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Automation and Robots in Services

Review of Data and Taxonomy

Matteo Sostero (European Commission Joint Research Centre)

Abstract

The service sector is the current technological frontier of automation, thanks to recent advanced in artificial intelligence and robotics, raising concerns for the future of work for a large segment of the workforce. This report surveys data on the variety and diffusion of service robots in the EU, in order to describe the state of automation in the service sector. *Service robots* are tangible artefacts of automation technology in the service sector and are relatively well defined by international standards, which makes it easier to track their diffusion. This report uses different data sources to show that the penetration of service robots is currently relatively low in the European economy, especially when compared to industrial robots. Moreover, service robots are used most often for manual tasks, in parts of the service sector that are most similar to manufacturing, such as logistics, inspection and maintenance, and surface cleaning. After comparing the different definitions and variety of service robots, this report proposes a general taxonomy for automation in the service sector, to guide future research.

Keywords: Service Robots, Automation, Service Sector, Taxonomy, employment

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Introduction

The impact of automation on employment is the focus of much attention and debate among academics and policy-makers. Conceptually, we define automation as the replacement of human labour input by machine input for some types of tasks within economic processes, following the definition proposed in Eurofound (2018). Technology to automate human labour has been most visible in the manufacturing and extraction sectors, assisting or replacing humans in dangerous or repetitive manual tasks.

The most visible form of technology in this domain are industrial robots which despite their expectation as a disruptive technology, mostly represent an incremental improvement on previous forms of industrial automation (Fernández-Macías et al. 2020), and their net effect on employment is unclear (Acemoglu and Restrepo 2017 and 2020, Antón et at., 2020).

Recent developments in artificial intelligence (AI) and robotics now aim to assist, or even completely automate, many clerical and social interaction tasks.[1] Indeed, international standards now distinguish between *industrial robots* and *service robots,* defined as "physical, mobile devices with some degree of autonomy [...] used to provide [professional] services, as opposed to manufacturing goods." (ISO 8373:2012). As shown in the next section, the term is also used in commercial and statistical settings, though this definition is not always strictly applied. For analytical purposes, it is helpful to focus on service robots, as opposed to AI in general, because service robots are tangible, relatively well-defined artefacts. This makes them easier to track in surveys and count, and allows meaningful comparisons across sectors.

Service robots are also a fast-developing market. Many technical advances in robotics, such as those presented at European Robotics Forum, have applications in the service sector, including healthcare, logistics, inspection, and cleaning – though the majority still involve industrial automation.[2] Industry groups, like the Robotics Industries Association Robotics Online, advertise professional service robots with applications ranging from customer service, to logistics, medicine, cleaning, and inspection. The same body expects the market for professional services robots to grow vertiginously, from $6.6 billion globally in 2017, to $37 billion in 2021.[3] Industry groups often predict a growing range of application of robots, and expect growing sales to match. The euRobotics non-profit – which is involved with the European Commission in the SPARC public-private partnership on robots – in its 2014 EU Robotics Strategy 2020 expected that "Robotics Technology will become dominant in the coming decade. It will influence every aspect of work and home. Robotics has the potential to transform lives and work practices, raise efficiency and safety levels, provide enhanced levels of service and create jobs. Its impact will grow over time as will the interaction between robots and people." (euRobotics 2014). Many recent studies also cite advances in AI and robotics (under varying definitions) as a possible threat to white-collar occupations in the service sector. Frey and Osborne (2013) argued that many occupations in the service sector are vulnerable to automation because of advances in artificial intelligence and robotics. The influential work of Brynjolfsson and McAfee (2014), and more recently of works of Ford (2015), Oppenheimer (2019), and Baldwin (2019) similarly warn of the implications of robotics and artificial intelligence for the future of work, including for many service jobs. A widely-cited 2017 report from McKinsey (Manyika et al., 2017) has found that many occupations in service sectors have among the highest potential for automation, including accommodation and food services, transportation and warehousing, and retail trade. However, despite the claims of disruptive technological innovation in

[1] AI and robotics are partially overlapping technologies (AI-HLEG 2020): only some type of robots embody artificial intelligence (following the AI-WATCH taxonomy, see Samoili et al., 2020). In principle, the automation of human labour can be achieved through different technologies, involving either hardware or software, and not necessarily through Artificial Intelligence.

[2] https://www.eu-robotics.net/robotics_forum/

[3] https://www.robotics.org

the robotics sector, Fernández-Macías et al (2020) show that the current state of industrial robots – which are more developed and more widespread than service robots – is in fact an incremental improvement on long-established industrial automation technology.

In general, attributing precise amounts of jobs or wages lost to specific technology on aggregate is difficult, because of the relative scarcity of suitable long-run data and the many factors, besides technology, driving employment and wages. In the manufacturing sector, where the use of robots is relatively more established, the empirical economic literature has tried to assess the overall effect of industrial robots on employment, wages, and labour productivity. In an influential contribution, Acemoglu and Restrepo (2017, 2020) look at the exposure of local labour markets in the United States to industrial robots from the 1990s, using data by the International Federation of Robotics. They find that an additional robot per thousand workers has reduced the employment-to-population ratio by a relatively modest 0.2 percentage points and wages by 0.42%. However, others find little to no effects in other settings. Dauth et al (2017) similarly look at the usage of robots in Germany in the period 1994-2014, where they are much common than in the United States, and estimate that they accounted for about 23% of the decline in manufacturing jobs. However, the authors also find that this loss was compensated by the creation of service-sector jobs, concluding that robots have had no aggregate effect on employment. Most notably, Graetz and Michaels (2018) looked at the international adoption of robots in manufacturing in the 1990s and 2000s, and found that robots did not significantly reduce employment, except for the share of low-skilled workers. Instead, they found that increased use of robots raised labour productivity and total productivity, and reduced prices. Recent research form the European Commission Joint Research Centre (JRC) has added further evidence against the disruptive effect of robots on employment in Europe. Klenert et al. (2020) find that robot adoption in Europe over the period 1995 to 2015 is positively correlated with total employment: they show that the deployment of one additional robot is correlated with five additional workers. On balance, the range of empirical evidence suggests that the overall impact of robots on employment is not dramatic, but so far rather limited, and may actually be positive. The different studies also show the importance of assessing the impact of new technology in the context of specific sectors of economic activity and institutions.

Regardless of the net effect on employment and wages, the growing areas of applications of robotics calls for further evidence on the impact of service robots on the nature of work, and may call for further standards and regulation. For instance, the EU European Agency for Safety and Health at Work (EU-OSHA) considers service robots in its Review on The Future of Work: Robotics. Although it does not provide or collect original data on diffusion or use, it raises many interesting questions on the use of robots in the workplace. Among these, there is the need for safety requirements, design guidelines for ergonomics, and better framing of the safety of human-robot interaction. The report suggests exploring use-cases of service robots to build a regulatory framework on occupational health and safety, including applications in healthcare and elder care; risk factors in human-machine interaction, and the need for skills and training of employees working with robots; and the psychological effects on motivation and well-being that service robots may cause on workers and managers.

Despite the growing range of applications for robots in the service sector, the business case for adopting them is not always clear. For companies, deploying robots is often a substantial investment, requiring changes in the layout of their sites, adapting their organisational processes, and acquiring the necessary skills. Not all business models will find it worthwhile to make that investment. In fact, some businesses use the presence of robots as a selling point in itself, in the hope of gathering publicity, a business model that is not necessarily sound. Some highly publicised cases of robotics in services have ended up flopping, as the start-up Zume which received much publicity for using robots for cooking and delivering pizzas, but abandoned the business earlier this year.[4] After receiving much publicity for using nearly 250 robots for hospitality since 2015, Tokyo's

[4] https://www.businessinsider.com/inside-story-what-went-wrong-softbank-backed-zume-pizza-2020-1?international

Henn Na Hotel reduced the number of robots by half in 2019 because they were unable to perform adequately without human intervention.[5]

In the popular imagination, robots are often depicted as intelligent humanoid devices that interact with humans to serve them. This image is also encouraged by the robotics industry, which advertises humanoid robots prominently, and emphasises demonstrations of human-robot interaction. As this report will show, the state of service robots in use today is both less technically advanced and more complex than this image suggests.

Getting an accurate overview of the state of automation and robots in services is challenging at this stage, for a number of reasons. The first is that as a form of automation in services, service robots are a relatively recent (and rare) technology. The second is that the industry's successes and hopes for future progress are more visible than its setbacks. News articles report the exploits of robots abound, but those are usually prototypes intended to show their technical capabilities, often without a viable commercial application.[6] The robotics industry also has a history of over-promising and under-delivering disruptive innovations that either do not materialise, or achieve much less than initially advertised.[7] For example, despite decades of research, sewing robots are still not widely deployed, because they can only handle simple garments like t-shirts, and are not economical compared to cheap skilled labour in the developing world. Moreover, some degree of automation has actually already occurred in the service sector in recent years, but did not take the form of robots as autonomous mobile machinery. Automated self-checkout cashiers and self-service kiosks in fast-food are now so familiar to workers and customers alike that they go unnoticed. This perhaps reflects the limitations of hardware technology, which lags behind the capabilities of software in human interfaces. Finally, compared to industrial applications in the manufacturing sector, automation in services is less mature, and even less commoditised. Many leading producers advertise customised solutions, including bundles of hardware and software that are adapted to the specific needs of their clients, rather than standardised off-the-shelf products. This resembles the early stages of the corporate ICT industry, before the advent of personal computers, when mainframes, terminals and software were sold as a bundle and customised to the needs of the business.

This degree of customisation of service robots in a fast-changing industry makes it difficult to account exactly for the diffusion of robots as a technology, because their purpose, value and shape varies according to the application. The statistics available so far reflect this: on the one hand, industry statistics, such as those produced by the International Federation of Robotics, provide figures for sale of robots in terms of value or volume, but contain little information on the businesses deploying the robots, and their actual use. On the other hand, company surveys like the ICT Community survey conducted by Eurostat report whether companies use service robots and list a few potential applications, but give no indication of the specific robot technology used, or their provider.

