complex problem-solving, cognitive abilities, social skills, and process skills, but companies are struggling to recruit and develop these human skills of the future (Deloitte, 2018).

Reskilling the workforce around the technology should be an obvious priority. However, while there appears to be government investment for doctoral studies in areas including AI, robotics automation and safety, process design and cybersecurity, there seems to be a huge gap in skills development between the levels of apprenticeships and undergraduate degrees, according to the experts we interviewed. Therefore, a machine operator who is made redundant would have little recourse to obtain new skills for robotics and AI.

Ethics in robot employment

But when and how is it ethical to use a robot? Today, "our robots do the dirty, dull, and dangerous tasks people might not want to do" (Yakowicz, 2016), as we mentioned earlier in this report. Not everyone however believes that the key motivation for creating robots is to eliminate the need for people to perform unattractive jobs. There is a contrasting perspective that robots should be deployed in occupations that require vigilance, responsibility and consistency, and that they should or could occupy any traditional human occupation (Takayama et al, 2008).[h]

An article in *The Register* (Out-Law.com, 2016) pointed out the following legal and ethical issues related to robot employment:

- the difficulty in apportioning risk and liability for a failure when a robot has hardware, software, telecommunications that all contribute to its use;
- data protection laws that cover information captured about employees;
- health and safety issues;
- displacement of employees by robots leading to unemployment and the social and economic problems arising.

Robots have ethical effects, positive and negative, on the people they displace, on their co-workers, and on the people they serve. A 2017 report for the European Parliament noted particularly the effects of robot care in the context of an aging population, stating that despite its many benefits to older people and people with disabilities, "human contact is one of the fundamental aspects of human care" and "that replacing the human factor with robots could dehumanise caring practices" (European Parliament, 2017).

[h] Takayama et al (2008) explored the opinions of lay people with an online questionnaire and concluded that in contrast to the simplistic notion that robots should do dangerous, dirty, and repetitivel jobs, public opinion favours robots for jobs that require memorisation, keen perceptual skills, and service-orientation, while humans are preferred for occupations that require artistry, evaluation, judgment and diplomacy.

Robots and other digital technologies

As cyber-physical systems, robots/cobots are complex devices. They require inter-disciplinary collaborations in their design, build and execution at many levels. In addition to the core skills of sensor development, programming and AI, coupled with mechanical and electrical engineering, designers also need to consider the wider ecosystem challenges the robotic entity would face, such as integration with other digital technologies.

Many developments are currently taking place in the Industry Internet of Things (IoT), termed Industrie 4.0 in Europe and the Smart Factory in the USA. These are discussed in further detail in the Lloyd's Emerging Risk 2018 report *Networked world: Risks and opportunities in the Internet of Things,* but it suffices to say that the future of manufacturing lies in these cyber-physical systems that combine human operators and machines such as robots/cobots equipped with sensors, microprocessors and radio-frequency identification.

Other countries such as Japan and Korea have also adopted similar smart manufacturing programmes. When placed within highly-automated plants, these robots/cobots can collect vast amounts of measurement data around processing times, queuing and set up times and error rates. In turn, data not only helps to optimise process flows, leading to better asset utilisation and improved quality; it can also inform the design of the next generation of robots/cobots. Crucially, it enables the robot/cobot manufacturer to develop alternative business models including through-life costing and outcome-based contracting.

Recent developments have extended the scope of cyber-physical downstream to the retailer. The next and most obvious extension is into the home (Parry et al, 2016), with developments such as the Hub of All Things (HAT) offering the potential to optimise supply chains from production to consumption and use.

Research at the moment however, tends to focus on specific topics and disciplines including sensors; communications such as 5G; networking; production engineering; computer science; data architectures and ontologies.

An important concept in integrating these ideas in a virtual environment is that of the "digital twin" (Tao et al, 2018), an idea first introduced by Grieves (2014) when discussing product lifecycle management in 2003.[i]

A digital twin consists of a physical product, a virtual product and the data that connects the physical and digital. In the context of Industrie 4.0, a virtual representation of the factory is created to simulate the physical site. The two are kept in tandem through the sharing of captured data from sensors and other mechanisms around the physical factory. A good example is ABB's RobotStudio developed based on its VirtualController, in which an exact copy of the factory software enables realistic simulations of the production robots to be tested and evaluated before they are transferred to the shop floor.

Having cobots in increasingly tightly-coupled industrial systems however, brings its own set of issues. Increased data collection in such cyber-physical systems, particularly through sensors on cobots, gives rise to the need for adequate storage space to hold the vast amounts of data being generated. In a potential future where such data is used to optimise flows inside the factory and supply chains both upstream and downstream, manufacturers need to mitigate risks of (systemic) failure resulting in large losses in the event of business interruption caused by a cobot breakdown. Many firms do so by building in redundancy as well as practicing production strategies such as contingency and forward planning and stockpiling, as well as increasing their use of 'plug and play' robots to safeguard against breakdowns.

Also, strong data security is paramount to safeguard against halts in production streams from potential hacking. Many manufacturers build their own closed networks for their cyber-physical systems, as well as practice segregation in restricting the data flow to and from the robots. Interviewee #10 stated that many manufacturers have internal networks that are strongly protected from integration to the wider network and therefore their access points are less easily tampered with. Interviewee #7 gave examples of automated warehouses where there is a firewall between front-office order entry and back-office picking so that only order information is provided to the robots.

[i] Glaessegen and Stargel (2012) define a digital twin as an integrated multi-physics, multi-scale, probabilistic simulation of a complex product and uses the best available physical models, sensor updates, etc., to mirror the life of its corresponding twin.

