acatech DISCUSSION

# Revitalizing Human-Machine Interaction for the Advancement of Society

Perspectives from Germany and Japan

H. Kagermann, Y. Nonaka (Eds.)

ロボット革命イニシアティブ協議会
Robot Revolution & Industrial IoT Initiative

PLATTFORM INDUSTRIE 4.0

acatech
NATIONAL ACADEMY OF SCIENCE AND ENGINEERING

acatech DISCUSSION

# Revitalizing Human-Machine Interaction for the Advancement of Society

Perspectives from Germany and Japan

**H. Kagermann, Y. Nonaka (Eds.)**

ロボット革命イニシアティブ協議会
Robot Revolution & Industrial IoT Initiative

PLATTFORM INDUSTRIE 4.0

acatech
NATIONAL ACADEMY OF SCIENCE AND ENGINEERING

## The acatech DISCUSSION series

This series documents symposia, working groups, workshops and other events organised by the National Academy of Science and Engineering. The relevant editors and authors are responsible for the contents of the publications in this series.

All previous acatech publications are available for download from: https://en.acatech.de/publications/

# Contents

# Foreword

**Prof. Dr. Henning Kagermann, Project Leader**

Chair of the Board of Trustees, former President, acatech – NATIONAL ACADEMY OF SCIENCE AND ENGINEERING

Global Representative & Advisor, Plattform Industrie 4.0

Industrie 4.0 was conceived as a reaction to the global economic crisis of 2009 and its far-reaching economic and societal consequences. The intention was to use the opportunities of the second wave of digitalization in order to ensure competitiveness and resilience of the economy through increased adaptability of products, processes, and organizational structures.

In addition, it sought to establish a phase of sustainable growth in which ecological (e.g., circular economy) and social or societal challenges (e.g., the future of work) were addressed, as well as their economic impact. Of course, the transformation process of the fourth industrial revolution must first of all provide specific benefits to individual users and citizens. Human-machine interaction (HMI) plays a central and crucial role in this process, particularly due to the increasing intertwining of natural and artificial intelligence (AI).

In 2016, the acatech Impulse *Innovation potential of human-machine interaction* already clarified: "The focus of HMI is shifting to the human user".[1] Therefore, we were pleased to follow our Japanese partners' suggestions and examine HMI in the context of solving social and societal issues.

While Japan and Germany are being confronted with similar societal challenges (e.g., aging population, skills shortage, etc.), the countries' methods to finding solutions differ as a result of diverging societal trends and culturally related problem-solving approaches. These differences must be analyzed and understood.

One important outcome of this paper is to clarify and highlight the similarities and differences between the two country-specific perspectives in the context of HMI in order to identify common areas of cooperation for future German-Japanese initiatives.

1 | acatech 2016, p. 9.

**Dr. Youichi Nonaka,**
**Co-Project Leader**

Senior Chief Researcher,
Center for Technology Innovation
– Production Engineering,
Research & Development Group,
Hitachi, Ltd.

Member of Robot Revolution &
Industrial IoT Initiative

Topics such as resource depletion, environmental burdens, declining birthrates, and an aging population are global challenges for the establishment of sustainable societies. Japan is focusing on these subjects because we have felt a real impact from these developments in society, for example with incidents in manufacturing caused by operational errors and/or machine deterioration.

In this era of the fourth industrial revolution, we feel it is not enough to define the problems and their impact on society today and in the future. Many publications tend to introduce new technologies such as artificial intelligence (AI), software-defined control (SDC), 5G communications, etc., but they do not focus on challenges and policies from sociological and organizational points of view. Changing this was the motivation of the German and Japanese colleagues gathered for this project.

Based on this motivation, this paper focuses on challenges and policies with quantitative research and assumptions in case studies delivered from Germany and Japan. It was quite a valuable experience for us to feel the similarities and differences between the German and Japanese perspectives on how to grasp the problem. Even though we are aiming for the same goal, our historical backgrounds and social structures influence the approach we take.

We expect that this paper will provide an opportunity to highlight the social impact of everyday issues confronting us. And we hope that our daily activities will make a more positive contribution to establishing a sustainable society.