Based on the data from robots manufacturers collected by the International Federation of Robotics (IFR 2018, 2019), most robots sold for use in the service industry today seem to be not customer-facing, nor fully autonomous or anthropomorphic. Among the best-selling types of service robots are vehicles or mechanical arms, with limited autonomy, sold to businesses to automate their processes in warehouses. Anthropomorphic personal robotic assistants do exist, but are a niche product, more often sold to private consumers than used professionally, and are better described as a form of entertainment than a genuine replacement for human assistants. Like previous technologies attempting to automate human labour, robotics tends to reach first the type of jobs that are described, in robotics industry parlance, as "dull, dirty, or dangerous" for humans. This

[5] https://www.wsj.com/articles/robot-hotel-loses-love-for-robots-11547484628

[6] Honda's ASIMO is perhaps the clearest illustration of this https://asimo.honda.com/

[7] https://techcrunch.com/2020/06/14/where-are-all-the-robots/

expression conveys (somewhat briskly) the notion that some the best targets for automation are tasks that are unpleasant or risky for humans to do. Indeed, the most commercially developed areas of robotics in the service sector target strenuous or repetitive work in logistics, specialised cleaning in large or hard-to-reach places, and hazardous maintenance of machines or components.

These applications may not pose an imminent threat to service-sector jobs as feared by some, but they may affect the conditions for some workers and occupations. Rather than robots assisting human workers or replacing them outright, companies that put robots at the centre of their operations can require workers to adapt to their limitations. For instance, one of the leading applications of service robots in the logistics sector is automated vehicles that carry shelves of products for human workers to pick and package. Robots handle the strenuous and repetitive task of navigating the vast but structured space of the warehouses, but they are unable to reliably pick the many different products sold through e-commerce – a task that still needs human vision, cognition and dexterity. The solution involves physically separating humans and robots, and standardising the tasks of human workers to fit the pace of work set by robots. Compared to automating the standardised and physical work of manufacturing – and manufacturing-adjacent applications like warehouse management – the diverse range of tasks and the interaction with humans present specific technical challenges. Robots still do not interact easily with humans, making it harder to carry out many of the core service tasks – such as understanding, helping, caring, or teaching (see Sheridan 2016 for a review of the state of innovation of service robots). These tasks, and jobs that involve them, arguably make up the bulk of employment in the service sector, and the economy at large. This interpretation suggests that current robot technology may intensify automation in those service sectors where work is standardised – or can be reorganised in this way – but may yet struggle to expand into the core activities of services. On balance, the current features and technical limitations of service robots already have implications for the changing nature of work, in terms of work organisation, employment relations, skills, and occupational health and safety.

Given the pace for technological progress in this sector, and the uncertainty surrounding the implications for employment, the most pressing questions for European policymakers surrounding automation in services are:

1) How many service robots are there today: how common are they across Member States, and is their adoption growing?
2) What do they do: in what sectors are they deployed and for which applications?
3) How do robots change employment and wages in the service sector, and the demand for different job profiles and skills?
4) How does adopting robots affect working conditions? In particular, how does it change the organisation of work, employment relations, occupational health and safety?
5) How is the diffusion of service robots affected by structural and regulatory factors – such as wage, unemployment, labour protection, and occupational health and safety?
6) How is it driven by business factors – business model, work organisation, skills of employees?

The first two questions are descriptive in nature and can mostly be answered with available aggregate statistics presented in this report. Ideally, answering systematically questions 3–6 would require directed studies, preferably from a representative, longitudinal survey of detailed company-level or sector-level microdata on wages, skills and tasks of employees, as well as the specific types of robots used and their application. To the best of our knowledge, such data is currently not available. To begin addressing these questions, this report proposes elements to build a taxonomy of robots for automation of services, to classify the different levels of integration of service robots in the service sector. This can help choose the sectors or companies to study in greater detail, both qualitatively and quantitatively, to better understand why and how they are adopting robots, and how this affects their workforce.

In order to gain a deeper understanding of how robots are affecting the service industry, we need to focus on specific applications. As Decker et al (2017) note, in general we cannot tell at this stage whether service robots will complement or replace human labour. This will ultimately depend on whether companies and consumers judge that the services the robots provide is a good substitute for those provided by humans. Compared to the manufacturing sector – which traditionally has achieved standardisation of products, processes, and tasks – the service sector is arguably more varied in terms of work organisation practices, tasks and skills. Therefore, service robots as a broad technology can only be assessed by studying examples of companies or sectors adopting specific types of service robots. More fundamentally, the ever-growing variety of tasks where robots can be used requires clear terminology and definitions, which are sometimes lacking in the discussion of this technology. The following section presents and compares different definitions of (service) robots, to derive a working definition used in the rest of this work.

Definitions

Defining service robots requires to clarify both the precise meaning of "robot" – which has a formal standard, although it is sometimes applied loosely – and that of "service". The latter can refer either to the sector of the economy (as opposed to manufacturing, or the primary sector), or the type of tasks that robots perform – service as in "serving and assisting human workers", in any sector of the economy.

In international standards

The official definition of robot, widely cited in the scientific and technical literature, is laid out in the ISO 8373:2012 standard (International Organization for Standardization [ISO], 2012)):

> *Robot. Actuated mechanism programmable in two or more axes with a degree of autonomy (i.e., the ability to perform intended tasks based on current state and sensing, without human intervention), moving within its environment, to perform intended tasks.*

This definition is at the same time intuitive and strict. It implicitly refers to a physical piece of machinery – which excludes software, such as software bots (e.g., *chatbots*), voice assistants, or image-recognition. It also requires robots to be mobile in two or more dimensions, thus excluding stationary devices like automated checkout machines. More importantly, it requires some degree of autonomy. This concept is perhaps more subjective, as current technology and regulation allows only for limited autonomy in robotics, but intuitively it is meant to exclude mobile machinery that follows pre-programmed instructions strictly and without feedback from their surroundings, such as 3D printers. Remote-controlled robotic actuators used in surgery are generally called robots, though they are not autonomous in any sense, as they are operated by human surgeons. Currently, this definition of robot is currently best represented by devices used in the manufacturing or extractive sector, and to a lesser extent in agriculture.

The ISO standard distinguishes between *industrial robots* and *service robots*, based on the sector of economic activity in which they are used.

> ***Industrial robot**: automatically controlled, reprogrammable [i.e., designed so that the programmed motions or auxiliary functions can be changed without physical alteration], multipurpose [i.e., capable of being adapted to a different application with physical alteration] manipulator [i.e., machine in which the mechanism usually consists of a series of segments, jointed or sliding relative to one another, for the purpose of grasping and/or moving objects (pieces or tools) usually in several degrees of freedom], programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications.*

This carves out a narrow definition of *service robot*, based mostly on sector of application, with some exceptions, based on the nature of the tasks that the robots would perform (emphasis added).

> ***Service robot****: robot that performs useful tasks for humans or equipment excluding industrial automation applications.*
>
> *Industrial automation applications include, but are not limited to, manufacturing, inspection, packaging, and assembly.*
>
> *While articulated robots used in production lines are industrial robots, similar articulated robots used for serving food are service robots.*

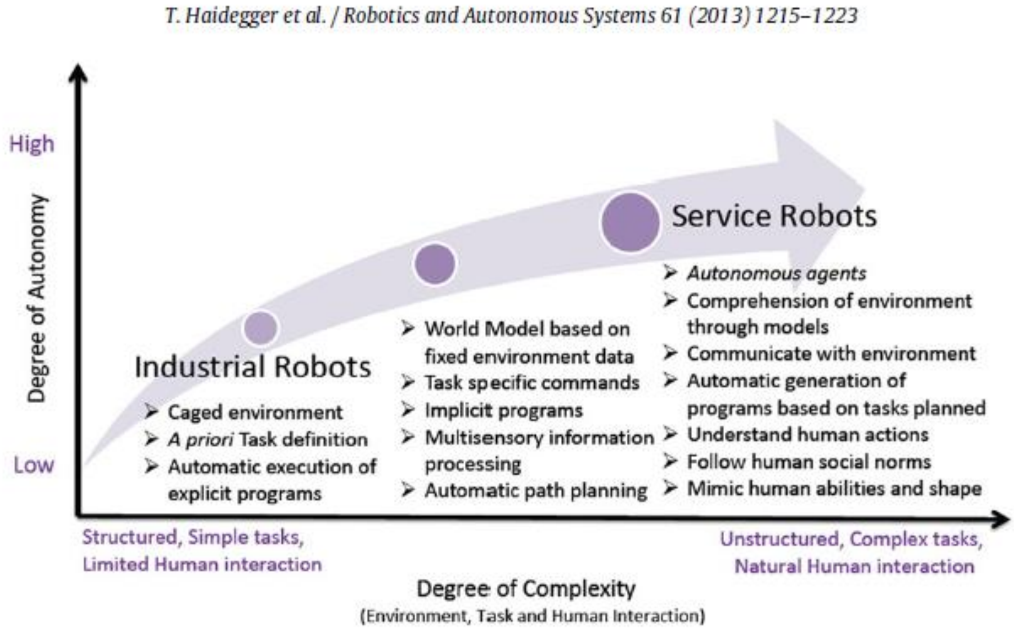
Strictly applied, this definition could exclude parts of the logistics sector, insofar as it involves packaging, but warehouse activities in the logistics sector should be considered in the service sector.

The ISO standard also distinguishes between professional service robots, used for commercial task, usually operated by a properly trained operator, and personal service robots, operated by consumers in non-commercial settings. Examples of the former are cleaning robots for public places, delivery robots in offices or hospitals, rehabilitation and surgery robots in hospitals, all of which are clearly used in productive settings in services. Personal service robots, by contrast, range from health applications (automated wheelchair, personal mobility assist robot) to personal entertainment (domestic servant robot, and pet exercising robot), but are products used by consumers in a private setting.

