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Service Robotics and Human Labor: A first technology assessment of substitution and cooperation

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HIGHLIGHTS

- We discuss how service robots interact with human labor.
- We identify different job segments that might come under pressure.
- We describe how human–machine cooperation should be developed from a work science perspective.
- We define first concluding criteria to assess service robots with respect to human labor.

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ABSTRACT

Since the beginning of robotics, the substitution of human labor has been one of the crucial issues. The focus is on the economic perspective, asking how robotics affects the labor market, and on changes in the work processes of human workers. While there are already some lessons learnt from industrial robotics, the area of service robots has been analyzed to a much lesser extent. First insights into these aspects are of utmost relevance to technology assessment providing policy advice. As conclusions for service robots in general cannot be drawn, we identify criteria for the ex-ante evaluation of service robots in concrete application areas.

1. Introduction

In the early days of using robots, German technology assessment of robotics and automation was in particular characterized by studies on the impact on the labor market. Back then, the basic principle of automation was strictly applied, i.e., the work processes were divided into individual action sequences in order to examine which of these sequences could be automated. As a result, a manufacturing process was established in which automatable action sequences were performed by machines while non-automatable tasks continued to be performed by humans. The main objective was the substitution of human labor in order to achieve an increase in efficiency through labor cost savings. Assembly lines were developed in which automated operations could be optimally coordinated, particularly in the automotive industry. The non-automatable actions to be performed by human workers constituted the so-called residual activities which were partly integrated in these assembly lines or remained as upstream or downstream tasks [1–4].

Today, due to major progress made in programming as well as further technological advances in engineering, robotic systems can increasingly take over non-standardized tasks previously reserved for humans—and at economically feasible costs. As a consequence, automation is no longer restricted to the production of standardized products in industry but increasingly becomes part of value creation processes in the service sector. Hence, the former paradigms of automated manufacturing have been put into perspective again. The focus has – at least partially – shifted from substitution to cooperation between human and machine. Often the aggregate of tasks performed by humans is designed in such a way that they no longer merely represent “residual activities” of automation. “Exaggerated” automation strategies were modified as to create meaningful tasks for humans, which can often be done in teamwork. Again, the economic cost–benefit analysis also plays a key role [5–7]. Today, the robot is increasingly able to perform not only manual and routine cognitive tasks but also non-routine manual and cognitive tasks. As a result, the general areas

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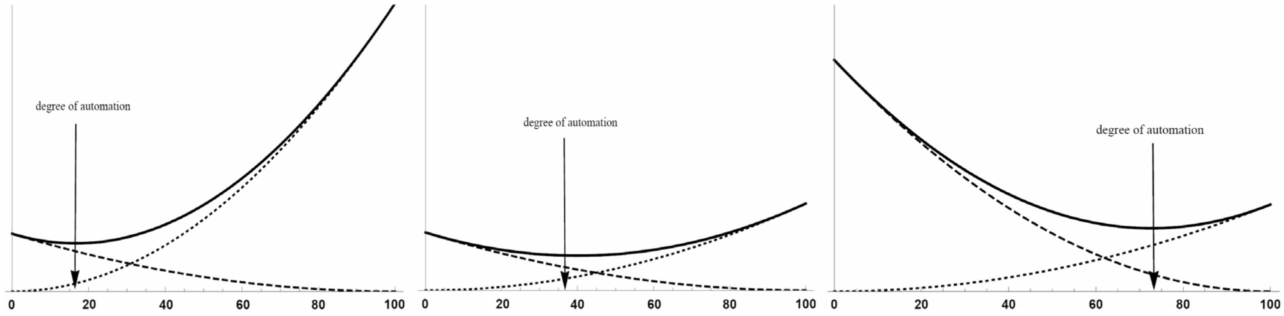

(a) Baseline scenario.

(b) Impact of reduced automation costs (dotted line shifts downwards).

(c) Impact of increasing labor costs (dashed line shifts upwards).

Dashed line – manual production; dotted line – machine production; solid line – semi-automated production;
Source: own presentation based on stylized cost curves.