Artificial intelligence and robotics

Artificial Intelligence (AI) is a core technology in the future development of robotics. Much of research in AI, such as deep learning for vision, speech recognition in interface design and the transition from supervised to unsupervised learning, are central to the future application of cobots.

Several leading robot and cobot experts we interviewed revealed important recent developments in AI research. Interviewee #9 identified significant developments taking place in sensing for safety, for example, where a knife is used on the end of a robot arm. Interviewee #2 pointed out how important vision systems and predictive analysis are for ensuring worker safety where heavy loads are being moved around a farm or retail site, while Interviewee #5 noted the challenges in developing AI for interpreting images on a conveyor.

Interviewee #8 emphasised the importance of AI for developing improved interface design, crucial for robotic use in all locations but particularly in the home. Interviewee #8, who conducts research on conversational interfaces, highlighted the challenges around designing an interface to minimise safety concerns where speech may be misheard or misunderstood and could lead to potentially life-threatening situations. A second problem is making the interface engaging and entertaining so that people will continue to interact with the device. Interviewee #8 emphasised that “we are nowhere near a humanoid robot” and “it is still science fiction”. Finally, although we might be able to instruct a robot to stack a dishwasher or do the ironing, it would do so very slowly and only for that specific home. It would also very unlikely be able to perform any other domestic chores.

Interviewee #10 discussed future cobots in unsupervised learning within a factory or home, highlighting the issue as to who owns any new Intellectual Property (IP) that is developed: the firm, the owner, the systems integrator or even the robot itself? As far-fetched as it may sound, it does raise the wider issue of AI-enabled cobots becoming independent actors. Interviewee #10 also foresees security and privacy concerns for firms whose IP lies in manufacturing. Having a device that can understand how their entire factory/supply chain works and analysing that data remotely might limit its adoption.

Potential cyber-risks, including hacking and data theft from systems as well as when devices are communicating give rise to concerns about malicious tampering. There are concerns that processes could be changed, or a systematic defect could be introduced, while factories and workspaces could be held at ransom; for instance with threats to shut down robots on a farm during peak picking seasons and hence allowing crops to rot. There is also the potential for deliberate unethical training of a cobot, although it would be the responsibility of the robot installer/systems integrator to minimise the likelihood of this occurring. The experts we spoke to say such incidents of using robots to cause damage are rare, but that the greater risk lies in the theft of the IP and ideas by disgruntled employees, particularly when they have a good understanding of how the systems function and how different components such as the sensors work.

Future developments in robotics are closely linked to those in AI. Indeed, all our interviewees highlighted that the future of robotics is really constrained by the future of AI. The developments in AI and their potential impacts on the insurance industry are discussed in further detail in Lloyd’s report *Taking control: artificial intelligence and insurance.*

Box 3: Developing conversational AI

The risk with conversational AI is the potential for systems to misunderstand the user (either through poor speech recognition, environmental noise, or language understanding), thus likely leading to an unintended action (wrong health information delivered, unintended purchase, driver distraction). These factors can be somewhat mitigated by good conversational AI design, for example, explicitly confirming user requests at crucial moments. This is currently the subject of much ongoing research.

In 2017, Amazon launched the annual Alexa Prize, inviting teams of university students to develop a chatbot capable of conversing with humans on a variety of subjects. Building on existing Amazon Alexa software, the teams would create a socialbot, advancing knowledge acquisition, natural language understanding, natural language generation, context modelling, common sense reasoning and dialogue planning.

The tech giant believes the way humans interact with machines is at an inflection point, and that conversational AI is at the centre of the transformation (Amazon, 2018). Hence it is investing substantially in the prize which it hopes will help advance the field.

A study of four sectors

– Industrial
– Agriculture and food
– Healthcare
– Retail

Emerging Risk Report 2019

Technology

5. A study of four sectors

To develop a more compelling picture of the robotics landscape we have selected four sectors in which robot and cobot solutions have been applied at varying scales. We will consider each of the sectors across the medium term (up to three years).

Industrial

Robots are commonly used in industrial environments due to their ability to perform operations and processes quickly, repeatedly and accurately. Traditional industrial robots are used for fabrication processing, foundries, welding, painting, coating and sealing, flexible fixturing and workpiece handling, as well as material handling and warehousing, assembly of mechanical and electronics, quality assurance, maintenance and repair and re-manufacturing (Nof, 1999). In addition to traditional robots operating in 'caged' or highly-controlled environments, there is increasing deployment of smaller, lighter cobots within both SMEs and large manufacturers, in environments where they are close to or interacting directly with humans. As the Loup Ventures report indicates, the market for these robots will continue to grow at a rapid rate due to increased labour costs and the need to avoid dirty, dangerous and difficult jobs (Murphy, 2017).

Robots, cobots and mobile devices are increasingly being developed for industrial tasks outside the traditional factory environment. Interviewee # 6 pointed to over £90m of funding by the UK's EPSRC into four major centres for robotics research outside of the factory.

One example is the increased adoption of cobots for transportation purposes in collaborative environments. Just as the first industrial robots were installed away from humans in factories and laboratories, the first vehicular robots were found in warehouses where they could be used to manipulate larger payloads or dexterously configure smaller quantities of merchandise. We are now seeing more transport cobots operating in closer proximity to humans with mobile robots used in a range of applications, extending the concept of Automatic Guided Vehicles (AGVs) to Autonomous Mobile Robots (AMR) (Schneier & Bostelman, 2015). The difference now is an important one. Whereas the standard AGV, which has been around for almost 50 years, follows fixed routes, the robotic AMR uses sensors and on-board computers to understand its operating environment and dynamically navigate using a map.