In the scientific literature

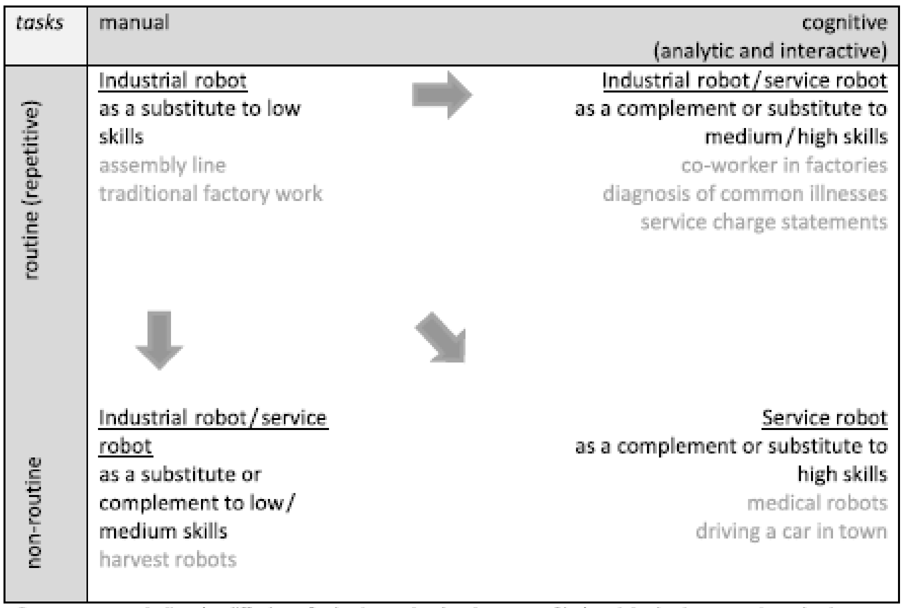
Although the term robot is sometimes used to denote interchangeably either physical machines or software (including in the scientific literature), whenever we make the distinction between industrial and service robots, we always mean physical machines. The engineering literature describes service robots as the technological evolution of industrial robots, insofar as their area of application is technically more complex. Indeed, consistently with Fernández-Macías et al (2020), we can describe the technical progress of robotics as a continuous series of incremental improvement, starting from long-established mechatronic automation technologies, towards autonomous robots who operate in standardised industrial environment, and finally expanding to interact with humans, operate in unstructured environments, and perform complex tasks, with a higher degree of autonomy. All these requirements involve additional technical obstacles, which have made the development of service robots more challenging.

Figure 1: The evolution of industrial and service robots. (source: Haideaaet et al.. 2013)



As Haidegger et al. (2013) note, there is a need to standardise the nomenclature of service robots based on the technical tasks that they can perform, and the level of their interactions that they allow with humans (see Figure 1). They outline a potential methodology for doing so, in engineering terms. In the social science literature, the relevant difference between service and industrial robots is the human quality of the tasks that they perform. For instance, Decker et al. (2013) show that whereas industrial robots mostly perform routine manual tasks in a standardised setting, service robots are expected to perform less routine (or less standardised) tasks, and those that require higher cognitive function for humans.

Figure 2: Task complexity of industrial and service robots (source: Decker et al, 2013)



Grey arrows symbolize the diffusion of robotics or the development of industrial robotics to service robotics; examples of use are given in gray; Source: own illustration based on the task categorization of Autor et al. 2003.

The framework proposed by the authors implies that, whereas industrial robots affected low-skilled factory work in assembly lines, service robots may affect employment in high-skilled service sector occupations. Regardless of their potential of automation, we should note non-routine cognitive or social interaction tasks are not necessarily linked to high-skilled occupations: many of them are in mid and low-skilled service sector and administrative jobs, such as waiters, personal service workers, retail workers, clerks and secretaries. Crucially, the authors stress that it is difficult to make predictions with any certainty and that whether service robots may complement or substitute human workers depends on the precise tasks that they perform.

In trade and commodity statistics

The relative recent development of service robotics diversity is reflected in the absence of product standards in international trade and commodity classifications. At the moment, these do not distinguish among different type of robots in terms of their application. Both the Harmonized Commodity Description and Coding System and the European Union's Combined Nomenclature only mention robots under the heading 8479.50-Industrial robots, n.e.s., which focuses on applications to industry, and makes no mention to services (Commission Implementing Regulation (EU) 2019/1776). The United Nations' Standard International Trade Classification, by contrast, makes no mentions of robots as a commodity category at all (STIC 2006).

Working definition

For the purposes of this report, we use the following reference definition, derived from the ISO standard:

> ***Service robots*** *are physical, mobile devices with some degree of autonomy. They perform tasks professionally the service sector, possibly alongside human workers. They are used to provide of services, as opposed to manufacturing goods.*

This definition can encompass some related concepts or definitions used in other contexts, depending on the specifics of their application, and the type of human-robot interaction:

- ***Social robots*** are "are able to interact and communicate among themselves, with humans, and with the environment".[8] In principle service robots can also be social robots (e.g., customer-service robots), but they do not have to be, especially in service-sector application when interaction with humans or other robots is not essential. Conversely, some social robots are meant for personal (not professional) use, and so are outside the scope of our definition of service robots.
- ***Cobots*** are robots designed specifically to work alongside humans in a shared workspace (IFR 2018b). This distinction, based on physical proximity, is especially important in industrial applications, where traditionally robots were confined to dedicated spaces for security reasons. For service robots, we would expect that physical proximity is the norm, rather than the exception, and so we should instead note when service robots cannot be used near humans.
- ***Bots*** are interface paradigm that connect users with software services.[9] The concept, short for "robot" has many definitions and applications. It can denote software that automatically performs routine digital tasks (such as browsing the web, clicking on links, collecting data). They are used in many contexts, including commercial, personal, political, or even criminal applications. ***Chatbots*** are a type or interface where users dialogue with virtual assistant. They can provide several degrees of automation, where end-users chat to ask questions and receive replies. In many cases, the more basic user queries are handled automatically by software, while more complex requests are handled by human operators seamlessly, ideally without the end-user even noticing. These capabilities also make chatbots difficult

[8] See the publication https://www.springer.com/journal/12369

[9] https://ieeexplore.ieee.org/document/8823642

to track and survey. Although chatbots are used for service tasks, including customer support, they fall outside our working definition of service robot because they are not physical devices.

Since some sources apply different definitions, we will also comment on alternative usages, to compare different instances of automation and robotics in the service sector.

Data on service robots

Eurostat

The most detailed and substantial evidence on the diffusion of robots in European companies is the Eurostat Community Survey on ICT usage in enterprises, which contributes to the European Commission Digital Economy and Society Index.[10] The 2018 edition of the survey included an optional module on the use of robots, as well as 3D printers.[11] In this section, we will consider the question related to robots only, leaving aside the separate questions on 3D printers. The same survey is being repeated in the 2020 survey, though it was not included in the 2019 edition. As a result, only the 2018 data is currently available. The data does not cover some countries that did not reply to the optional module, namely Belgium, Ireland, Croatia, Latvia, Luxembourg, and the United Kingdom. For the 2020 edition, all questions on robotics are compulsory.

The optional module F of the 2018 ICT Community Survey questionnaire asks if the enterprise uses any of the following types of robots, and gives a few examples of their applications:

a) Industrial robots (e.g. robotic welding, laser cutting, spray painting, etc.)

b) Service robots (e.g. used for surveillance, cleaning, transportation, etc.)

The questionnaire provides definitions for both terms. For industrial robots, this follows the ISO standard:

An industrial robot is an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications.

The definition of *service robot* follows closely our reference definition:

A service robot is a machine that has a degree of autonomy and is able to operate in complex and dynamic environment that may require interaction with persons, objects or other devices, excluding its use in industrial automation applications.

Like our reference definition, this one permits, but does not require, interaction with humans. However, it is unclear what the "degree of autonomy" contrasts with the level of autonomy often found in industrial robots. Consistently with our interpretation, the questionnaire goes on to say that "software robots (computer programs) and 3D printers are out of the scope of the following questions." (Emphasis in the original)

As we have noted, the survey module on robotics was not repeated in 2019, but is again included as a compulsory module in the 2020 questionnaire, whose results are not yet available at the time of writing. This second version has slightly expanded definitions, which give more examples, presumably to help respondents differentiate industrial and service robots:

An industrial robot is an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use. Most

[10] https://ec.europa.eu/eurostat/cache/metadata/en/isoc_e_esms.htm

[11] https://circabc.europa.eu/sd/a/1fbef4a1-4c31-4b6a-afe8-19ee6d7e3b0f/ICT-Entr2018-Model Questionnaire V1.2.pdf

existing industrial robots are based on the robot arm with a solid base and a series of links and joints with an end effector that carries out the task.

A service robot is a machine that has a degree of autonomy that enables it to operate in complex and dynamic environment that may require interaction with persons, objects or other devices, excluding its use in industrial automation applications. They are designed to fit their tasks, working in the air (e.g. as a drone), under water, or on land, using wheels or legs to achieve mobility with arms and end effectors to physically interact and are often used in inspection and maintenance tasks.

This new definition of service robots gives examples emphasising their mobility in different environments, perhaps in contrast to the “solid base” of industrial robots, which implies less mobility.

Both in the 2018 and 2020 survey case the respondents reply that they use service robots, the survey goes on to ask their areas of application among those listed, with multiple selections possible:

a) Surveillance, security or inspection tasks (e.g. use of airborne drones, etc.)

b) Transportation of people or goods (e.g. use of automated guided vehicle, etc.)

c) Cleaning or waste disposal tasks

d) Warehouse management systems (e.g. palletising, handling goods, etc.)