Fig. 1. Input costs and optimal degree of automation.

of application for robots broaden and they can be used both to substitute even more job profiles than before and help mitigate shortages within the labor market. Due to their capabilities, robots also increasingly act as collaborators of human labor. Overall, this means that robots do not necessarily substitute human labor, but complement it and, in specific areas, make it even more productive. In the following, this paper will elaborate on these considerations and demonstrate how technical progress can enable not only a transition from industrial to service robotics but also a shift in the relationship between human and machine from a formerly substitutional to a complementary one. These considerations will be linked to the so-called capital-skill complementarity hypothesis which addresses the relationship between physical capital and different types of skills (cf. [8]). This perspective addresses both challenges and opportunities for human labor resulting from technological change.

The inherent complexities are highly relevant for any technology assessment of robotic systems. On the one hand, the use of robots is aimed at optimal implementation of technical possibilities in order to achieve economic gains. On the other hand, it must be investigated from a work science perspective what exactly the tasks are that humans are supposed to perform in cooperation with machines. This paper addresses some key issues related to service robotics, which in this connection represents the "natural" further development of industrial robotics. Already in 1994, the Fraunhofer Institute for Manufacturing Engineering and Automation (Fraunhofer IPA) – one of the key players in the field of robotics – phrased the following definition of service robots, which is still valid today [9]:

"A service robot is a freely programmable mobile device carrying out services either partially or fully automatically. Services are activities that do not contribute to the direct industrial manufacture of goods, but to the performance of services for humans and institutions".

In service robotics, the circumstances differ from those of industrial robotics because the environment can only very rarely be completely redesigned with regard to the use of robots (for example, an entire stable for milking robots). That means that the robot system must be able to react flexibly to different environments in which services can be rendered. In that respect, cooperation with humans becomes more multi-faceted. When the service is rendered to people, e.g. hair-washing, the challenge for the robot system is even greater.

This paper aims to describe main lines of argumentation of two disciplinary approaches, namely (labor) economics and work science. The goal is to derive some general observations about the assessment of service robots and to outline first findings on technology assessment of specific service robot systems. In this respect, this paper is an important preparation for the contextual case-by-case analysis of service robots.

2. Framing the economic argument: from substitution to complementarity

2.1. Human labor and automated production as perfect substitutes

The introductory discussion is based on a stylized production process in which labor and automatic production are assumed to be perfect substitutes. This implies that a certain output can be produced in identical quality by either input alone or any convex combination of both inputs. For given cost curves, it is thus easily possible to derive the partitioning of tasks being performed either by humans or machines or, put differently, the cost-minimizing degree of automation.

Fig. 1 plots on the horizontal axis the cost-minimizing degree of automation, which lies between 0% (complete human production) and 100% (complete automation). Total production costs (solid line) result from the utilization of labor (dashed line) and robots (dotted line).[1] It is natural to assume that the latter are increasing and the former are decreasing with the degree of automation. Given this specification, any change in any cost component also affects the optimal degree of automation: e.g., it increases whenever process innovations reduce the cost of machine production (panel [b]) or when human production becomes more expensive (panel [c]). Total costs, however, are minimized for intermediate degrees of automation.

Due to the assumption of perfect substitutability, co-working or any complementary relationship in the sense that a robot assists a human being and the corresponding allocation between labor and machine may not be analyzed within this simple framework. The presentation, however, is useful to better understand the impact of robots in those fields where human labor is threatened by machines. Up to now, this has mainly been the case in the field of industrial robotics where machines took over routine and mostly manual tasks with a strong repetitive character. Today, however, great potential is seen in the utilization of flexible co-working robots and service robots which – also in industrial robotics – increasingly take over non-routine tasks as well.

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[1] The cost minimum usually does not equal the degree of automation where the cost curves of human and machine production intersect. Such a minimum would only arise if both cost functions were symmetric.