Cobots in collaborative environments must be designed to minimise safety concerns. Important design factors (Kildal et al 2018) include proximity detection systems that slow down or stop movement, and collision detection systems that operate through force- or torque-sensing in the robot's joints, enabling subsequent reaction to that collision. Another safety factor (according to Interviewee #9) is hand-guiding where the robot is under the direct control of an operator. This requires sensor and actuator systems that enable the robot to be physically manipulated by the user without resistance. Also important are a projection-based space monitoring system, safety zones around the cobot's immediate area of influence and variable stiffness in actuators (Kildal et al, 2018).

Box 4: Cobots in industrial environments

Some examples of cobot use in industry include:

- ABB's YuMi, a collaborative dual-arm small-parts assembly robot that works alongside humans on ABB's socket lid assembly line handling springs, child locks and child lock covers. ABB has also announced that they will build an advanced robotics factory in Shanghai, using YuMi and other automated machines in safe proximity to humans to produce other robots (Moon, 2018).
- Adidas has opened two "Speedfactories" in Bavaria and in Atlanta, where both traditional robots and cobots are used. The time to manufacture a shoe is reduced from 60 days to six days (Wiener, 2017).
- In one of the largest international implementations, Foxconn in 2016 reportedly installed 40,000 robots replacing 60,000 workers (Fingas, 2016) and in February 2018 it was planning to invest US$4 billion into robotics and developing automation (Francis, 2018b).

Further examples of cobots working alongside humans exist in welding (Universal Robots, 2017) and coating (Universal Robots, 2019). In fact, almost all of the application areas for traditional robots outlined by Nof 20 years ago (Nof, 1999).

Interviewee #9 raised an important issue; when a cobot, which may otherwise be deemed unsafe, is applied to a dangerous process in a way that could reduce the overall risk. For example, a worker tending a hazardous machine could trap and lose a finger. The process is made safer by deploying a cobot to tend the machine, thereby saving the worker's finger. However, the robot could collide with the worker and cause a lesser injury. In this instance the overall risk is reduced, but the company may delay or add further safeguarding and reduce productivity to mitigate the new risk the cobot brings. According to Interviewee #9, health and safety staff have suggested that in such cases the cobot should be deployed as overall safety is improved. However, their industrial partners have been cautious, citing concerns over litigation for deploying an unsafe robot.

By becoming a key part of a factory's cyber-physical environment, cobots will lead to less waste throughout the supply chain and increased production capabilities. As manufacturing at scale grows, unit costs will fall, and alternative leasing models will be deployed.

Focus on the future

Cobots in this sector are currently at the early adopter stage of the life cycle, with a few major manufacturers creating scale economies. As the unit costs of cobots will continue to fall, the economic case for adoption will become much easier. Furthermore, as RaaS (see Box 1) becomes more widely available the cost of ownership will drop substantially. Demand is being led by industrial markets such as China, with the current drive for onshoring helping to increase demand in the USA.

The most pressing constraint is health and safety considerations. Once processes are developed to address those concerns, cobot adoption in industrial applications will grow more rapidly. Interviewee #9 reported that from recent industry workshops, safety always comes out as the number one barrier to adoption, followed by issues of trust and acceptance (which are closely related to safety). This requires research into safety technologies, but also engagement and upskilling of stakeholders. Market research (The Manufacturer, 2017) highlighted lack of knowledge as the main barrier to uptake of automation, followed by the bespoke nature of products and concerns about the length of time to get a return on investment. Cobots promise to provide solutions to the latter, whilst the former requires training and education, and closer collaboration with the R&D community. This also relates to the issue about who has responsibility – it is not just safety technology that is required, but knowledge and training of users.

In the next 3 to 5 years, as unsupervised learning in AI develops and interface design improves, we will see more industrial processes augmented by cobots. Cobots will enable the benefits of the human (e.g. cognitive and perceptual abilities) to be combined with those of the robot (e.g. speed, precision, repeatability, lifting capacity).

Finally, the combination of cobots with Additive Layer Manufacturing (ALM) and Industrie 4.0 will enable far more efficient factory and supply chain optimisation with the potential for more localised, smaller and responsive production facilities that reduce the need for large-scale transportation.

Insight: Implications for insurance

1. Increasing adoption of cobots in environments that work closely with humans provides new markets for insurance products. These markets are likely to be international, but as the pressure for onshoring and responsive manufacturing grows, opportunities in western economies are also expected to grow rapidly. The development of RaaS business models will also expand opportunities with SMEs, which may previously have been priced out of the robot market.
2. Faulty cobots have the potential to cause damage to property (e.g. a moving robot might drive into a supplier’s vehicle) and to other workers.
3. The risk profile of employer’s liability and public liability could change as liability could be pushed back onto the robot product manufacturer/designer.
4. There is potential for large-scale losses resulting from business interruption in supply chains using cobots. Removing cobots from a production line might incur extensive costs and be very time-consuming particularly if it involves product re-design.
5. Increasing adoption of robots in dangerous environments (e.g., nuclear decommissioning and space) would reduce risks as process are automated reducing the number of employee injury claims.
6. Data from cobots and Industrie 4.0 enable a much greater understanding of risk and offer opportunities for improved models. There are opportunities to collaborate with clients to share data.
7. There is an opportunity for the insurance industry to work directly with manufacturers on identifying risks around robot deployment. This may help to address some of the concerns of Health and Safety officers and drive up adoption.

Agriculture

The agricultural sector has proved a challenging, but potentially rewarding opportunity for robot developers. In the first era of robot development, the factory provided a highly-structured and relatively safe environment where processes are relatively constrained, and humans can be excluded from the area of operations. Farms represent a far less structured and homogenous environment, and there is clearly more human interaction albeit with the potential for control over access. The potential benefits of robot use in this sector are significant; it enables longer working hours, a stronger appetite for repetitive tasks and greater adaptability to unpleasant working conditions. Against these opportunities are various challenges including the diversity of farming environments, a lack of agile equipment, high set-up costs, and the need to learn and adapt to new processes. Demand for agricultural robots is also being driven by shortage of farm workers particularly in the USA, Japan and a post-Brexit UK.