e) Assembly works performed by service robots

f) Robotic store clerk tasks

g) Construction works or damage repair tasks

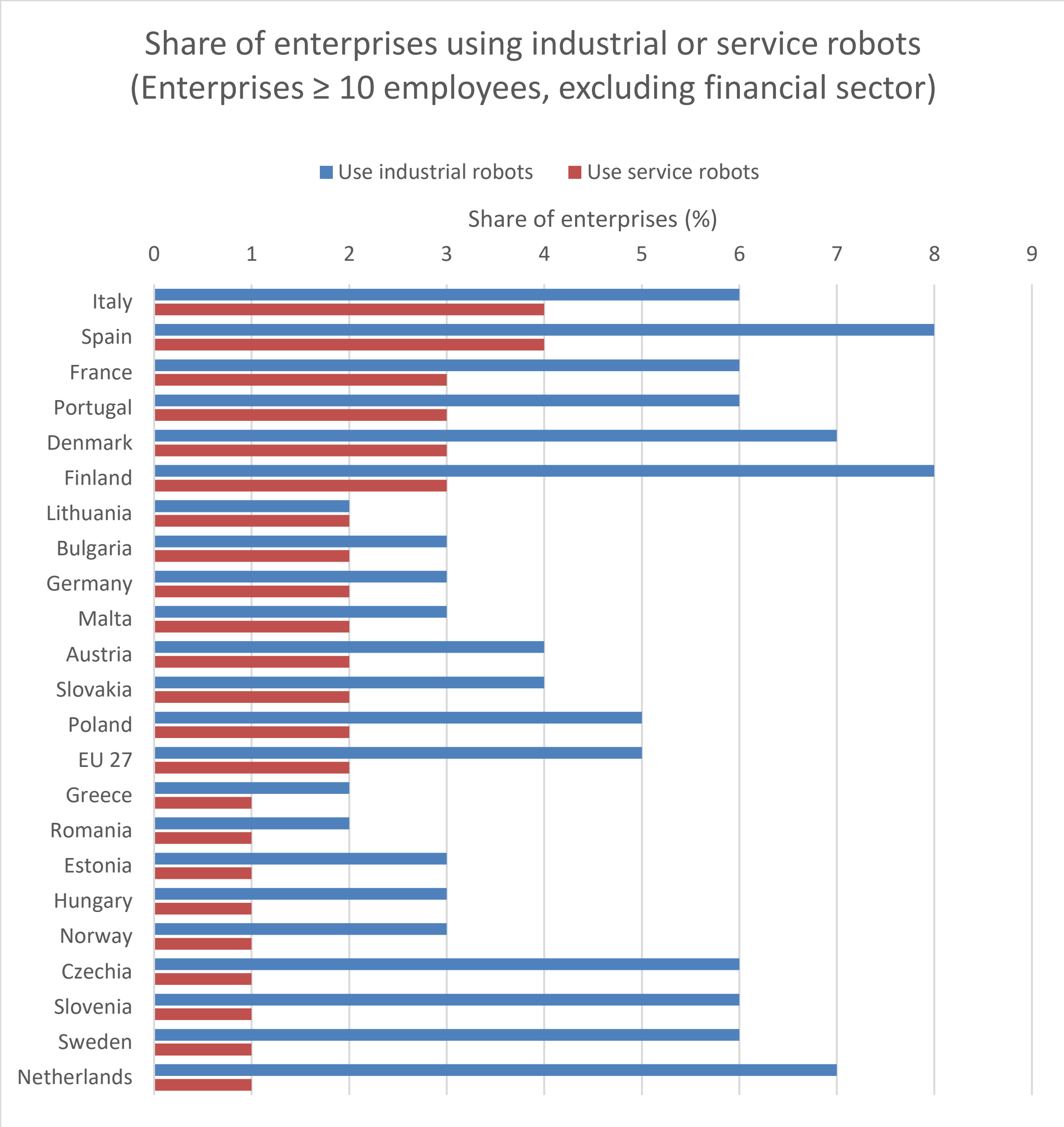
We should note that, despite the definition used in 2018 excluding industrial automation applications, its results show numerous cases of service robots used in the manufacturing sector. (Indeed, assembly is a typical manufacturing task.) In what follows, whenever possible we will report the figures distinguishing between service sectors and manufacturing.

Data on diffusion

The results of the Eurostat ICT Community Survey in 2018 are the best available evidence on the prevalence of robots in the European Union today. Across all participating countries, only around 2% of companies reported using service robots in 2018. By comparison, industrial robots are found in 5% of firms. Considering that the figure for service robots also includes companies in manufacturing by Eurostat’s definition, the prevalence of robots that are actually used in the service sector is even lower, as described in the following subsection.

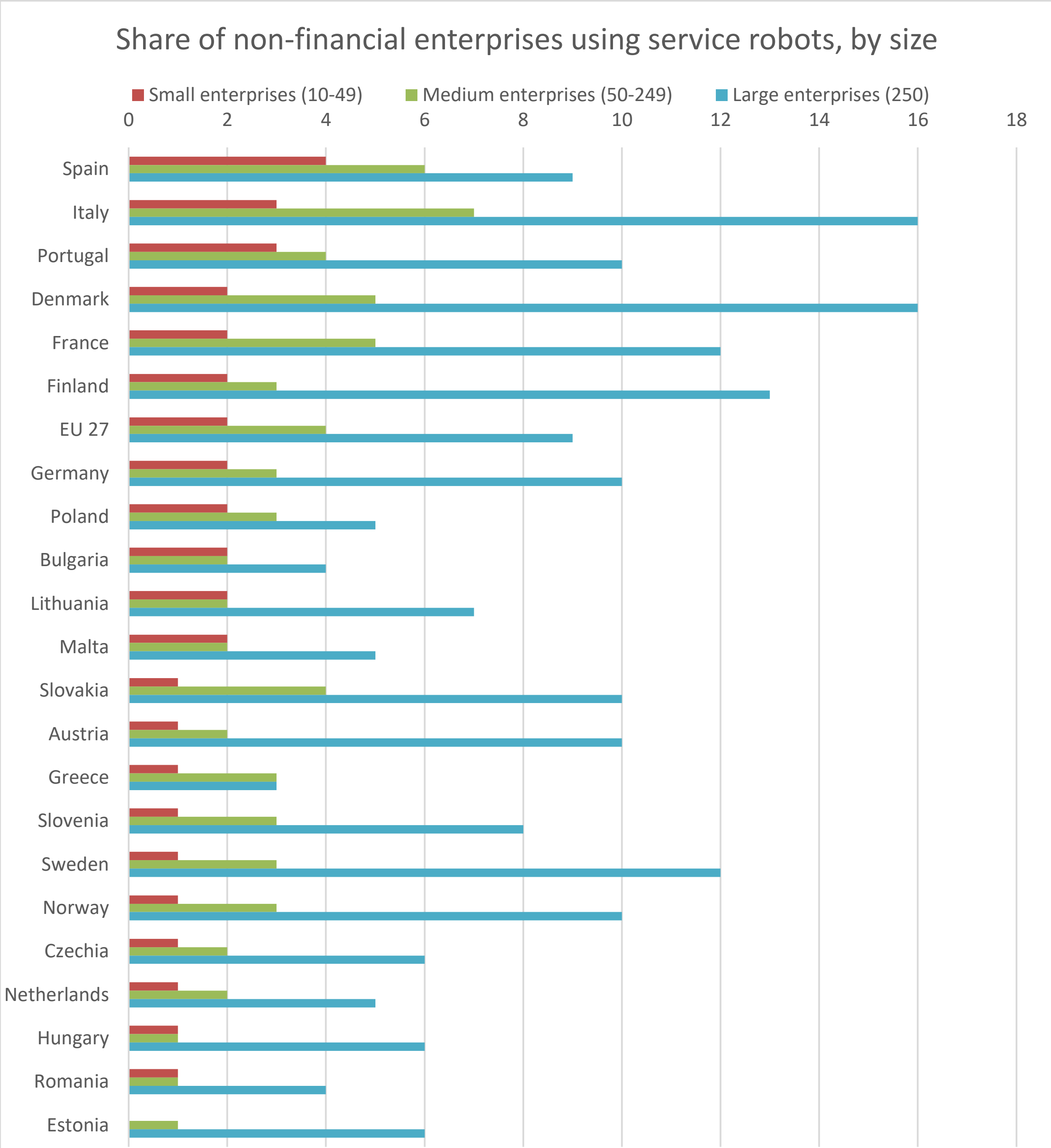
The adoption of service robots varies across Member States. Although the figures reported by Eurostat are rounded to the nearest percentage point, we can still meaningfully distinguish between countries. The prevalence of service robots is highest among Spanish and Italian companies, at 4% of firms in both countries. A second group of adopters, with a prevalence of 3% includes Danish, French, Portuguese, and Finnish firms. Perhaps surprisingly, only around 2% of firms in Germany report using service robots. This cross-country pattern defies any easy generalisation, except perhaps noticing a higher-than-expected share in countries with higher unemployment rates, such as Italy and Spain.

Figure 3: Only a minority of EU companies use robots. Industrial robots are more common than service robots



Larger companies are more likely to use service robots in every country. This is no surprise, considering that medium and large enterprises are likelier to adopt new technology in general. They also have easier access to capital to make the necessary investment, and can tap the necessary skills. Figure 2 shows the breakdown in the share of companies using service robots by number of employees. As before, the numbers presented by Eurostat include both manufacturing and services (excluding finance), and are rounded to the nearest percentage point. Service robots are most common in large Italian and Danish companies (around 16%), and are found in 13% of Finnish enterprises and 12% of Danish and French ones. Interestingly, among the small and mid-sized German companies that make up the Mittelstand in Germany, only 3-4% of them use service robots, compared to 10% in large companies in the same country. This low level of adoption also contrasts to 3–7% in similarly-sized Spanish, Italian, and Portuguese firms.

Figure 4: Larger companies are much more likely to use service robots than smaller companies



These differences across Member States underscore the need to understand the factors influencing the adoption of service robots, including the sectors and applications in which they are used.

Data on applications

The use of service robots is more widespread in retail trade, but also with some isolated clusters in ICT, telecommunications and business support. Eurostat presents the number of companies with 10 or more employees using service robots disaggregated by sector, spanning manufacturing and services. We present the tables separately for the manufacture of goods (Table Table 2) and for services, including construction, and excluding finance (Table Table 1). In services, the highest European average rate of adoption is in retail excluding motor vehicles at 4%, led by Danish and Finnish retail companies, 12% and 10% of which, respectively, use service robots. A similar pattern, albeit at a lower scale, is found in wholesale trade. In services, there are a few isolated clusters of sectors in countries with unusually high rates of adoption of service robots, including 21% of Norwegian and 10% of Portuguese companies working in repair of computers and communication equipment, 8% of Norwegian and Estonian telecommunications companies, and 8% of Portuguese companies in the electricity, gas, steam air-conditioning and water supply industry. We cannot rule out the possibility that these differences across countries are also driven by different interpretations or confusion by respondents over the distinction between industrial and service robots. We should note that the 2020 version of the questionnaire formulates the definitions more extensively and gives more examples, which should help in reducing confusion.

Compared to service sectors, relatively more companies in manufacturing report using service robots, as Table Table 2 shows. On average across the EU, the share of companies using service robots is highest in the automotive manufacturing sector at 7%, going as high as 15% in Slovakia, 13% in Italy, and 12% in Portugal. The service robots in question are presumably a more advanced iteration of industrial robots already used in car manufacturing, as described above in Heidegger et al. (2013) and Fernández-Macías et al (2020). Beyond the automotive sector, a relatively high share of companies report using service robots in the manufacture of petro-chemicals, pharmaceuticals, rubber and plastic: 10% of Danish and Italian companies, 8% of French ones. Service robots tend to be relatively common across Europe also in the manufacture of electrical equipment and machinery, and in high-tech manufacturing of computers and electronics in Italy and Estonia.