2.2. From industrial to service robotics—broadening the fields of application

The following thoughts relate to the long-standing discussion of the impact of industrialization on labor. A common way to address such questions may be summarized under the label of the so-called capital-skill complementarity hypothesis. It draws back on Griliches [8], who first stated that physical capital is more complementary to skilled than to unskilled labor. An immediate consequence is thus that there is natural substitution pressure on unskilled labor performing repetitive tasks that may easily be codified. The argument also highlights that the skill level is a significant determinant driving the relationship between various inputs of production. More recently, similar arguments have been picked up, e.g., by Autor et al. [10], Brynjolfsson and Mcafee [11], Acemoglu and Autor [12]; Frey and Osborne [13], Autor [14], Brynjolfsson and Mcafee [15] or Arntz et al. [16], who discuss the skill content of recent technological change and especially the role digitization plays herein. Especially Frey and Osborne [13, p. 38] argue that, given the recent employment structure, a large share of employment is at high risk as computerization increasingly also penetrates both cognitive and non-routine tasks. It is not fallacious to expect that existing skill requirements and job profiles will also come under pressure as more and more value creation processes in the service sector become automated. Thus, the diffusion of service robots is expected to have a major labor market impact.

As a consequence of technological change, human–machine relationships become increasingly complex and may not be reduced to mere substitution of human labor by machines. Instead, we already observe co-working in a sense of collaborative activity between humans and machines on assembly lines where both inputs are complementary; a co-working machine enhances productivity of human labor. In any case, the utilization of the machine still mostly takes place in a self-contained factory.

Altogether, the impact of robotics technology is driven by numerous interacting effects. Increasing machine intelligence allows for interaction not only between humans and machines but also between machines only (M2M). As a consequence, the possible application fields for robots continuously expand and increasingly leave well-defined and protected environments like factories. In that sense, the aforementioned substitution pressure is no longer restricted to routine manual tasks. Even though the overall implications of robotic activity are not clear, it is obvious that in the future not only repetitive routine tasks but also duties with ambitious skill requirements may be resolved by robots that increasingly provide solutions for non-routine or cognitive functions.

2.3. A formal representation of substitution and complementarities

The discussion may also be linked to a specific aggregate production function that characterizes the relationship between various inputs by their respective elasticity of substitution (a so-called CES production function).[2] Roughly speaking, this elasticity specifies to which extent a given ratio of factor demand – e.g., the demand for human labor over the utilization of a robot – reacts to changes in the respective factor price ratio.[3] If the percentage increase in the input ratio exceeds the percentage increase in the respective factor price ratio, the inputs are substitutes. Otherwise they are complements. The underlying production function enables a differentiated analysis of possible relationships (complement/substitute) between various production inputs. As a matter of principle, these relationships can also change over time. Given aggregate production as the output of, e.g., the three inputs physical capital, skilled and unskilled labor, capital-skill complementarity as stated before holds if the elasticity of substitution between capital and unskilled labor exceeds the elasticity of substitution between capital and skilled labor. Skilled labor thus reacts less sensitive to changes that are induced, e.g., by technological change.

An even more general approach which allows for different elasticities of substitution between *any* two inputs might be formalized by a two-level CES production function.[4] We illustrate this for the case of an aggregate production function with four inputs and apply the argumentation to the interaction between different categories of human labor and a robot. The inputs considered are highly skilled human capital (H), medium- and low-skilled labor (M and L) as well as a robot (R). The corresponding production function might have the following representation[5] :

$$Y = AH^{\alpha}\left[a\left\{bR^{\theta} + (1-b)\,L^{\theta}\right\}^{\frac{\rho}{\theta}} + (1-a)\,M^{\rho}\right]^{\frac{1-\alpha}{\rho}},$$
$$0 < \alpha < 1, \quad 1 \geq \theta,\ \rho > -\infty, \quad A, a, b > 0.$$

Within the equation, A represents a factor-neutral productivity parameter; a and b are distribution parameters.[6] Concerning the input factors, the specified production function has the following implications: Skilled labor, H, is complementary to any of the other inputs. The level of the substitution parameters, θ and ρ, allows both for substitutive ($0 \leq \theta, \rho \leq 1$) and complementary ($\theta, \rho < 0$) relationships between R, L and M. At an aggregate level, a robot might at the same time complement certain types of skills (highly qualified human capital) while substituting less skilled labor.