Cobots have already been put to a range of uses in agricultural settings, but these tend to be highly-controlled environments. For example, in 2017 the IFR reported that farmers around the world purchased 5,700 milking robots, which are rapidly becoming the de facto technique for milking cows. This is the most successful robot system deployed across global farming and points to the opportunity for high adoption rates once the technology works. Interviewee #2 stated that the next most significant trend in the sector will be crop-harvesting robots which will need to be autonomous, thus adding complexity and worker risk. In the US there are already fully autonomous tractors. Their application in the UK might however be slower: as Interviewee #2 said, a "robot going wrong in the middle of a prairie is one thing, a robot going wrong in densely-populated UK is another."

Labour-intensive tasks performed by cobots, like the picking of fruit, are still under development. Interviewee #1 pointed out that the task of identifying and picking oranges from a tree is already very challenging, and each tree is very different; a task with which a human picker is much more adept. Interviewee #2 noted that cobots are already being used in simple tasks such as moving freshly-harvested crops, which are far more realistic short-term goals. Interviewee #2 believed that the more sophisticated use of cobots in this sector is at least five years away.

Cobots are also being used in tasks related to preparing the ground for crops. Thorvald is a commodity autonomous mobile robot used by a University of Lincoln research team as a mobile platform on which to develop a prototype soil compaction mapping system. By producing more and better data around the soil, such a system can offer more focused precision farming methods (Fentanes et al, 2018).

Robotics in agriculture could also potentially reduce environmental impact. Robotic devices executing precision tasks and operating either alone or in clusters can be less damaging than combine harvesters with their significant weight and load-bearing footprint. An excellent summary of the application of robotics in agriculture is provided by Duckett et al (2018).

Beyond pure agricultural applications, robots are also playing a far-reaching role along the food chain. Having robots that can assist with bagging, packing, processing and shifting makes shorter supply chains possible. The potential for integrating robots within a blockchain-enabled supply chain is increasingly being discussed as a panacea for food traceability (Pearson et al, 2019). Whilst such solutions do not prevent errors in data entry, they act as a deterrent to more traditional fraud mechanisms.

The adoption of cobots in the agriculture and food sector is significantly behind that of manufacturing (albeit automated milking has been around for quite some time). The sector is fraught with challenges such as terrain and complexities of identifying produce ripeness. In short, much of cobot application in agriculture is still at the early phases of technology readiness levels and yet to be trialled at scale.

More widely, the development and deployment of robotics in agriculture has some overlaps with the construction sector (e.g. working in difficult terrains, complex manoeuvring and the dexterity in movement required). Interviewee #7 noted significant potential in the construction sector, particularly with bricklaying robots. But although our interviewees commented that cobot use in construction is still at very early stages, monitoring and learning of opportunities and risks in agri-robots is likely to lead to similar applications in the sector.

Focus on the future

In farming and agriculture, robots are at a very early stage of adoption. Many current developments are still in the laboratory or in early stage testing with an increasing number of university spin-outs. Similar to manufacturing, current adoption is being restricted by health and safety concerns and limited to highly-constrained environments. However, Interviewee #2 identified increasing pressure to speed up developments and applications because of labour shortages across the sector. As this shortage can potentially become more severe, the pressure for firms to adopt automation and robotics will increase.

As robotic devices develop they could possibly facilitate precision farming. As they become part of an integrated system, they may be configured to handle a whole range of more specialist analytic and technical tasks, from soil analysis to precision seed planting. Further benefits from robot labour include the ability to increase productivity, for example by harvesting throughout the night when the terrain and produce are much cooler and therefore less prone to decay than in the daytime heat. Agri-robots are also being used in hazardous situations such as the application of UV-C to crops in place of pesticides, a task too dangerous for humans. Their adoption can only grow as demand for food without pesticide use accelerates.

In the future, farmers might start using low-cost standardised robots to convert their produce into supermarket-ready packed and sorted goods. Contingency planning might become more difficult; while the loss of one or several workers in a production line can be replaced quite easily, it is harder to do so on a cobot line, as having additional but underutilised labour capacity is prohibitively expensive.

From a workforce perspective however, agricultural cobots will still require a degree of specialist human support, at least in the medium term. Devices will need to be supported and maintained. New tasks will need to be programmed and taught, or at least heavily supervised.

Insight: Implications for insurance

1. With the advent of precision farming, sensor-driven data from the fields coupled with external climate and weather data will enable farmers to develop algorithms that exploit their land, recognising for example, local differences in the soil. This in turn might enable more bespoke and accurate crop insurance.
2. Interviewee #2 pointed to a future for agriculture where farms and fields will have robots with drones together with tractors, but with high levels of intelligence. This scenario introduces new risks such as potential losses from hacking or design faults and increased losses from theft of highly valuable items.
3. Light co-bots weighing below 100kg are inherently more vulnerable to natural catastrophic events. There is the potential for aggregation risks with a field manned by 20 robots which are more vulnerable to windstorm damage compared to 20-tonne tractors. The ensuing property damage and business interruption losses could be large.
4. There is potential for large-scale losses resulting from business interruption in supply chains using cobots. Removing cobots from a production line might incur extensive costs and be very time-consuming particularly if it involves product re-design.

Healthcare

The healthcare and wellbeing sector provides a huge range of potential opportunities for robotics. As robots become more adaptable, reliable and swifter in their response times, they are better able to operate near humans. The sector offers a variety of scenarios for robot-delivered services with humans in varying degrees of mobility; early solutions have ranged from surgical procedures to rehabilitation tasks.