We do not know exactly what kind of robots the companies actually installed from these figures alone. However, we know why they are being used, by looking at some of the more common applications cited by the companies that adopted them. Table Table 3 shows the most common applications of service robots by companies that operate strictly in service sectors, while Table Table 4 lists the applications for service robots by companies that have adopted them in the manufacturing sectors. The most common use-case in any sector is warehouse management, cited by 44% of companies using service robots. (This percentage is a subset of the small share of companies that report using service robots in the survey.) This application is common for the broad retail and logistics sector, namely for over 60% of companies using service robots in retail and wholesale trade and 38% of those using them in transportation. Warehouse management is also cited by 50% of the companies that use service robots in manufacturing, especially in food, food preparation and beverage sectors, wood and derived products, an in the petrochemical sector. Here, too, we can easily see how robots can be tasked with moving stock of products in warehouses. In other sectors, such as professional, scientific and technical activities, however, it is harder to imagine how those companies are service robots for warehousing tasks. The second most common application of service robots is transportation of people or goods, cited by 20% of companies that report using service robots in all sectors, including retail and logistics in services, and across manufacturing. This task overlaps somewhat with warehouse management, and can be carried out by a variety of autonomous and semi-autonomous vehicles, or conveyor systems.

The third most common application for service robots is for assembly tasks, mostly in manufacturing, particularly of high-tech computers and electronics (76% of companies using service robots) and motor vehicles (59%). This has been a traditional task for industrial assembly robots from the beginning, because it is standardised and involves precise repetitive movements.

The distinction between industrial and service robots in assembly is not clear, though it presumably involves the degree of autonomy, complexity, and human interaction required of the robot.

An equally common use for service robots, this time more prominent in the service sector, is cleaning and waste disposal, notably in energy supply, but also in accommodation and food and beverage (50% of companies that use service robots), and in administrative and support services (46%). Here, we should perhaps distinguish between on the one hand robots designed for specialised cleaning tasks, such as pipes, tank, machinery, as well as waste disposal machines, and on the other hand more generic robots used for cleaning surfaces. We expect the former to be more common in energy and manufacturing sectors, and the latter to be used on large surfaces such as factory floors, warehouses, hotels, and exhibition spaces.

Among less-frequent uses of service robots are surveillance and inspection, cited by 15% of companies using service robots and construction or damage repair tasks, cited by 8%. Service robots for surveillance and inspection tasks is especially used in professional services, information and communication, and across manufacturing. These come in many shape or forms, depending on the structure or machinery to inspect, or space to monitor. Robotic store clerk tasks are relatively rare, used in only 9% of companies, but somewhat more common in retail trade and trade of motor vehicles. Here, too, we cannot say precisely what type of machinery is meant in this case. Perhaps they may be simply self-service kiosks, though that would stretch the definition of robot used by Eurostat. Robots that are used in construction or damage repair tasks are more common in the construction sector, the trade of motor vehicles, and manufacturing.

Finally, we should note that about 12% of those using service robots declare doing so for other reasons than the ones listed above. The share is higher in services, especially administrative and support services (35%), trade in automotive (29%), accommodation, food, and beverage services (28%); and information and communication services (24%). These sectors, and the types of robots they use, may also prove interesting. Overall, the data seem to suggest that among the few companies that use service robots, they use them for dirty, strenuous, or repetitive tasks, in line with our expectations.

Table 1: Percentage of enterprises of 10 or more employees using service robot, non-manufacturing sectors

	EU	BG	CZ	DK	DE	EE	EL	ES	FR	IT	CY	LT	HU	MT	NL	AT	PL	PT	RO	SI	SK	FI	SE	NO
Electricity, gas, steam, A/C and water supply	2			2	1	2	4	5	5	1	3	3	1		2	1	3	8	0	3	2		4	4
Construction	1	1	2	1	1	0	4	3	2	1	0	3	0	2	0	1	2	2	0	0	1		1	1
Wholesale and retail trade; repair of motor vehicles	3	2	1	6	3	1	2	3	4	3	0	2	1	1	2	3	2	2	1		1	7	1	1
Retail trade (excluding automotive)	4	2		12	6	0	0	3	4	3	1	2	2	0	1	5	1	3	1		2	10	1	0
Trade of motor vehicles and motorcycles	2			2	1	3	0	2	3		0	3	0	0	3	0	3	3	0	0	2		2	1
Transportation and storage	2	3	1	2	1	1	1	6	4	2	1	0	1	1	2	0	5	4	0	0	1	2	1	2
Accommodation	2	5		0	1	0	0	5	1	3	0	0	2	1	1	0	0	2	0	0	2		2	3
Information and communication	1		1	2	1	3	1	1	0	1	0	0	0	0	0	3	2	2	0	0	0	2	1	2
Real estate activities	1			0	0	0	3	1	1	1	0	0	0		0	0	2	0	0	0	1		3	0
Professional, scientific and technical activities	1			2	1	0	0	2	1	1	0	0	0	3	1	2	1	0	0	2	0		1	1
Administrative and support service activities	2		0	2	0	0	0	5	4	4	0	4	0	1	1	1	6	2	1		2	1	2	0
ICT sector	2		3	2	2	4	1	3	0	3	0	1	0	0	0	3	3	4	1	0	0	1	1	4
Wholesale trade, except automotive	2	2	1	3	1	1	3	4	3		0	1	1	2	2	2	3	1	2	1	1		1	1
Accommodation and Food and beverage services	1	2	0	0	1	0	0	3	1	2	0	1	1	2	0	0	2	2	0	0	2		0	1
Publishing; media; programming & broadcasting	1	0		0	1	1	0		1	1	0	0	0	0	1	1	0	0	0	0	0		2	0
Telecommunications	1			1		8	0				0	0	0		0	0	1	5	0	0	0		0	8
Computer programming, consultancy , etc.	1		1	2	2	2	1			2	0	0	0	0	0	3	2	3	0	0	0		2	3
Business support: Rental and leasing, employment, security, services to buildings office administrative	2		1	2	0	0	0	5	4	5	0	4	0	1	1	1	6	2	1		2		2	0
Travel agency; tour operator etc.	0	0		0	0	0	1	2	0		0	0	0	0	0	0	0	0	0	0	0		0	0
Repair of computers and communication equipment	2	0		0	0	0	0	1	2			0	0				5	10	3	0	0		8	21

Some sector labels were edited for space. Source: Eurostat: isoc_eb_p3d

Table 2: Percentage of enterprises of ≥ 10 employees using service robots, manufacturing sectors

Manufacture of:	EU	BG	CZ	DK	DE	EE	EL	ES	FR	IT	CY	LT	HU	MT	NL	AT	PL	PT	RO	SI	SK	FI	SE	NO
All manufacturing	4	2	2	5	4	1		6	4	6	1	3	2	4	2	3	2	5	1	3	3	4	2	2
Processed food, beverages, tobacco, textile, leather, wood; publ. & printing	3	1	1	6	3	0	1	6	4	4	1	2	1	7	3	3	1	3	1	2	2	5	2	3
Coke, petro-chemical & basic pharma, rubber & plastics, others	6	2	3	10	8	0	3	6	8	10	4	3	2	3	3	2	3	6	2	5	7	5	3	4
Basic & fabricated metal (excl. Machinery)	4	4	3	2	4	0	6	6	4	5	0	3	2	4	1	5	2	6	2	1	2	3	1	1
Electrical equipment, machinery	5	2	2	3	3	2	2		4	8	0	6	3	0	1	3	2	11	3	3	3		2	4
Beverages, food and tobacco products	4	1	2	9	3	0	2		4	9	1	2	1	9	4	5	1	5	1	7	2		3	3
Textiles, wearing apparel, leather and related products	1	1		3	3	0	1		1	1	0	1	0		2	1	1	1	1	0	3		0	2
Wood & derived; paper; printing	3			3	3	0	1		5	3	0	4	0	3	2	1	1	4	0	0	1		1	2
Computer, electronic and optical products	4			6	3	8			3	10		3	3		0	5	2	2	4	0	2		1	9
Motor vehicles, trailers and semi-trailers, other transport equipment	7		6	4	4	2	0		8	13	0	2	6		2	8	5	12	6	5	15		4	2
Furniture and other manufacturing; repair and installation of machinery	2		1	1	1	2	2		2	3	0	3	1	0	0	0	1	5	1	2	2		0	1
Computers etc., motor vehicles, furniture, other manufacturing, repair & installation	4	3	2	3	3	3		6	3	7	0	4	3	0	1	2	2	8	2	3	5	3	2	2

Some sector labels were edited for space. Source: Eurostat

Table 3: Applications of service robots in enterprises of the service sector that use them (EU average for enterprises of ≥ 10 employees using service robots, service sectors)

	Surveillance, security or inspection	Transportation of people or goods	Cleaning or waste disposal	Warehouse management systems	Assembly works	Robotic store clerk tasks	Construction or damage repair	Other purposes
All sectors (manufacturing and services, excluding finance)	15	22	21	44	21	9	8	12
Electricity, gas, steam, A/C and water supply	31		55	14	18	15		
Construction		16	37		17	5	38	14
Retail trade (excluding automotive)	11	30	16	65	4	18	2	5
Wholesale trade, except automotive	10	21	16	64	18	10	11	14
Transportation and storage	22	36	21	38	8	14	4	18
Information and communication	30			12			8	24
Professional, scientific and technical activities	38	11	39	34	14	8	7	6
Administrative and support service activities	6		46	18	10	7	5	35
ICT sector			30	24	31		9	15
Trade of motor vehicles and motorcycles	17		33	21	18	13	25	29
Accommodation; Food & beverage services	17		50	11				28
Computer programming, consultancy etc.						17	11	

Source: Eurostat. NB: Average excludes data for BG, CZ, DE, ES, which was unavailable or insufficient

Table 4: Applications of service robots in enterprises of the manufacturing sector that use them (EU average for enterprises of ≥ 10 employees using service robots, manufacturing sectors)

	Surveillance, security or inspection	Transportation of people or goods	Cleaning or waste disposal	Warehouse management systems	Assembly works	Robotic store clerk tasks	Construction or damage repair	Other purposes
Manufacturing (general)	14	27	11	50	38		6	8
Beverages, food and tobacco products	16	23	13	71	25	5	4	7
Processed food, beverages, tobacco, textile, leather, wood; publ. & printing	14	26	13	66	28	6	4	6
Coke, petro-chemical & basic pharma, rubber & plastics, others	8	39	12	51	33		2	5
basic & fabricated metal (excl. machinery)	24	24	9	33	42		9	9
Textiles, wearing apparel, leather and related products	18		29			15	3	0
Wood & products of wood & cork, except furniture; articles of straw & plaiting materials; paper & paper products; printing & reproduction of recorded media	7	38	16	53	42	7	2	5
Computer, electronic and optical products	23	34	11	37	76	3	5	2
Electrical equipment, machinery		22	16	51	42	2	10	7
Motor vehicles, trailers and semi-trailers, other transport equipment	20	24	11	42	59	2	4	
furniture and other manufacturing; repair and installation of machinery and equipment	24	24	31	46	49	0	17	
Computers etc., motor vehicles, furniture, other manufacturing, repair & installation	11	22	11	47	48		11	7

Source: Eurostat. NB: Average excludes data for BG, CZ, DE, ES was unavailable or insufficient

International Federation of Robotics

The second main source of data on service robots comes from the *World Robotics – Service Robots* report for 2018 and 2019. The report is published by International Federation of Robotics (IFR), an industry non-profit organisation. It follows a similar report on industrial robots, for which it compiled a dataset on the "installation and operational stock of Industrial Robots" by country, applications, and industry. However, there is yet no equivalent dataset for service robots, because the sector is still developing and it is not always easy to distinguish it from industrial applications – like the industry at large, the IFR started distinguishing between industrial and service robots only recently.