2.4. Skills and tasks and the transformation of robotics

Concerning robotics, substitution potentials arise from the possibility of providing certain tasks automatically. In industrial robotics, this mostly holds for repetitive manual tasks that are codifiable. Programmed work sequences may easily be executed by machines. In structured environments, it is mostly highly skilled labor that will be less exposed to substitution pressure.

More generally speaking, if one interprets the emergence and evolution of service robots as the natural continuation of industrial robotics, one might follow the categorization first provided by Autor et al. [10], who analyze the skill content of recent technological change. They distinguish routine/non-routine tasks on the one hand and cognitive vs. manual tasks on the other hand.[7] Fig. 2 gives an overview. Applying this 2 × 2 matrix to better understand the emergence of service robotics out of industrial robotics, one might roughly argue that industrial robots are broadly used for manual routine tasks, thereby threatening unskilled workers. Due to digitization and M2M collaboration, the other constellations within the 2 × 2 matrix increasingly get penetrated by ever more

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[2] CES stands for constant elasticity of substitution. Compare the seminal paper of Arrow et al. [17]; more recent application by Duffy et al. [18].

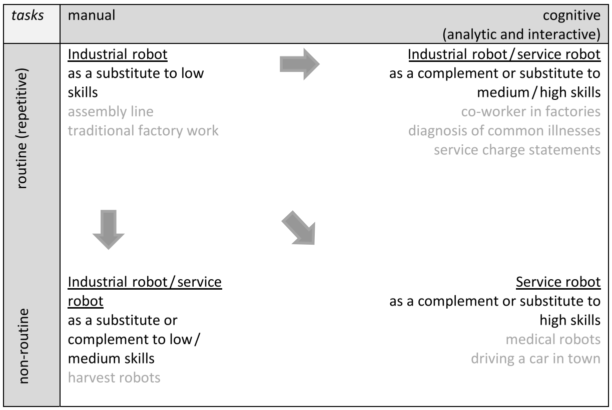
[3] Being more precise, the elasticity of substitution measures how a factor ratio reacts to changes in the marginal rate of substitution between these two parameters. Optimal factor allocation implies that the marginal rate of substitution equals the (reverse) factor price ratio.

[4] Cf. Sato [19] for the first specification of such a production function.

[5] This type of production function has been extensively used to empirically test the economic implications of technological change; cf., for example, Duffy et al. [18] or Klump et al. [20].

[6] We skip a differentiated discussion of the formal implication of the parameters A, a and b here. The interested reader may be referred, e.g., to the book of Chiang [21].

[7] The authors thereby focus on the impact of increased computerization that can be observed in almost any field of economic activity. According to them, navigating a car through city traffic is not understood as being a routine task. In the meantime, Frey and Osborne [13] argue that driving a car in a city (a non-routine cognitive task) may already be done by machines.



tasks	manual	cognitive (analytic and interactive)
routine (repetitive)	Industrial robot as a substitute to low skills assembly line traditional factory work	Industrial robot / service robot as a complement or substitute to medium / high skills co-worker in factories diagnosis of common illnesses service charge statements
non-routine	Industrial robot / service robot as a substitute or complement to low / medium skills harvest robots	Service robot as a complement or substitute to high skills medical robots driving a car in town

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.

Fig. 2. Skills and tasks: transformation of industrial to service robots.

sophisticated machines which then are able to perform complex tasks.

As a consequence, the relationship between human and machine changes over time: both are substitutes in early phases of technological development and become complements as the technology advances. At the same time, also skill levels evolve.[8]

It becomes obvious that even at the same level of value creation the overall labor market consequences, however, are quite unclear. Broadening possible fields of application thus does not necessarily imply that increasingly manual and cognitive tasks will be overtaken by machines. Automation in the service sector frequently implies taking over non-routine tasks. Due to complementarity effects, especially high-skilled workers may become more productive as they become co-workers of machines and both complement each other even at the same level of value creation.

3. Substitution of human labor by service robots—the work science perspective

Strictly speaking, the question whether human labor is substituted by service robots can only be answered in a non-speculative way if the benefit of human labor output is identical to that provided by a robot, presuming that in a capitalist society the cost–benefit analysis then made is always the sum of individual business decisions. This presumption is, however, undermined by numerous variables of which predominantly those of a work science perspective will be discussed in the following.