Surgical robots

In 2017, the global surgical robotics market was valued at US$56,300 million; it is expected to reach US$99,000 million by 2024 at a CAGR of 8.5% during the forecast period (Allied Market Research, 2017). The use of robotics in surgery has been found to shorten lengths of hospital stay, decrease complication rates and allow surgeons to perform finer tasks. The costs are longer intraoperative times, equipment costs and the training costs associated with using the equipment (Hussain et al, 2014). Current evidence points to a strong cost-benefit case in the fields of urology and gynaecology (Hussain et al, 2014), while extensive, large-scale randomised clinical trials currently underway should identify those procedures most appropriate for robotic surgery (Lai, 2017).

At the UK's University College Hospital, an immersive 3-D monitoring system is used to provide the surgeon with a close-up view of the operation, while a surgical robot with four arms can be remotely directed with considerable dexterity, resulting in reduced risk of complications as well as training benefits for others observing the recorded procedure (Adams, 2018). More impressively, in 2017 it was reported that a robot dentist in China was able to carry out the world's first successful autonomous implant surgery by fitting two new teeth into a woman's mouth without any human intervention (Yan, 2017).

As surgical systems continue to evolve with new technologies, uniform standards for surgical team training, advanced human machine interfaces, improved accident investigation and reporting mechanisms, and safety-based design techniques should be developed to reduce incident rates in the future. While robotic surgical systems have been successfully adopted in many different specialties, a study by Alemzadeh et al (2013) has found that while the overall numbers of injury and death events have stayed relatively constant over the years as the number of procedures has increased, device and instrument malfunctions have affected thousands of patients and surgical teams by causing complications and prolonged procedure times.

The US is believed to be leading the way in the adoption of robots in surgical and medical environments while Japan is at the forefront with developing robots for the home. Such cobot developments are significant, as home care is a sector predicted to face enormous labour shortages in many western economies.

The use of robots in hospitals is not restricted to surgery. In the field of hospital hygiene, Westchester Medical Centre in Valhalla, NY, trialled a Xenex UV disinfecting robot to clean its intensive care unit, resulting in a 70% reduction in hospital-acquired C diff infections (Nagaraja et al, 2015). Robot logistics systems such as Aethon's TUG can carry equipment or pharmaceuticals up to 400kg around hospitals, freeing up porters and relieving nurses of carrying heavy loads.

Box 5: The breathing stone

A somewhat extreme example of a cobot is the Breathing Stone developed by start-up Biobeats. The stone is a manufactured device that identifies your stress levels from variations in your heart rate. It uses this information to prompt breathing exercises to music and therefore lower your stress.

The Breathing Stone has been adopted by Chelsea and Westminster Hospital, which gives around 200 patients a month access to the device prior to surgery. Biobeats claims that physical/mental stress is reduced by around 23% after the device is used in pre-surgery waiting rooms.

This device meets the definition of a cobot in that it senses (heart rate), thinks (uses AI to analyse patterns of heart rate) and acts (guides breathing). Although it doesn't meet the standard image of a fixed industrial cobot, it provides an example of how technology is adapting to meet patient needs and providing innovative applications of AI.

Robots in physical therapy

Healthcare robotics is also used in physical rehabilitation therapy and support, where specialised systems can repair limbs and other motor functions through targeted physical support. Robotic therapy has been as helpful in physiotherapy (OTPotential, 2018), while little difference in cost has been found between robot-assisted therapy, intensive comparison therapy and the usual care costs (Wagner et al, 2011).[j]

Much research has been conducted on specific joints for robotic solutions, but they do not always take human models as their precedent. For instance, octopus tentacles can provide powerful and adaptable, in the sense of form-fitting, mechanisms (Wei et al, 2018).

In China, Shanghai Fourier Intelligence Co. has produced therapeutic robots for upper and lower limb rehabilitation. Each robot can treat about up to 20 people per day. “Since there are 30,000-plus rehab facilities in the US, over 15,000 in Europe and more than 2,000 in Australia, you can imagine the size of the market in China,” Shanghai Fourier CEO and partner Alex Gu told *Shanghai Daily* (Shanghai Fourier, 2018).

Social care

Conversational AI has immediate application where robots are already fulfilling informational rather than physical needs. For example, in healthcare there is research and development of text and speech conversational bots for mental health therapy, and for health information provision. There is also research on physical robots in hospitals and care homes which can guide patients to locations or encourage them to do rehabilitation exercises.

One of the additional benefits that increased use of robotics provides comes from the application of AI; the huge amounts of data collected in robotic procedures may be used to train algorithms to begin the journey towards fully independent action and advice.

Robots in the home

With the home care sector predicted to face enormous labour shortages in many economies, robots are currently being developed and tested to interact with the elderly and dependent to help them with their day-to-day needs (Priyandoko et al., 2017).

Japan is at the forefront with developing robots for the home, with offerings such as SoftBank Robotics’ Pepper, designed specifically to exhibit empathy in a whole range of human modes both in terms of understanding and acting. Japanese government-funded research institute RIKEN has developed the Robear, a robot that helps people in their homes by lifting them from their beds and into a wheelchair.

Allied Market Research (2017) considers robotic services to be the fastest-growing market segment as the number of people with chronic conditions in the global population rises.

Within the general area of assistance, different types of robots can offer a variety of ways to help (Hosseini & Goher, 2017). Relatively simple, short and restricted tasks can be carried out by professionally-programmed robots such as Roomba or Navi Bot cleaner robots or feeding-aid devices like Bestic or My Spoon that can serve users in eating and nursing. They can also record crucial behaviours that keep a person healthy and safe and immediately send an alert to health services if an anomaly is recorded.