# Executive summary

A maturing workforce and aging machines and infrastructure have the potential to cause social challenges in countries such as Germany and Japan. In order to solve these problems, maintain a high level of manufacturing efficiency, and establish a sustainable society, these countries are increasingly turning to digital technologies, for example cyber-physical systems (CPS), AI, and robotics. These next-generation growth engines are being supported by initiatives like Industrie 4.0 in Germany and Society 5.0 in Japan.

In digital society, interacting with machines is becoming more and more similar to interacting with people. As a result, the gap between humans and machines is permanently narrowing. This transformative power in current technological developments applies to all areas of life and has significant consequences on interactions between humans and machines (HMI). General work routines and employment conditions are also being impacted. This paper explores distinct questions on how Japan and Germany are responding to these developments:

- How will work (and the workplace) potentially evolve in the future?
- How do companies need to evolve their workforce?
- How do companies need to evolve their organization and processes?

In order to answer these questions, this paper is structured as follows:

Chapter 1 begins with a short introduction that describes the context and the focus of this paper.

In Chapter 2, we point out emerging issues in smart manufacturing, specifically by referring to societal boundary conditions and circumstances in Germany and Japan.

In Chapter 3, we examine the future way of working in the context of Industrie 4.0 and social issues regarding employment, working style, and human resource development. Statistical data on labor population, quality, and productivity are brought in, as well as estimates of changes in labor structures from German and Japanese perspectives.

Chapter 4 sheds light on the anticipated increase in diversity – in regard to both humans and machines – in the near future, and it presents solution policies with sustainable innovations across the life cycle of products and services. In this context, the chapter examines the emerging gap due to diversity and discusses the opportunities and challenges of managing the real and cyber worlds. It also points out sustainable innovations with diversity, drawing on country-specific case studies.

In Chapter 5 we focus on human-machine collaboration in the context of smart manufacturing and the impact it will have on manufacturing work in the future. Potential solutions may give rise to new styles of interaction. Additionally, integrating humans and self-learning machines will call for operations and management to be flexible and adaptable. A possible result could be the creation of better and more satisfying work.

Finally, in Chapter 6 we present our conclusions.

Generally, digital technologies are expected to solve social challenges. Yet they will also require social transformation, since they will perform routine cognitive tasks that were previously the domain of humans. Essentially, to establish a sustainable society, it is necessary for humans to be able to create high-value-added work continuously and to be able to shift from work that potentially becomes obsolete to high-value-added work at any time. Also, it is necessary for machines to not only carry out non-high-value-added work, but to also be a mechanism of creating high-value-added work by interacting with humans. According to these requirements, the digital transformation can enable a novel, human-centered manufacturing system in which humans concentrate on lifelong skill improvement and continuously create high-value-added work. Essentially, this system revitalizes HMI, allowing both humans and machines to play a role in shaping digital society.

Ultimately, we should strengthen the public interest in digital society, share knowledge acquired from interactions between humans and machines, and work to establish a sustainable society that focuses on human well-being. We encourage members of the public to start considering and discussing the scenarios and actions together for the future.

This collaborative project between Germany and Japan is valuable, as it takes into consideration recognized similarities and differences between the two countries on how to deal with the issues at hand. Although both countries are aiming for a similar goal, their historical backgrounds and social structures are impacting their methodologies and focal areas in finding solutions. In closing, we encourage open discussions among multiple countries in the effort to establish a sustainable society.

# Project team

## Leader/Co-Leader

- Prof. Dr. Henning Kagermann, acatech, Global Representative & Advisor of the Plattform Industrie 4.0
- Dr. Youichi Nonaka, Hitachi, Member of Robot Revolution & Industrial IoT Initiative