First of all, it must be pointed out that a robot does not necessarily represent a mere copy or imitation of human skills, but can include an expansion of human skills to an extent that the question of a cost–benefit analysis does not even arise. The skills of humans to land on Mars or to dive in the deep ocean are limited compared to those of a robot. In addition, also services that could in principle be performed by humans or robots alike may reveal substantial differences in quality. To the advantage of robots, this may relate to the accuracy of today's medical operations supported by robots, or to the advantage of humans, this may pertain to the emotional quality of services that robots cannot deliver (or can only simulate, with the simulation being obvious). In some areas, the differences in quality are clear; in others they require a more detailed analysis.

Especially in the service sector there are a number of tasks for which the above-mentioned cost–benefit analysis is at least made. These calculations are stimulated by new possibilities of human–robot cooperation which enable the joint action of humans and robots within one workspace. The following perspectives are relevant for the possible sharing of functions between humans and robots in service work systems:

- the organization of social and corporate work including the legal framework (i.e., different job profiles of service personnel, night and shift work, health protection);
- the tasks to be performed by humans and robots (i.e., operational, monitoring or decision-making tasks);
- the possibilities of and limits to the realization of such tasks in terms of (information) technology (depending e.g. on the robot's ability to move, its sensor system and cognition, including the entire periphery such as protective devices).

These are organizational perspectives of the allocation of functions between humans and robots who are in an interdependent relationship and hence cannot simply be read from top to bottom or vice versa. For example, phenomena in the field of social work organization – like demographic change or the shortage of nursing staff – can serve as an impetus for the use of robots. On the other hand, new technological possibilities like immediate cooperation between humans and robots can also stimulate the increased use of robots.

3.1. Information technology perspective

Indeed, at least the marketable development of robots has been stimulated by the new possibilities of human–robot collaboration (HRC). Due to their size and speed, industrial robots can pose a considerable safety hazard to staff in a work system. Therefore, such robots operate within a protective cage with no one being allowed in there during operation. This involves substantial costs (space requirements, protective devices) and limits the flexibility of the robot system—in general, the production workflow cannot be changed while the system is in operation.

In recent years, robot systems have been developed that in principle allow the robots to leave their cages. Specific opportunities for function sharing between humans and robots arise from optical, acoustic and haptic signal processing systems robots are increasingly equipped with. On the one hand, this makes it possible to reliably stop the robot's movements also below the emergency stop level (e.g., by the user simply touching the robot's arm). On the other hand, this results in additional options for programming the robot over and above using a computer or a manual programming device (e.g., through manual movement of the robotic arm). This can enable users to program the robot via natural speech or specific teaching methods, such as demonstrating/imitating [22–26]. All of this promotes the flexible use of service robots also by technically untrained staff and makes it possible that their work process knowledge [27,28] gains importance in the human–robot collaboration.

Both the operation of the robot without a protective cage and simple methods of robot control are critical requirements and stimuli for the use of robots in the service sector because, unlike in an industrial context, there are hardly any work environments in the service sector that are standardized or standardizable for the use of robots, and equally no highly-skilled specialists for controlling them.

3.2. Task-oriented perspective

In manufacturing, work manifests itself in the product. It is past labor in a materialized form. Given a certain quality, you cannot tell whether a car was manufactured in Germany or in China, or predominantly by qualified or non-qualified staff or by

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[8] One also has to be aware of the fact that what separates different skill levels (i.e., high, medium or low) changes over time and across different application fields.

robots. In the service sector, however, work manifests itself in the very service activity. This means that the customer/client normally comes in contact with people or bodies that perform service tasks or respective operations. It also implies that the benefit of a service rendered by robots or by human labor in the service sector is much more difficult to compare than in a manufacturing environment. Does friendliness or sympathy, for example, belong to a service or is it an insignificant accessory? In the meantime, the "quality of the relationship" between human and robot has been analyzed as part of several scientific approaches (cf., for example, [26,29]).

At this point, the idea of a contrastive task analysis (cf. [30,31]) is to identify different qualities of human and machine performance. In this sense, a useful technical system is not simply the most realistic illustration of what the users themselves know, do and are able to do. It is more a matter of a quality of the information technology which is complementary to the skills of the user.