Robots can also be designed to offer companionship and intervene when appropriate. This type of cobot is generally programmed to be socially cooperative and come in many different forms, usually robotic domesticated animals such as Sony’s AIBO robot dog, the Pleo dinosaur, and the Paro baby seal. Already used in healthcare around the world, Paro is being considered as a form of emotional support for astronauts in space. The robotic seal is classified as a Class II therapeutic medical device by the US FDA and is utilised by the UK’s NHS as a form of non-pharmacological therapy for dementia (Chaturvedi, 2018).

[j] In Wagner et al (2011)’s study, 127 participants were randomised to usual care plus robot therapy, usual care plus intensive comparison therapy, or usual care alone. At 36 weeks postrandomisation, the total costs were comparable for the 3 groups; $17,831 for robot therapy, $19,746 for intensive comparison therapy, and $19,098 for usual care.

Focus on the future

Although fully-autonomous robot surgeons for complex procedures may be 10 years away, the shorter term will see an increase in remote-control surgical procedures using multiple redundant internet channels to minimise the risk of control dropout during the operation. The benefits for battlefield surgery and more economical procedures in developing countries and remote regions are considerable. One of the major drivers in healthcare is the level of investment from public and private research funders and VCs. Consequently, we can expect to see a significant growth in medical devices in the next five years.

In healthcare robotics, most cobots are fairly basic, requiring significant development in sensing, learning and the development of improved methods of interaction. Many countries tend to delay the entry of technological developments to market in the healthcare sector to ensure high quality, safety and cost effectiveness (Petkova, 2010). However, in the next three to five years we can expect to see extensive developments in the sector as knowledge gained elsewhere is applied in healthcare. For instance, developments in other areas such as material sciences “will allow lighter, more customizable structures with more tightly integrated actuation and sensing” (Gassert & Dietz, 2018) as lighter materials and improved sensors are incorporated. This means we should see more specific and personalised systems better able to meet patient’s needs, offer more stability and robustness and at lower prices.

Insight: Implications for insurance

1. New business opportunities in medical and healthcare robotics will continue to grow relatively quickly on the back of significant research and VC funding. As consumers become used to healthcare provision through cobots, there is a positive network effect leading to scale economies and increasing use. This opens up opportunities for insurers to expand offers for both medical malpractice and product liability coverage.
2. Similarly, opportunities for insurers are offered by emerging use of robotics in healthcare markets in countries experiencing labour shortages and ageing populations such as Japan, but also increasingly across western economies. Development of assistive robots can be used across multiple customers to provide specialist services such as physiotherapy.
3. Manufacturers and clinicians both owe a duty of care to end consumers and patients respectively. Robotics in the healthcare sector can complicate the assignment of liability. Clinicians using robots without the necessary training, or incorrectly operating may amount to medical malpractice. A robot may be defective and covered under product liability policies. The difficulty lies when where robots are not fully autonomous and there is not a consensus whether the clinician is negligent, the robot is defective or both.

Retail

The overall retail market for cobots is estimated to be worth more than US$11 billion across a range of applications such as shopping malls, receptionists and guides in hotels, airports, museums and amusement parks. Cobots also have significant potential to provide guidance in banks and to carry out simple repetitive cashier functions.

Cobots mainly used in warehouses are Autonomous Mobile Robots (AMRs). For example, in 2017 Amazon had over 100,000 robots in use worldwide, with plans for many more (Heater, 2017) whilst Ocado has 1,100 in one single 18-acre facility in South East UK (Kleinman, 2018). Robots are also increasingly being used not just to move products across a space but to deliver directly to the customer, such as Best Buy's Chloe which picks up the CDs and DVDs ordered through touchscreens and delivers to the customer. Best Buy's 'Tally' robot travels through warehouse aisles and tally up stock and can work out if items had been wrongly priced or put in the wrong place. The Starship delivery robot can travel outside the warehouse on pavements at around 4 miles an hour and carry a load of around 9kg. However, Interviewee#1 pointed out that these might need to be limited to very flat landscapes within low-crime zones.

In South Korea, E-Mart is using LG's shopping carts that can follow the customer around and navigate shopping aisles (Synek, 2018). One of the future benefits of the electronic cart is the ability to scan items as they are put into the cart and therefore reducing the need for check-out assistants. Giant Food Stores are using a cobot (Bowles, 2019) called Marty that alerts customers around it when it sees something it considers a hazard. It then sends a message to humans (located, in this case, in the Philippines) who are monitoring the stores on TV screens to determine if the potential hazard is something about which they need to alert the store manager. Investment in such a cobot is economically viable because US slip-and-fall accidents can be expensive if the retailer is found to be at fault.

Cobots also have the potential to transform the customer experience. A recent survey (Ismail, 2017) found that nearly half of British consumers have experienced bias because of their individual characteristics, beliefs and/or appearance. Only 8% of respondents felt that chatbots will be biased; this is despite concerns that human bias could be transferred onto modern chatbots.

However, some customers will still prefer personalised attention, and abilities such as accurate problem diagnosis, emotion identification and picking up social cues are notoriously very difficult to automate. Interviewee #4 told us that a lot of work is currently taking place in identifying emotion. At Carnegie Mellon University's Robotics Institute, its director Martial Hebert has said that the challenges are not so much in the robotics but in "Understanding people, predicting people, and understanding their intentions. Everything from understanding pedestrians for self-driving cars, to understanding co-workers in collaborative robot manufacturing, any application that involves interaction with people at any level." (Anandan, 2018).

Focus on the future

Cobots are very likely to have increasing and swift adoption across the retail sector as the economics of job replacement, particularly in back-office operations, is fairly straightforward. In warehouses, AGVs are being replaced by more sophisticated devices that can adapt to hazards, other devices and minimise risks to human operators. In the short term, the major constraint is likely to be developing policies and procedures to ensure health and safety concerns are met.