## Core Project Team

- Prof. Dr.-Ing. Reiner Anderl, TU Darmstadt, Head of the Research Council of the Plattform Industrie 4.0, Member of the Steering Board of the Plattform Industrie 4.0
- Prof. Dr. Elisabeth André, University of Augsburg
- Megumi Aratame, Meiji University
- Prof. Dr. Andreas Dengel, DFKI
- Sarah Haas, Infineon
- Koichi Iwamoto, RIETI
- Prof. Dr. Jun Ota, The University of Tokyo
- Dr. Matthias Peissner, Fraunhofer IAO
- Prof. Dr. Sabine Pfeiffer, Friedrich-Alexander-Universität Erlangen-Nürnberg, Member of the Research Council of the Plattform Industrie 4.0
- Dr. Carsten Polenz, SAP, Member of the Steering Board of the Plattform Industrie 4.0
- Prof. Dr. Peter Post, FESTO, Member of the Research Council of the Plattform Industrie 4.0, Member of the Steering Board of the Plattform Industrie 4.0
- Joachim Sedlmeir, acatech
- Dr. Xiaonan Shi, Mitsubishi Electric
- Tanja Smolenski, IG Metall
- Daisuke Tsutsumi, Hitachi

## Contributors

- Dr. Sheraz Ahmed, DFKI
- Mohammad Al-Naser, DFKI
- Takenori Baba, Mitsubishi Electric, Member of Robot Revolution & Industrial IoT Initiative
- Dr. Martin Eckert, Hitachi
- Mitsushiro Fujishima, Mitsubishi Electric, Member of Robot Revolution & Industrial IoT Initiative
- Josef Haid, Infineon
- Lisa Hubrecht, acatech
- Kazuya Kawai, Information-technology Promotion Agency, Japan (IPA), Member of Robot Revolution & Industrial IoT Initiative
- Emeritus Prof. Fumihiko Kimura, The University of Tokyo, Member of Robot Revolution & Industrial IoT Initiative
- Dr. Hitoshi Komoto, National Institute of Advanced Industrial Science and Technology, Japan (AIST), Member of Robot Revolution & Industrial IoT Initiative
- Matthias Lieske, Hitachi
- Prof. Dr. Michiko Matsuda, Japanese Standards Association (JSA), Member of Robot Revolution & Industrial IoT Initiative, Kanagawa Institute of Technology
- Kazuo Nakashima, Robot Revolution & Industrial IoT Initiative
- Dr. Takehiro Niikura, Hitachi
- Tobias Paulus, Infineon
- Natalie Schnelle, SAP, Member of the Plattform Industrie 4.0
- Dr. Kiyotaka Takahashi, Hitachi
- Yumiko Ueno, Hitachi
- Prof. Dr. Yasushi Umeda, The University of Tokyo

# 1 Introduction

Globalization has accelerated in each of the three industrial revolutions that have occurred up to now, and many people have moved across national and international borders for employment. This readiness to relocate became the foundation for rapid economic growth in both Germany and Japan. When the proportion of children (0 to 14 years of age) in the total population is less than 30 percent, and the proportion of seniors (65 years and older) is less than 15 percent, an economy is expected to grow dramatically. Such a period of growth potential is called the *demographic window of opportunity*. According to the National Intelligence Council (2012), Germany's window started before 1950 and ended in 1990; in Japan, it was from 1965 to 1995; in the United States of America from 1970 to 2015; and in China from 1990 to 2025. These figures show that developed countries such as Germany and Japan are currently positioned in a post-window phase. What is required is an economic growth initiator separate from the window.[2] In reality, these societies face issues that could cause social challenges associated with a maturing workforce and aging machines and infrastructure. Also, productivity declines can be expected in an older population due to decreased vision, lowered reactive ability, and diminishing physical strength. In Japan, for example, accidents increasingly occur as a result of operator error and/or machine deterioration.

In order to solve these problems, maintain efficiency, and establish sustainable societies, these countries are turning to digital technologies, such as CPS, AI, and robotics. These next-generation growth engines are being supported by initiatives like Industrie 4.0 in Germany and Society 5.0 in Japan. Both initiatives aim to solve social problems and stimulate economic growth with the ultimate goal of creating a human-centered society that integrates cyber and physical space to achieve the United Nations (UN) Sustainable Development Goals (SDGs).[3] As a higher degree of digitalization also correlates with increasing energy consumption, related environmental consequences (e.g., carbon dioxide emissions) must also be taken into account for the sustainable development of societies.