The robot technology's strengths lie in the precise execution of operations – also under adverse conditions of space and time – which allow a certain degree of standardization, but also include a certain range of variation. If tasks were predominantly invariant, the question would be what the flexibility of a robot is needed for: for doing laundry, a washing machine is probably more suitable than a robot. On the other hand, if there is no way to standardize the execution of the task, the robot will soon reach its limits. Looking after small children, for example, which does not only entail pure supervision but also empathetic reactions to the child's behavior exceeds the current and foreseeable capability of service robots. Within a certain spectrum, however, service robots could possibly take over a range of tasks which require a lot of effort from humans (with negative health effects), do not correspond to the human diurnal rhythm (night work) or exceed the capabilities of old, sick and disabled people.

This goes for task sharing with clients as well as with service personnel (still) in the work system. With regard to maintaining and developing the skills of service staff, it is important to ensure that tasks of decision-making are not substituted by the robot but are controlled by service personnel. Otherwise the so-called automation paradox occurs, which means that, during normal operations, human workers have to carry out cognitively draining activities, and in case of malfunctions or unexpected situations they suddenly have to make highly sophisticated decisions which they do not master anymore. Here, too, the principle of complementarity in the sharing of tasks between humans and robots applies from a work science perspective, i.e., robots take on tasks where humans are not or hardly able to do so. This principle is particularly relevant when it comes to the decision-making authority between service personnel/client on the one hand and the robot on the other. The question arises because modern robots have a system of artificial intelligence (AI) with the help of which they can take decisions (to a limited extent, i.e., semi-autonomously). It is a matter of interaction between human and artificial intelligence (cf. in more detail [32]): When is the robot allowed or expected to render a service autonomously based on a situational analysis without being given the express order to do so? When is it allowed to correct human mistakes even without explicit instructions?

3.3. Perspective of social work organization

Presuming that robots can render services to the same level of quality as human service personnel, this raises questions regarding the availability and remuneration of suitably qualified staff as well as the legal regulations both for their and the robots' deployment.

To illustrate the points mentioned above, the care sector is used as an example, as it is an area where the use of service robots is sometimes considered: As long as the remuneration for care services is poor and workforce needs are met by foreign workers, there is little reason for a widespread use of service robots to substitute human services. Furthermore, it is a question of social acceptance, which has already triggered a controversy in connection with the robot seal "Paro" used in the treatment of dementia patients [33]: Whilst care services in Germany are already very clearly defined as and limited to the instrumental provision of a desired function, it is in no way agreed that people in need of care, relatives, carers, health insurances, etc. will accept as "care" what a robot is able to render. Even in case of a possible labor shortage in the care sector, the use of robots will be a limited option—if all technical problems are solved. "Limited option" means that service robots will presumably cooperate with human care personnel within a work system and will interact with people (care personnel as well as clients/customers) who are not trained in the operation of robots.

What was very roughly outlined here for the care sector is also applicable to other service areas. The aspects that should always be considered include:

- the expectations (= needs + demands) of customers/clients, their respective affordable needs, and the political enforceability of these expectations;
- the skills, work input and remuneration of the service personnel currently performing these tasks as well as the reservoir of existing workforce;
- profitability considerations (and possible obligations) of the service providers, and
- the efficiency, purchase and maintenance costs of robotic technology.

In addition, when service robots are used in a private environment, the application strategies for robots may to some extent become detached from the mentioned considerations of cost and revenue due to personal preferences and interests of the robot users.

This goes hand in hand with the following: Service tasks cover a broad area of private and business life: from garbage separation to looking after toddlers or dementia patients. Presumably these tasks are not of equal importance to all people and it is therefore not irrelevant who performs these tasks. Hence, it is less a question of social acceptance of service robotics as a whole, but the question relates to specific service tasks. The problem of social acceptance has a much stronger effect on forecasts of substitution than in the manufacturing sector where customers have long become accustomed to, e.g., cars manufactured by robots: Who would like to substitute the nanny by a robot in child care, even if the robot manufacturer could credibly demonstrate that the robot can also handle children with specific educational needs?