The World Robotics report is based on the IFR's survey of around 750 robot manufacturers. These report their selection of products, the current level of sales, and sales forecasts for the following years. These projections for future sales come from the robot manufacturers themselves, and tend to be very optimistic about the industry as a whole. Although these figures are widely quoted in industry commentary – often more prominently than the actual sales figures themselves – given the historical pattern of excessive enthusiasm in the robotics industry, we believe that sales projections should be taken with extreme caution.

In terms of actual sales, about 271,000 service robots were sold worldwide in 2018, for a total revenue of $9.2 billion. The two leading applications are logistic systems (around 110,000 units, or about 40% in terms of total value and sales), and inspection and maintenance (about 106,000 units). This is in line with the usage suggested by Eurostat data. Unlike in Eurostat, the IFR data also points to the use of service robots for medical and defence purposes. Around five thousand medical robots were sold in 2018, but at around $2.8 billion, they were the second largest source of revenue for the industry. High-value defence robots sold at least 14,000 units, but made around $1 billion in revenue, though figures for the defence sector are not always disclosed.

Sales of other types of professional service robots are much more limited: around 11,000 public-relations robots, and 7,700 cleaning robots, mostly for personal, non-professional use. By comparison, service robots for personal and domestic use, such as robot vacuums, lawn mowers, pool cleaners, and personal assistant or entertainment robots saw aggregate sales of 16.3 million units in 2018, but their low average sales price means that total value was around $3.66 billion. Nearly all categories of robots saw double-digit yearly growth figures in 2017 and 2018, averaging 60%, though mostly from a low base; though even the best-selling logistics robots grew in line with the market average. Sales forecasts for the following years are equally rosy, with annual industry growth estimated at 41%, though they were made before the coronavirus pandemic.

The sales figures presented by the IFR also indicate that, at least in terms of units sold, companies based in Europe sold as many professional service robots as companies based in the Americas – around 75,000 units in 2017 and 130,000 in 2018. Perhaps surprisingly, the Asia-Australia region only shipped around 19,000 robots per year in the same period, though the report notes that the coverage of companies is not uniform across countries.

The report presents whatever limited data is currently available, namely worldwide distribution, by units and value, for 2017 and 2018, and sales projection for the following years. Unfortunately, it gives no country-specific figures showing the exact countries or sectors where the robots are currently installed. Therefore, from this data alone, we cannot measure the diffusion of service robots in the European Union.

The most valuable piece of information from the World Robotics report is arguably the detailed classification of service robots in terms of nearly sixty different areas of application (see Table 5 below). This taxonomy, developed by the IFR in collaboration with the UNECE, provides a useful survey of the comparative technical development of the different technologies available, and an estimate of their relative diffusion, albeit from worldwide figures. For each area of application, the report may list the commercial names of some robots, as well as describing their intended use-cases (the operations or tasks that they perform), and listing producers and websites. There may also be some data on their diffusion, from commercial or official sources. In a few cases, the report may also present some stylised cost-benefit considerations and major obstacles to further diffusion, which may provide insights on the type of infrastructure adaptation and investment required, or hints on the wages of workers that the robots may replace.

Table 5: IFR-UNECE classification of service robots

1-7 Robots for domestic tasks
1 - Robot companions / assistants / humanoids
2 - Vacuuming, floor cleaning
3 - Lawn mowing
4 - Pool cleaning
5 - Window cleaning
6 - Home security & surveillance
7 - Others
8-11 Entertainment robots
8 - Toy/hobby robots
9 - Multimedia robots
10 - Education and research
11 - Others
12-14 Elderly and handicap assistance
12 - Robotized wheelchairs
13 - Personal aids and assistive devices
14 - Other assistance functions
15 - Other personal/domestic robots
16-21 Field robotics
16 - Agriculture (broad acre, greenhouse, fruit-growing, vineyard)
17 - Milking robots*
18 - other robots for livestock farming
19 - Mining robots
20 - Space robots
21 - Others
22-26 Professional cleaning
22 - Floor cleaning, professional*
23 - Window and wall cleaning (including wall climbing robots)
24 - Tank, tube and pipe cleaning
25 - Hull cleaning (aircraft, vehicles, etc.)
26 - other cleaning tasks
27-29 Inspection and maintenance systems
27 - Facilities, plants
28 - Tank, tubes, pipes and sewers
29 - Other inspection and maintenance systems
30-33 Construction and demolition
30 - Nuclear demolition & dismantling
31 - Building construction
32 - Robots for heavy /civil construction
33 - Other construction and demolition systems
34-38 Logistic systems
34- Autonomous guided (AGV) vehicles in manufacturing environments*
35 - AGVs in non-manufacturing environments (indoor)
36 - Cargo handling, outdoor logistics
37 - Personal transportation (AGV for persons)
38 - Other logistics
39-42 Medical robotics
39 - Diagnostic systems

40 - Robot assisted surgery or therapy 41 - Rehabilitation systems 42 - Other medical robots	
43-45 Rescue und security applications	
43 - Fire and disaster fighting robots 44 - Surveillance/security robots without UAV 45 - Other rescue and security robots	
46-50 Defense applications	
46 - Demining robots 47 - Unmanned aerial vehicles 48 - Unmanned ground based vehicles (e.g. bomb fighting) 49 - Unmanned underwater vehicles 50 - Other defense applications	
51 Underwater systems (civil/general use)	
52 Powered Human Exoskeletons	
53 Mobile Platforms (general use)	
54-58 Public relation robots and joy rides	
54 Hotel and restaurant robots 55 Mobile guidance, information, telepresence robots 56 Robots in marketing 57 Robot joy rides 58 other public relation	
59 Other professional service robots not specified above	

Although the definition of service robot used by the IFR is based on the ISO standard, the report includes an expansive understanding of the service sector, some areas of applications considered in the World Robotics report extends beyond our working definition of service robotics. In particular, robots for domestic tasks are used outside commercial settings. The same applies to rescue and security, and defence applications. Field robots are deployed in the agricultural, extraction sector, or occasionally in scientific research. Exoskeletons are not autonomous, and are not included in the reference definition of robot. Among all these areas of application that are actually in the service sector, some deserve particular consideration, based on the volume of commercially available robots, their relative sophistication, and diffusion, and are discussed in the final section of this report.

Eurofound Company survey

Another potential source to monitor is the European Company Survey 2019. Jointly carried out by Eurofound and Cedefop, it covers workplace practices in relation to work organisation, human resource management, skills use, skills strategies, digitalisation, direct employee participation and social dialogue. The 2019 edition of the survey for managers, currently being processed, included a single question on whether the establishment uses robots, with no reference to its type or purpose. However, the results of the survey may be useful to correlate the use of robots in service sectors as such with other employment information such as work organisation practices, corporate governance, and the skill level of the employees. The results are still not available, but will be soon.

Other potential sources

Several robotics industry groups present the growing development of service robots. However, none of them seems to provide original detailed data on adoption or sales of robots. For example, Robotics Online, sponsored by Robotic Industries Association a trade group, provides updates and marketing materials for service robots producers. The sales figures – and projections – it quotes come from the IFR report. Autonomous Solutions, gives an overview of automated vehicles for “Dull, Dirty, And Dangerous Jobs”. It acts with companies in different areas, in mining, automotive, agriculture and construction, wine-making, cleaning, security, research, military. However, it provides no sales figures, case studies, or client lists.

Final remarks on applications, limitations, and extensions of existing data

The figures reported by Eurostat give a valuable general overview – the only one of its kind – on the adoption, distribution and applications of service robots across European companies. In general, the ICT community survey is designed primarily to appraise the state of technology adoption across Member States. It is not intended to provide detailed evidence at the level of individual companies on the reasons for adopting technologies, or the ways in which they are embedded in the firm. As a result, the survey is relatively imprecise.

The survey uses an expansive interpretation of service robot that partially overlaps with its own definition of industrial robot. This may have caused confusion among respondents, and makes it harder to focus precisely on the service sector, as distinct from manufacturing. The survey asks whether companies use any industrial robot, or any service robot, but not their type or quantity. Service robots are not commoditised – they come in different types and sizes, and imply vastly different levels of investment and integration into company processes.

The survey results only report the share of companies using robots disaggregated by country, size, and sector. In any of these, percentages are rounded to the nearest integer, which makes it difficult to compare precisely the share of adopters across different countries. Furthermore, the sector disaggregation, at approximately NACE 1-digit, is quite broad. Finally, the list of applications for service robots that companies could choose from is somewhat limited. In most cases, we can only surmise the specific type of service robot they refer to, and their application. Among the companies that use service robots, 12% use them for different purposes than those listed, which indicates that the use-cases envisaged by the survey where too limited. Since the only available figures refer to 2018, we cannot know how the adoption of service robots has changed in the last couple of years. Moreover, the 2018 module on service robots and 3-D printers of the ICT survey was optional, which means that not all Member States collected these statistics. Once the results of the 2020 ICT survey are released, we will be able to draw on a larger number of countries, and compare how countries and sectors have evolved.