This paper focuses on aging employees, declining birth rates, skills of young workers, and the resulting challenges for the factory of the future. The discussion seeks to establish how these problems should be defined and what new approaches in HMI can contribute to achieving the goal of sustainable societies. In interactions with machines, human behavior and individual capabilities are often limited by traditional structures and systems, based on standardized machine interfaces. Against the background of a qualitative change of humans and machines, the hypothesis is that a novel form of human-machine symbiosis has to be defined that involves different population groups – such as older and younger people, disabled people, and people from different cultural backgrounds – along with old and new machines, and machines with different specifications. In addition, new strategies and technologies are needed to harmonize and revitalize HMI.

In cooperation with partners from science and industry in Germany and Japan, this study intends to address these questions, presents several aspects for discussion, and offers different approaches to solving the problems from the perspectives of these two countries.

2 | See National Intelligence Council 2012.
3 | See Akaishi 2018, UN 2019.

# 2 Emerging issues in smart manufacturing

Hardly any technological development is currently changing our lives and thinking as much as the process of digitalization. This phenomenon is impacting entire economies and how we work.[4]

The far-reaching, technology-induced changes in the production sector are subsumed under the term Industrie 4.0. The integration of CPS (sensors, actuators) leads to a comprehensive (inter-) connection of single components and whole production systems. As a result, it is not only possible to leverage optimization potential in traditional production routines, but also to realize flexible, value-added networks and innovative business models. This process of change is further accelerated by AI – and machine learning (ML) in particular.[5]

Nevertheless, today we are still at the beginning of this journey, which will lead to a powerful and disruptive transformation process that also impacts our relationship with the machines around us. At the heart of this development, machines must be seen as serving humans and society. The central focus of HMI is shifting to the human user, whereby (self-)learning machines adapt more and more to the individual competencies, tasks, and needs of the users, instead of requiring them to stick to rigid and fixed control schemes.[6]

As a consequence, interacting with machines becomes increasingly similar to interacting with humans. Therefore, the gap between man and machine is permanently narrowing. Every one of us is already confronted with HMI – even in our private lives. Hearing aids, wearable sensors, and collaborative robots are just a few typical examples for the ubiquitous interaction with technical devices in daily life.[7]

It is expected, however, that the transformative power of the current technological developments applies to all areas of life. This particularly includes developments in the field of AI, as well as innovative concepts and applications of HMI. Equipping previously analogous (production) facilities or systems with integrated capabilities for processing and communication affects interaction between technical systems and machines (M2M). Additionally, it also has significant consequences on the interaction between humans and technology. That, in turn, impacts employees' general working routines and conditions.[8]

All these consequences depend highly on societal boundary conditions and circumstances. This study portrays the situation in Japan and Germany with a variety of examples and case studies to highlight how these two societies are facing the upcoming changes.

In each of the next three chapters, we will explore distinct questions and look at how Japan and Germany are responding to them:

- How will work (and the workplace) potentially evolve in the future?
- How do companies need to evolve their workforce?
- How do companies need to evolve their organization and processes?

4 See Allianz Industrie 4.0 Baden-Württemberg 2017.
5 See also PLS 2019.
6 See acatech 2016.
7 See acatech 2016.
8 See Gorecky et al. 2014.

# 3 The future of work

In Germany, working methods in the context of Industrie 4.0[9] are referred to as "Arbeit 4.0", or "Work 4.0". Here, digitalization and other trends like globalization, demographics, and cultural and societal changes are considered, including aspects of training and co-determination.[10] Social partners, such as work councils or trade unions as well as companies' management, have realized that the future of work has a significant impact on employees, collaboration, and companies' organizations. As a consequence of the digital transformation, employees are facing significant changes in the way they work and collaborate – both with humans and machines.[11] Moreover, it also effects the quality of work, job satisfaction, health, and skills.[12]

Therefore, in this chapter, we focus on societal issues around employment, working methods, and human resource development. We provide statistical data on labor population, quality, and productivity, and forecasts on changes in labor structures.

## 3.1 Population change, labor market, productivity, and quality of work

In Japan and Germany, rapid population decreases and an aging society as a result of a lower overall fertility rate compared with a worldwide level can be observed (Table 1).[13] A decrease in the working population has already begun.