The opportunities are also clear in more face-to-face environments. Cobots offer the potential for 24-hour opening both in retail and also in warehouses where they can run 'lights out' operations. There are however, significant technical challenges in robot-human interaction, as Interviewee #8 pointed out that robots misidentify things and can introduce hazards. The challenge is to make the interaction accurate, but also engaging and informative so that the customer will enjoy a safe experience.

Insight: Implications for insurance

1. As a consequence of increased adoption and high-value machines, the property risk profile will increase.
2. Interactions with cobots create potential hazards for both employees and customers (e.g. being struck by an object carried by a cobot or by the cobot itself could cause bodily injury) and could result in expensive litigations.
3. The risk profile of employer's liability and public liability could change as liability could be pushed back onto the robot product manufacturer/designer.
4. There will be opportunities for the provision of ancillary services around warehouse and shop floors layout and design based on risk reduction.

Conclusions

6. Conclusions

The market for cobots is a fast-growing sector in the global economy and presents potential for specialty insurers. The large traditional robot – challenging to design, make and maintain – is being replaced with cobots that have voice recognition, are linked to industrial IoT, can be set up in half a day, use open-sourced code and can optimise around libraries of algorithms with learning capabilities and in many cases, are more mobile and agile. The adoption of cobots is opening up a new world of commercial possibility for developers, suppliers, users and insurers, at the same time as creating new risks, some of which may be unknown today. Other risks will reduce and change. This will necessitate innovation in both existing and new lines of business.

Safety remains the main concern and number one barrier to adoption, followed by issues of trust and acceptance (which are closely related to safety). These will require research into safety technologies, but also engagement and upskilling of stakeholders as lack of knowledge is the main barrier to uptake of automation, followed by the bespoke nature of products and concerns about the length of time to get a return on investment. This also relates to the issue about who has responsibility – it is not just safety technology that is required, but knowledge and training of users.

The report shows how the adoption of cobots is currently constrained by safety, security, liability and physical risks. By helping insureds identifyi the risks and by setting out ways to mitigate them, insurance could help increase and speed up cobot adoption. It suggests that robotics designers and manufacturers, systems integrators and users should work with the insurance industry to mitigate and transfer the risks associated with robotics more fully. As cobots are used in more and more sectors, insurers should take a proactive role in talking to insureds and potential clients to review and assess all risks. By leading in this space, the insurance sector will acquire the necessary knowledge to provide insureds with guidance on cobots best practices, thereby shaping the ecosystem in which they operate and the product offering.

To conclude, predicting how rapidly robot and AI technology will be adopted and implemented will occur is difficult, but it is highly likely cobots will play a significant role in transforming many industries, sectors and regions across the world in the next 5 years and beyond. Insurers can facilitate this growth by working with sectors to develop the products and services they need.

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Appendix A: Glossary of terms - Robots

Terms for robots that are used widely in this report are:

- Cobots or collaborative/cooperative robots: Devices that operate near humans, usually working with them in a shared space.
- Industrial robots: Robots used in manufacturing, in applications that include assembly, welding, pick and place. These are usually traditional ‘caged’ robots that are fixed, but they could also be cobots.
- Service robots: All types of robots except industrial robots used in manufacturing.
- Professional service robots: A sub-group of service robots used for commercial tasks, for example, medical or surgery robots in a hospital or fire-fighting robot. Usually under the control or guidance of a trained operator.
- Mobile robots: Devices that are capable of moving around in their environment instead of being fixed in one physical location. Examples include Automatic Guided Vehicles (AGV) and Autonomous Mobile Robots (AMR).
- Personal care/personal service robots: A sub-group of service robots that operate closely with humans, usually in direct contact, to contribute directly to their wellbeing. Can include consumer/domestic robots used in the home, such as vacuum cleaner and gardening robots. Usually controlled by a layperson.
- Self-learning robot: A robot that acquires skills or adapt to its environment through learning algorithms.

Note that industrial/service classification is done according to application area. None of the categories refer exclusively to cobots (however, they are very likely to be in close proximity to humans).

Appendix B: Safety standards

As robots fall under the broad definition of machinery, they are subject to the EU Machinery Directive 2006/42. Where they are intended for the consumer markets, they come under the purview of the General Product Safety Directive 2001/95.

The design, manufacture and operation of robots and cobots are within the scope of several layers of International Organization for Standardisation (ISO) Standards and Technical Specifications (TS):

ISO 12100:2010 specifies principles of risk assessment and reduction and underlies the standards governing the design of robots.

ISO 10218-1:2011 specifies requirements and guidelines for the inherent safe design, protective measures and information for use of industrial robots. It is aimed at the robot manufacturer. Part 1, 5.10 covers collaborative operation requirements, such as a visual indication when the robot is in collaborative operation. It provides for four modes of safe working (Platbrood & Görnemann, 2018):

1. Monitored safe stop - where the robot is stopped while the operator enters the safe space;
2. Manual control - where the robot is manually guided at a safe speed by the operator;
3. Force and power limitation - where contact between the robot is detected and the power and force of those contacts are limited;
4. Distance and speed monitoring - where the robot detects the presence of a person and moves away to avoid contact.

ISO 10218-2:2011 specifies safety requirements for the integration of industrial robots and industrial robot systems as defined in ISO 10218-1, and industrial robot cell(s). The integration includes the design, manufacturing, installation, operation, maintenance and decommissioning of the industrial robot system or cell, necessary information for the design, manufacturing, installation, operation, maintenance and decommissioning of the industrial robot system or cell and component devices of the industrial robot system or cell. It is aimed at the robot integrator.