Overall, the data of the ICT Community Survey of Enterprises answer the question of how many service robots there are, by looking at their prevalence across companies (and, soon, their growth), though it does not inform us on the stock of installed units, or their value. The data can also point us to what they do, by looking at the sectors in which they are installed, and the applications for which they are used. However, the survey is silent on the deeper reasons of innovation and the intra-firm dynamics with respect to labour policies.

By contrast, the World Robotics – Services report by the IFR describes in detail the variety and capabilities of existing service robots, and lists extensively their areas of application. However, the globally aggregate sales figures it collects can only give us an approximate idea of the prevalence of service robots. The sales projection included in the report should also be interpreted with caution, as they come from producers themselves, who have an interest in generating interest in their products. Moreover, the sales projections were compiled before the COVID-19 pandemic, which may affect the industry in unpredictable ways. On the one hand, the pandemic may increase the desire to automate tasks and expand e-commerce, boosting the sales of robots. On the other hand, it may also disrupt sectors like aviation or shipping, thus reducing the demand for some types of robots.

Ideally, to fully understand how service robots are being used in the service sector, we would like to combine the breadth and coverage of the ICT community survey with the depth of classification of the IFR. To our knowledge, the scope of existing Eurostat surveys, including the ICT community survey, is currently too broad to address these points conclusively. Understanding fully the patterns of adoption of service robots would probably require an ad-hoc survey targeting enterprises in the service sector, focused on the specific kind of service robot technology used, it applications and tasks, and how it fits with existing workforce and operations. We can also obtain this sort of insight on a smaller scale, through case studies. We can select specific examples of service robots, using the IFR-UNECE classification as a reference, and the names of the robots and companies listed there as a starting point. The following section describes a tentative taxonomy of service automation that could help guide the selection, and distinguish the different types of automation in the service sector.

Some examples of robots and automation in services

The previous sections describe the challenges in measuring the state and direction of automation in the service sector. Even considering robots as a physical technology (in contrasts to software), with a relatively well-codified standard, we are confronted with a wide array of specimens, in many shapes and sizes. We also understand that robots are often sold not as off-the-shelf individual units, but as parts of bundles of machinery, infrastructure, software and services. This section discusses some specific examples of robots and related technology used for automation in services. By enumerating a few concrete examples, we can better understand what they have in common and what sets them apart, and thus derive a preliminary taxonomy of automation in services. This emerging taxonomy is developed specifically for this project based on our understanding, but it is also informed by the concepts of ontologies and classifications of service robots presented by Haidegger et al (2013) and Wirtz et al (2017).

Logistics robots

Logistics robots perform many tasks that were initially developed for tightly controlled and standardised manufacturing environment, and that have been extended to warehousing, wholesale and e-commerce sales in the service sector. Among these, Automated (or Autonomous) Guided Vehicles (AGVs) to move around cargo – such as crates, shelves, and occasionally people – were first used in the structured spaces of factories and required special flooring for motion guidance. With advances in robotics, these devices require relatively simpler signage, such as floor marking stickers. They are increasingly able to move autonomously and avoid obstacles in less structured environments, such as airports or large floors. According to the IFR report, AGVs can perform a range of tasks:

- Assembly: Moving products through production processes
- Kitting: Collecting parts for assembly
- Transportation: Loading pallets and loose parts
- Staging: Delivering pallets for production processes
- Warehousing: Moving products from stretch wrappers to docks or storage
- Order Picking: Moving ordered products to trailer-loading area for distribution
- Parts/Just-In-Time (JIT) Delivery: Towing trailers of parts and materials to consumption points
- Transfer/Shuttle

This range of capabilities means that AVGs can also automate postal services, and be used as couriers in hospital settings, airports, and office spaces.

Figure 5: Two examples of automated guided vehicles. The KUKA omniRob (left) with a modular design that can include a mechanical arm. The Swisslog/KUKA CarryPick (right) moves shelves around a warehouse and brings them to human workers, for them to pick and package the product from the shelf.

In general, adopting robots for logistics still requires significant investment and adaptation by companies to reshape their environment by adding signage, standardise their procedures and equipment. As a result, the producers of robots for logistics, such as KUKA and Swisslog, provide highly integrated offerings, spanning machinery, installation, consulting, software, and maintenance. The products and services they offer are also customised to the requirements of their clients. Another producer, Kiva Systems, which used to supply different companies in retail sales, was acquired by Amazon in 2012.[12] It is now called Amazon Robotics, and it seems to make robots exclusively for the e-commerce giant. This level of bundling of products and services, their customisation for clients, and the level of vertical integration may make it difficult to compare sales in terms of units of robots sold across different producers.

In terms of work organisation and working conditions, the use of these robots in e-commerce is notable for the partial task automation they achieve, and the adaptation they require to interact with humans. The task of retrieving an object for packaging is split between robots and humans: the robots retrieve the entire shelf containing the object requested, and bring it near human workers. In so doing, they relieve human workers of the effort of walking vast distances among identical shelves. Indeed, the robots navigate reliably in warehouses because of their consistent structure, helped by floor markings, and avoid each other and obstacles thanks to sensors. However, they cannot directly pick the object requested because they lack the dexterity to handle the wide range of products stocked on shelved – a task that still needs human vision, cognition and dexterity. Moreover, robots and humans work relatively closely in warehouses, but interact in very limited ways. Even in a relatively standardised, manufacturing-adjacent application like warehouse management, implementing service robots requires adapting the existing space to work around the limitations of the technology. They also imply a different pace of work for human employees, and potentially a different combination of skills.

Floor-cleaning robots

Floor-cleaning robots are used in large spaces with smooth surface requiring regular cleaning. They are autonomous guided vehicles, and in certain applications can require limited human intervention or supervision. For instance, Auto-C (pictured below, left) is used to clean the floors in Wal-Mart

[12] https://www.bostonglobe.com/business/2013/12/01/will-amazon-owned-robot-maker-sell-tailer-rivals/FON7bVNKvfzS2sHnBHzfLM/story.html

stores in the United States, either autonomously, or guided by a human operator. Specialised applications to healthcare include the UVD robot, which uses ultraviolet light to disinfect surfaces in hospitals. On a smaller scale, domestic vacuum robots like the Roomba are successful examples of personal service robots, not intended for professional use. All these cleaning robots are designed to perform a specific task – cleaning floors– and require relatively smooth and predictable surfaces to operate.

Figure 6: The Auto-C by BrainOS (left) is used by Wal-Mart to clean floors in its stores. The UVD robots (centre) clean and disinfect hospital rooms. The Roomba (right) is a best-selling personal cleaning robot for domestic use.

Robots in healthcare

According to the IFR, medical robots make up a significant share of revenues in the robotics industry, despite selling relatively comparatively few units. The applications listed in the World Robotics report include diagnostic systems, Robot-assisted surgery and therapy, rehabilitation systems, and other medical robots. The most common among these are robots to assist surgery, such as the da Vinci robot by the American company Intuitive Surgical (pictured below). This system, costing around $2 million, has sold over 4,000 units since it was developed in the 1990s. It is a notable case of a robotic technology augmenting the capabilities of highly skilled operators. The robot carries out the movements directly instructed by surgeons, while reducing trembling and allowing movements that are more precise. Crucially, the robot is not autonomous in any meaningful sense, but is a tool (albeit a complex one) in the hand of a qualified professional.

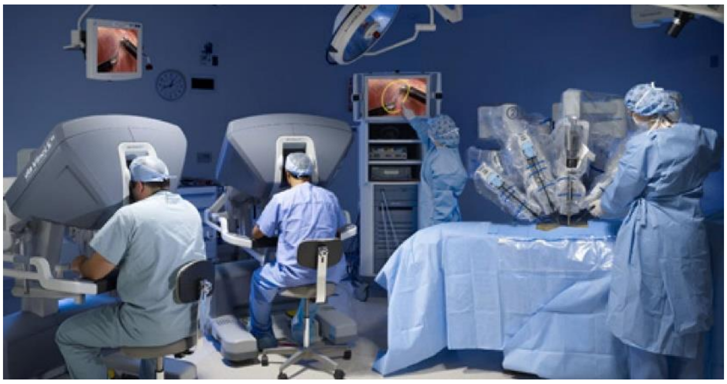


Figure 7: The da Vinci robotic assisted surgery system by Intuitive Surgical.

Automated checkout and self-service kiosks

Automated checkout in retail and self-service kiosks in fast-food restaurants have automated some tasks in these sectors. They performs a relatively narrow set of tasks in standardised settings, and they require humans to adapt to their limitations: by ordering through a touch-panel display, or by scanning products one by one in stores. Although these technologies are not robots as such – they are not mobile, or autonomous in any sense – they are widely deployed in several countries, and a successful case of automation in retail and restauration. They also illustrate a possible change in work organisation resulting from automation: the part of work previously carried out by workers is partially automated by the machine, and the remainder is shifted to customers, who complete their orders and scan their groceries themselves.

Figure 8: Unbranded self-service kiosk developed by DieboldNixdorf

The relationship between the producers and adopters of this technology is also notable: the companies making these systems work in close partnership with their clients to design custom solutions, branded and tailored to the needs of the retail store adopting them.

A tentative taxonomy of service automation

The few examples selected above illustrate the diversity of ways in which automation is implemented. They hint at some of the relevant features that differentiate among technologies in terms of how they affect work by humans. This subsection enumerates a few of these elements, to better classify these instances or automation in services.

The first crucial attribute of a service robot, as the IFR/ISO definition requires, is that it really operates in the **service sector**, as opposed to industrial robots used in manufacturing or agriculture. By this measure, logistics robots can be used in retail and wholesale trade, and e-commerce, which technically satisfies the definition. Still, some of their applications – like warehousing, packaging and shipping – could also be described as manufacturing-adjacent: they are not exclusively the preserve of service-sector businesses, and are essentially the same in industrial applications.

Second, we should distinguish, as the ISO standard does, between **professional** service robots (used by companies in professional setting) and **personal** service robots (used by consumers non-commercially). We are interested only in the former, because they affect production and economic activity within companies, and thus can affect working conditions and employment. In principle, robot lawn-mowers, pool-cleaners, and vacuums could affect the demand of domestic services – and the quantity of labour demanded of human gardeners and cleaners. However, these robots, which are usually smaller and less expensive than their professional-service counterparts, are sold in large quantities to many individual users. This makes it comparatively more difficult to survey their prevalence, and to understand why they are purchased, and how they are used.