We have observed the following reasons:

- Germany has shown a trend of relatively small or even negative population growth since the early 1970s.[14]
- Japan was the first country in which more than 20 percent of the population is 64 and older.[15]
- Both countries are learning to deal with the related social challenges.

| Country name | Population [Unit: in thousands] | | |
|---|---|---|---|
| | 2016 | 2060 | Increase-decrease rate [%] |
| USA | 322,180 | 403,504 | 25.2 |
| China | 1,403,500 | 1,276,757 | -9.0 |
| **Japan** | **127,749** | **86,737** | **-32.1** |
| **Germany** | **81,915** | **71,391** | **-12.8** |
| UK | 65,789 | 77,255 | 17.4 |
| France | 64,721 | 72,061 | 11.3 |
| India | 1,324,171 | 1,745,182 | 31.8 |
| Italy | 59,430 | 54,387 | -8.5 |
| Brazil | 207,653 | 236,014 | 13.7 |
| Canada | 36,290 | 45,534 | 25.5 |
| Korea | 50,792 | 47,926 | -5.6 |
| Russia | 143,965 | 124,604 | -13.4 |
| Australia | 24,126 | 35,780 | 48.3 |
| Spain | 46,348 | 43,114 | -7.0 |
| Mexico | 127,540 | 166,111 | 30.2 |
| Worldwide | 7,466,964 | 10,165,231 | 36.1 |

Table 1: Changes of populations in major countries
(Source: own presentation based on Atkinson 2019, p. 24)

- One of the differences between the two countries is migration background.
  In Germany, more than 23 percent of the population have a migration background.[16] In Japan, that figure is less than 2 percent of the population.[17]

Generally, the process of digital transformation changes society fundamentally. But according to the economic outlook published by OECD, overall labor productivity growth decreased over the last few years in most OECD countries. For Germany as well as for Japan, a slight decrease can be identified (see Figure 1).

There are various interlinked causes for this productivity slowdown, particularly including the effects of the financial crisis and the subsequent slow recovery of the global economy.[18]

9 In terms of innovation policy, this development is addressed in Germany with the "Strategic Project Industrie 4.0", see also Kagermann et al. 2013.
10 See BMAS 2017, Hoose 2018.
11 See Allianz Industrie 4.0 Baden-Württemberg 2017.
12 See Botthof/Hartmann 2014.
13 See Atkinson 2019.
14 See World Bank 2019.
15 See UN 2017, p. 238.
16 See Destatis 2018a, p. 35.
17 See MIC 2019a.
18 See OECD 2019, p. 56f.