The ISO 10218 standards are currently being revised under the regular five-year ISO review cycle, and a new version is expected in May 2021. Recognising the growth of collaborative robot use, many topics and requirements are being discussed, including listing all the relevant safety functions, developing more specific safety requirements for brakes and mobile robots, and cybersecurity (Pilz, 2018).

ISO/TS 15066:2016 is a technical specification for collaborative robots. It only applies to cobots in industrial environments, although its principles are relevant to other sectors. This is a specification and not a standard, but will in time be incorporated into ISO 10218. Its main focus is to provide a comprehensive risk assessment guide of all the motions, interactions and operations a robot should perform. Every automated application where humans are present requires this risk assessment, and collaborative applications need a range of safety mechanisms to keep human workers safe. Passive safety features can include fire resistance, manual movement capability, elimination of sharp edges and protrusions, padding, speed restrictions, low inertias of moving parts to limit the effects of collisions and maximum static forces, as well as switch strips mats and vests (Karwowski & Rahimi, 2003).

ISO 13482:2014 applies to personal care robots (BSI, 2014). It provides guidance for assurance of safety in the design, construction, installation and use of the robot in three categories:

1. Mobile service robots (e.g. open curtains, doors or windows, clean or vacuum, fetch and carry items such as drinks, or plates of food, pick up objects from the floor, switch equipment on or off);
2. Physical assistant robots (getting up from a chair or out of bed, getting into and out of a bath or shower, help with getting dressed, help with basic personal care such as combing hair);
3. Person carrier robots (within their home, around public buildings, or other public spaces, between predefined locations).

Manufacturers (and suppliers) that comply with ISO 13482 should identify potential risks, issue clear labelling and instructions, ensure safe movement and reduce chances of ‘bad’ decisions. For example, a person carrier robot should ensure that a passenger is correctly seated before starting to move, or that it stops in a location where it is safe for the passenger to get off.

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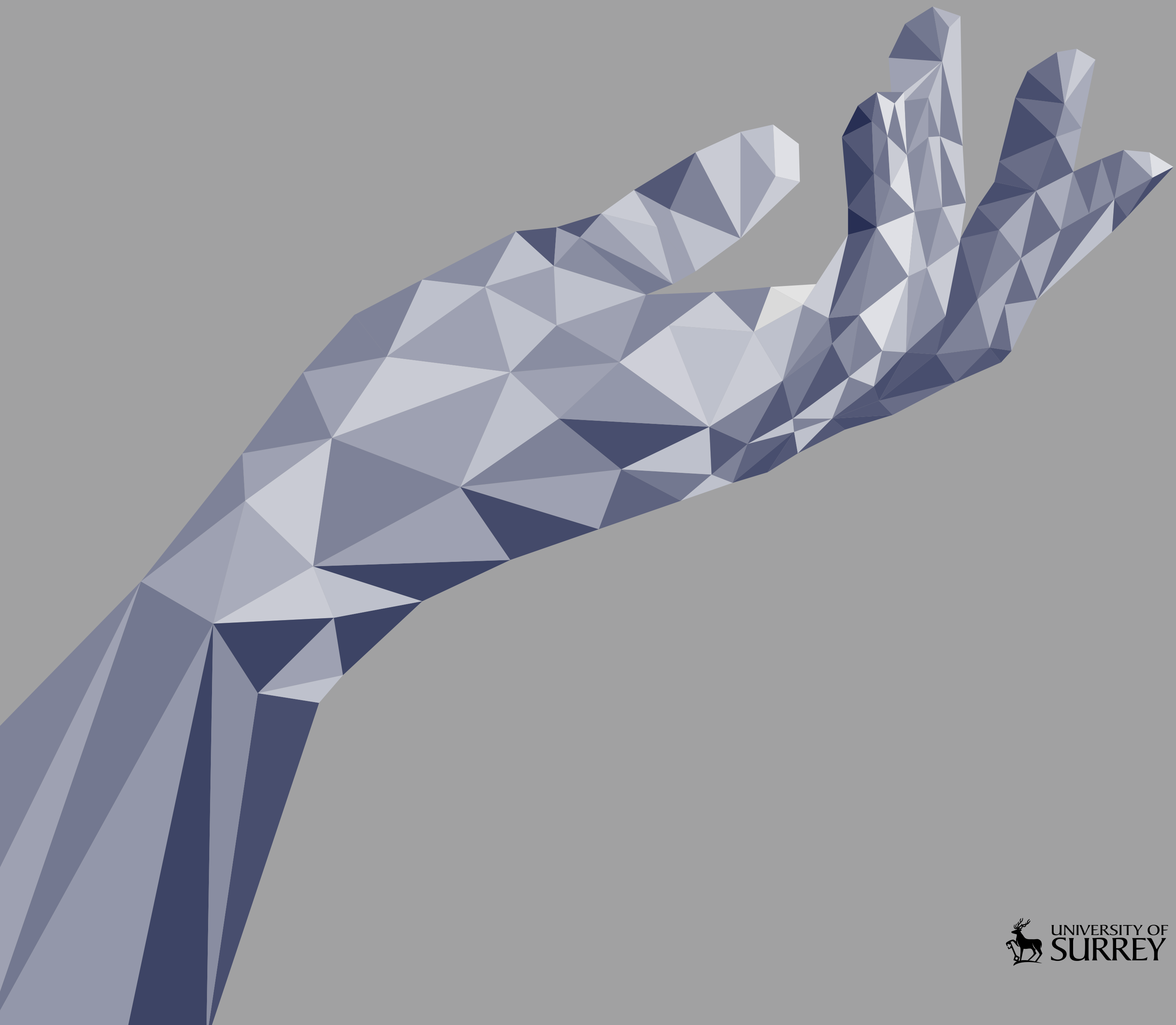

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