The next set of attributes to classify these examples is whether they meet our reference definition of service robots – namely whether they are *physical* (rather than virtual), *mobile* (as opposed to stationary), and to what extent they are *autonomous* (as opposed to merely propagating physical stimuli, like a mechanical arm). The requirement of robots being **physical** machines excludes all software applications, many of them often branded as “robot” or “bot”. Chatbots, who assist customers through text, are software that is usually available through customer devices, as opposed to being embodied in devices designed solely for the purpose. The same goes for robo-advisors in financial services – algorithms that suggest investment strategies based on the preference of their clients. Personal voice assistants such as Apple Siri, Microsoft Cortana, or

Google, though not often called robots, also fall in the same category. **Mobility** includes both automated guided vehicles, which move around in space, and mechanical arms, whose extremities move in three dimensions, despite being often anchored to a stationary structure. Self-checkout cashiers and self-service kiosks, by contrast, have no moving parts: they are interfaces for humans, who move objects near the machine. **Autonomy** is a more subjective and relative concept. Fundamentally, all robots follow instructions codified in software, what varies is how directly they are controlled or supervised by humans. For our purposes, we mainly distinguish between so-called "actuators", which are constantly guided by human operators – like robotic arms or probes for surgery, or exoskeletons – from devices moving without direct human supervision and interact with their surroundings, like autonomous guided vehicles and some floor-cleaning robots.

Next, we should distinguish between the different types of **human interaction** that service robots can achieve. Following their predecessors in industrial settings, some types of service robots like mechanical arms in logistics may not allow for any human interaction at all, and are fenced off from humans for safety reasons. Among robots that are expected to interact with humans some of the time, we distinguish between primarily **employee-facing devices** – like the vehicles or conveyor systems used in logistics – from mostly **customer-facing** devices, like self-service kiosks, or the rare personal assistant or concierge robots. The former require more accommodation, including dedicated infrastructure, standardised interaction, and consequently training for workers. Customer-facing devices are generally simpler to operate, but perform a narrower set of tasks.

The final attribute to consider is the degree to which robots are intended to **complement or substitute human workers** in a wide range of tasks. This will necessarily be a matter of degree, as robots can currently perform a narrow set of tasks. At one extreme, we include robots that augment human capabilities, such as robotic surgical arms that allow surgery from a distance, or at a greater level of precision, but are fundamentally controlled by human operators. Inspection and maintenance robots may also be used in places that humans could not reach before, but also in places where it was dangerous to do so. In this case, they can either complement human labour – by expanding the capabilities or range of tasks that humans can perform – or substitute it outright – by automating some tasks almost completely, like floor cleaning. Even in cases of substitution, on close inspection, are a matter of degree, and of defining the boundaries of tasks. The archetypal example of substitution is in assembly and related tasks in manufacturing, where many tasks previously performed by humans can be performed by robots.

Table 6: Example taxonomy of automation for selected service technologies

Generic or colloquial name	***Industry***	***Example***	***Service sector***	***Profess. vs personal***	***Physical***	***Mobile***	***Autonomy***	***Human interaction***
Automated Guided Vehicle	*Logistics, e-commerce*	*SwissLog/KUKA CarryPick*	*X*	*Profess*	*X*	*X*	*X*	*Worker*
Customer service kiosk	*Fast-food, Retail, E-commc*	*DN, Acrelec*	*X*	*Profess*	*X*			*Customer*
Cleaning	*Offices, airports, factories*	*Adlatus, Kärcher*	*X*	*Both*	*X*	*X*	*varies*	*None/ Worker*
Chatbots for customer service		*Flow.AI*	*X*	*Profess*	*Software*		*limited*	*Customer/ Worker*
Robot-assisted surgery	*Healthcare*	*DaVinci*	*X*	*Profess*	*X*	*X*		*Customer/ Worker*
Point-to-point delivery systems	*Healthcare*	*Helpmate, TUG*	*X*	*Profess*	*X*	*X*	*X*	*Worker*
Exoskeletons	*Healthcare, Manufacturing*			*Both*	*X*	*X*		*User / Worker*
Autonomous tractors	*Agriculture*			*Profess*	*X*	*X*	*X*	*None / Worker*
Milking robots	*Agriculture*	*DMS, Merlin, Taurus*		*Profess*	*X*	*X*	*X*	
Crop-picking, weeding	*Agriculture*	*RIPPA, Hortibot*		*Profess*	*X*	*X*		*X*

Table 6 illustrates how this framework could be applied, by examining a few select technologies, and summarising the assessments presented above. For each of them, we also try to point to the producers of the robots in question, and areas of application. The examples span applications in the service sector and beyond, and serve to illustrate the different combination of characteristics.

On close inspection, most technologies do not fulfil all the criteria at the same time: customer service kiosks are not mobile or autonomous, though they are widely deployed, and so may still be interesting to study. Automated guided vehicle satisfy all criteria, though their interaction with humans is limited. Cleaning robots are also good candidates, if we consider only those in professional services.

Overall, this approach is merely a starting point to sort among examples of technologies, but it can be extended to include other types of robots, and further guide our study of automation in the service sector.

Conclusions

Many scholars and policymakers alike expect that a wave of automation will soon disrupt the service sector. The prospect of a new generation of service robots, able to serve and interact with humans, would extend the frontier of automation from industrial manufacturing tasks to service activities. This raises a number of questions about the future of work in the service sector. Most notably, how will these new types of robots interact with human labour, and how would that affect the demand for different types of skills? What will drive the diffusion of service robots? Will it be affected by structural and regulatory factors – such as wage, unemployment, labour protection, and occupational health and safety? Will it depend mostly on business factors, such as business model, work organisation, skills of employees?

This report examined the evidence on the current state of service-sector automation of European Union, by surveying of the limited available sources of data on the prevalence of service robots. Among these, the Eurostat ICT Community Survey presents the best cross-country evidence on the prevalence of service robots in Europe. Only around 2% of companies in the European Union report using service robots. By comparison, around 5% of them report using industrial robots. At the moment, service robots are concentrated in a few sectors and applications. The leading use cases are warehouse management for logistics in wholesale and retail trade and transport, inspection and maintenance, and cleaning. The survey has a number of limitations that limit the scope for combining its results with other administrative sources: it uses an expansive interpretation of service robot that overlaps with industrial robots; it only reports the approximate share of companies using them in broad economic sectors and size group; and only accounts for a few possible use-cases of the robots. Finally, the survey only offers a limited snapshot from the year 2018, as the questions on robotics were part of an optional module of the survey, and not all Member States collected these statistics. The module is being re-implemented as a compulsory section in 2020 at the time of writing, with an updated definition of service robot. The results for 2020 will provide better cross-country coverage, and will hopefully allow to see trends in the diffusion of service robots over the last couple of years.

A better sense of what existing service robots can actually do, and what they look like, comes from the World Robotics–Services survey by the International Federation of Robotics. The document presents aggregate sales data coming from around 750 companies producing sales robots. Starting from the definition of service robot developed by the International Organisation for Standardisation, it uses a rich classification of around 60 areas of application for service robots developed jointly by the IFR and the UN Economic Commission for Europe. The global aggregate sales data collected in the IFR report cannot tell us much on the geographic prevalence or distribution of service robots, but the sales volumes of different types of robots by application show the relative development and diffusion of specific technologies. The leading application of service robots is again in logistics systems, covering around 40% of sales of professional service robots. These are often sold as a bundle of robots, the necessary infrastructure, and consulting and maintenance services, and range in shape from autonomous guided vehicles, to mechanical arms for picking items, or a combination of both. Inspection and maintenance robots make up a similarly sized market, which spans a wide range of robots with sensors and cleaning capabilities for cleaning anything from fuel tanks, to machinery and ships hulls. Robots for logistics, together with those for inspection and maintenance, jointly account for nearly 80% of service robot units sold. This is no surprise, considering that the tasks that they seek to automate fit with the historical trend of robots being used first for tasks traditionally described as “dull, dirty, and dangerous” in industry parlance. The COVID-19 pandemic has underscored the importance several essential sectors, including health care and logistics. At the same time, it has shown how workers in those sectors, in every occupation, are frequently exposed to health risks, which derive in part from the way their work is organised. Developments in service robotics will doubtless attempt to address these risks, for instance by limiting the need for physical proximity between humans, or by making cleaning easier and more effective.

So far, medical robots and defence robots have specialised areas of application, with fewer units sold, but at higher prices, adding up to a significant share on industry revenues. However, the variety of service robots used in medicine and defence is difficult to classify; the technology varies a lot, as clients request customised solutions, which makes it difficult to obtain comparable figures for sales. The report also forecasts annual growth of 41% for the service robots at large, based on the sales projections of the manufacturers surveyed. The figures suggest a burgeoning industry, but as self-reported sales projections, they should be taken cautiously. Moreover, these forecasts predate the COVID-19 pandemic, which may affect demand for automation in unpredictable ways.

Overall, based on the data presented in this report, we can conclude that automation in the service sector – in the form of service robots – is small but growing. Despite the image that the industry projects, currently there are very few consumer-facing humanoid robots in active use. Indeed, leading areas of application for service robots are mostly specialised machinery used behind the scenes in manufacturing-adjacent parts of the service sector, covering logistics, inspection and maintenance, and cleaning. Ultimately, the measure of success of service robots is whether companies actually adopt them over the long run. By that metric, only these few areas of application mentioned above count as successful. Indeed, based on the current state of technology, we can expect increased automation in those service sectors where work is standardised – or can be reorganised in this way – but we expect slower diffusion into other areas of services that involve more interaction with humans. Nevertheless, the coronavirus pandemic may yet increase the demand for robots, not only in cleaning and in healthcare, but also in other areas of services where human interaction is unsanitary.

With the current data on the topic, many pressing questions remain unanswered. The most important is how service robots currently deployed fit within companies: whet they imply in terms of work organisation, working conditions, health and safety, and the demand for skills. As pointed out in the scientific literature, these questions can only be answered in reference to specific examples of service robot technologies, used by companies in the real world. This case-study approach would examine a few cases of select technologies, as used by specific individual companies in their respective narrow economic sectors. To inform this selection process, this report proposes a taxonomy of automation in services – in terms of the relevant attributes of service robots and their applications – and illustrates it by discussing a few example technologies.

To help address these questions, this report proposes a taxonomy of service automation, in order to map different technologies in terms of their purposes and attributes.

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