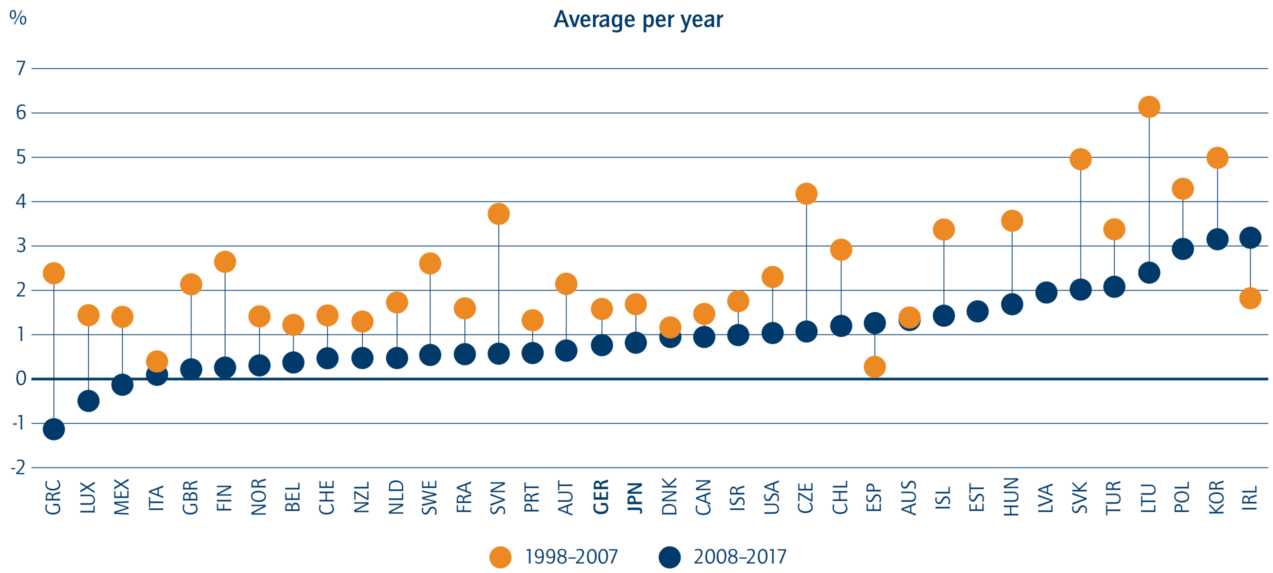



Figure 1: Labor productivity growth in OECD countries (Source: own presentation based on OECD 2019, p. 57)

Figure 2 indicates the global ranking of unit labor costs in the manufacturing industry.[19] This comparative index (Germany is standard at 100) reveals high unit labor costs in Germany; in Japan, these costs were about 18 percent below the German level in 2016. Even the quite high level of productivity in Germany fails to fully compensate for the drawback of these high unit labor costs, which in turn potentially challenge competitiveness.[20] The Japanese manufacturing sector, however, saw a drop in productivity and declined steadily in a global view – in times of a weaker yen and the growth of technological advances in other countries.[21]

Table 2 is a ranking of human resource quality; Japan is no. 4 and Germany no. 11.[22]

| Ranking | Country | Rating |
|---|---|---|
| 1 | Finland | 85.86 |
| 2 | Norway | 84.54 |
| 3 | Swiss | 84.51 |
| **4** | **Japan** | **83.44** |
| 5 | Sweden | 83.29 |
| 6 | New Zealand | 82.79 |
| 7 | Denmark | 82.47 |
| 8 | Netherland | 82.18 |
| 9 | Canada | 81.95 |
| 10 | Belgium | 81.59 |
| **11** | **Germany** | **81.56** |
| 12 | Austria | 81.52 |
| 13 | Singapore | 80.94 |
| 14 | Ireland | 80.79 |
| 15 | Estonia | 80.63 |
| 16 | Slovenia | 80.33 |
| 17 | France | 80.32 |
| 18 | Australia | 80.08 |
| 19 | UK | 80.04 |
| 20 | Iceland | 79.74 |
| 24 | US | 78.86 |
| 32 | Korea | 76.89 |
| 34 | Italia | 75.85 |
| 44 | Greece | 73.64 |
| 45 | Spain | 72.79 |

Table 2: Quality of human resources
(Source: own presentation based on Atkinson 2019, p. 80)