3.4. Interim conclusion

The perspectives outlined above are explicitly or implicitly anticipated by a robot manufacturer: What technological options can be implemented today for a service robot (information technology perspective), what tasks is the robot able to perform in contrast to and/or in collaboration with humans (task-oriented perspective), and what affordable and legitimate needs of private or institutional service providers are met by such a technological artifact (societal perspective)?

What is important is that these are mental anticipations of reality, not reality itself. These anticipations on the part of robot manufacturers are also influenced by "trends" in relevant discussions (topics such as Industry 4.0, demographic change, humanoid robots, etc.). To what extent the service robots manufactured on the basis of these anticipations meet affordable needs of potential customers can certainly not be predicted for service robotics or the service sector in general. This requires a specification of the service areas and an analysis of foreseeable development of wages/qualification of the employees, of the strategies of local companies and institutions, as well as of the relevant legal regulations.

4. First conclusions for technology assessment of service robots

Assuming that robots are developed for services currently rendered by human labor, service robots will probably take over at least parts of these tasks. This brings about changes in the work of humans who will now render services with the support of robots. In case of a complete takeover of the entire service task, the change would, in an extreme case, imply that humans do not work anymore and become unemployed. Another possible situation is that the collaboration with service robots enables humans to render their services more efficiently, which could eliminate half of all jobs in this service segment. From the perspective of interdisciplinary technology assessment [34], it would now be interesting to know whether a statement can be made ex ante on how a partial or entire substitution would affect the work processes of humans and what economic effects this substitution can be expected to have on the labor market.

The results presented in this paper demonstrate that no generally valid conclusions can be drawn. Depending on whether the collaboration between humans and robots constitutes a substitution of tasks or complementary task sharing, the impacts on the labor market can be completely different. Also statements as to the level of personnel put under particular economic pressure by the use of service robots cannot be generalized. Due to the cost–benefit ratio resulting from the low costs of labor for services classified as simple or low-skilled, modern service robots are not likely to gain market share in this segment. Therefore, it is more likely for service robotics to put people with a medium level of education under some pressure.

Also from a work science perspective, the situation is complex. The information technology perspective indicates that robots – with regard to their hardware – generally become less of a safety risk and therefore – unlike industrial robotics of the past – generally enable close collaboration with humans. This progress in the hardware development of robots and their capacity of processing environmental information goes hand in hand with advances in programming service robots that enable also people without training in information technology to control service robots to a limited degree. Taking a closer look at the tasks service robots are intended to be used for, one can identify areas in which a successful deployment of service robots is already conceivable today. The use of service robots is especially promising for those tasks that imply a lot of effort, health problems, a difficult diurnal rhythm or a specific physical burden for humans. The perspective of social work organization as a whole takes account of availability and remuneration, the expectations of potential customers, the skills of current personnel, as well as the performance capability and purchase and maintenance costs of robotic technology. Still, the fact that according to these parameters a use of robots may be practical does not say anything about the factual acceptance of these service robots. This requires a very detailed analysis of the service segment the robot is to be used in.

So the possibly disillusioning conclusion is that generalizing statements cannot be made—neither from an economic nor from a work science point of view. However, criteria can be derived from both disciplinary perspectives which enable an assessment of specific service robotics systems within their respective operational context. From the analysis of these contexts it is then indeed possible to develop performance criteria which make a successful cooperation between humans and service robots in a service context probable. The work science analysis of these cooperative services and the overall economic analysis allow drawing relevant conclusions for interdisciplinary technology assessment. This can firstly result in direct recommendations for technological development, for example, for optimizing the human–machine interface for a specific cooperative task. Secondly, there may be indications for legal regulations, e.g., when it must be determined who or what is liable for a damage that occurs in connection with a cooperatively rendered service.

Statements regarding service robotics in general are hard to be justified on the basis of this set of criteria because the quality of the services, the potential for standardization of work environments, the design of the human–machine interface, the level of education of the human service providers, etc. are so varied that a contextual analysis is imperative—with a level of detail below the common service sectors. As a consequence, there will be no general technology assessment of service robotics as such, but exemplary studies will have to be conducted for different service robots.

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