19 See Schröder 2017, p. 78.
20 See Schröder 2017, p. 75; 78.
21 See Nikkei Asian Review 2017.
22 See Atkinson 2019.

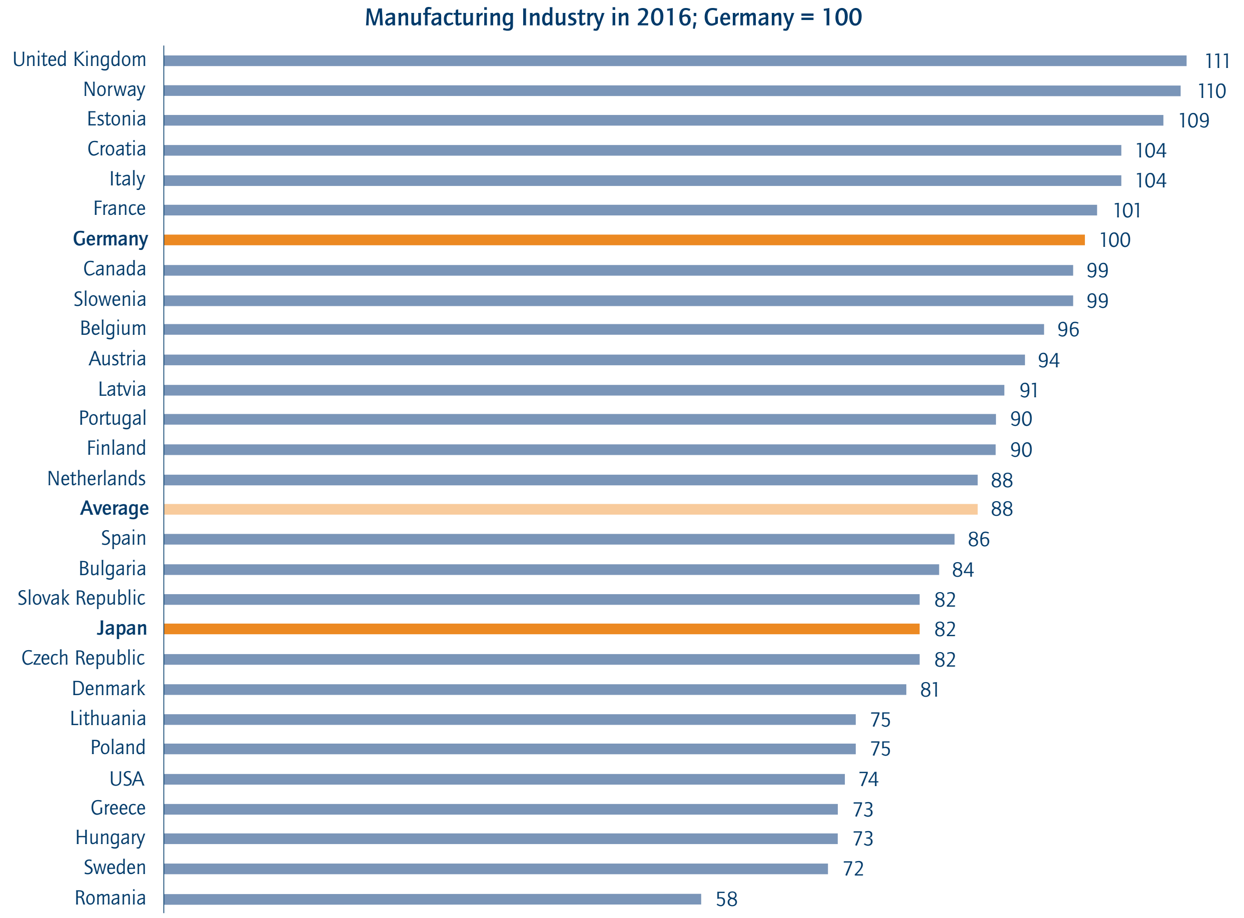



Figure 2: International comparison of unit labor costs in manufacturing (Source: own presentation based on Schröder 2017, p. 78)

## Risk of change and risk of automation

According to Arntz et al. from the OECD, there were two types of risks for workers in 2016: a 50–70% risk for "change in tasks", and a 70–100% risk for "automation of tasks".[23] Nedelkoska and Quintini (2018) published an updated estimation of these risks in OECD countries (Figure 3).

For 16% of the workforce in Germany, 13% in Japan, 9% in the United States, and an average of 14% in OECD, the substitution risk is 70–100%.[24]

This estimate was a consensus among experts throughout the world.

As for Japan, according to the Work Force Survey 2017 by the Japanese Ministry of General Affairs, the workforce was 67.2 million. That means that 8.7 million workers run the risk of substitution (calculation: 67.2 million × 0.13 = 8.7 million).

Germany and Japan need to increase their labor productivity by improving human skill sets. In this context, worker skills may be enhanced by digitalization to ensure the competitiveness of industries in spite of a decreasing population and a changing workforce.

23 See Arntz et al. 2016.
24 See Nedelkoska/Quintini 2018.

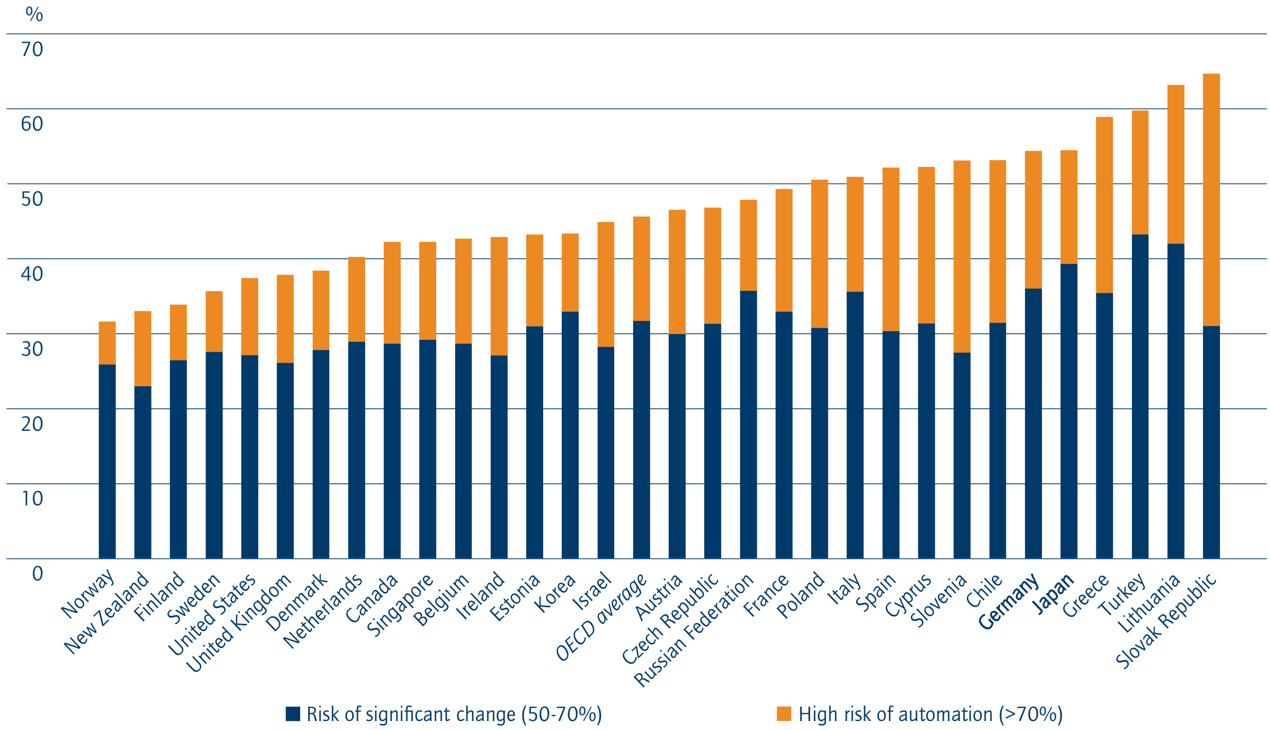



Figure 3: Cross-country variation in job automatability, percentage of jobs at risk by degree of risk
(Source: own presentation based on Nedelkoska/Quintini 2018, p. 49)

In order to achieve effective sustainable growth, innovations and investments must be raised.

Digitalization may help to offer potential employees more high-value-added jobs and add higher value to industry itself. Humans can assign tasks to machines that can be better performed by machines, freeing up creativity and human capital.

Society has to support these changes so humans and machines have the opportunity to evolve together in a harmonized way. Thought needs to go into what such a working environment might look like. The following case studies describe the situation in the labor structure of both countries and the required skill changes.

## Case study in Japan: Economic disparity by ICT investment – implications from US studies

For the United States, Prof. David H. Autor of Massachusetts Institute of Technology revealed the mechanisms and processes that lead to a structural change in the world of employment. The process of replacing human workers with machines and the resulting economic disparity are caused by active investment in information and communication technology (ICT, see Figure 4).[25] In Japan, there is no comparable analysis, but the mechanisms and processes that exhibit structural change of employment, and the process of replacing humans with machines, are thought to be almost the same as in the United States. This research was the most significant output in a series of "the future of work" research works, and subsequently it has strongly influenced a great deal of subsequent research.

Autor explains that the active ICT investments changed employment structures for more than 13 years. Routine cognitive tasks have been replaced by computers. But in the future, the same phenomenon will continue to be implemented across the board. Even if routine cognitive tasks are highly difficult, or if many years of training are required for humans to learn them, they can be programmed based on logic. (Note: Academically, routine tasks are divided into cognitive tasks and manual tasks. The former is being replaced by computers and the latter by robots).

25 | See Autor 2015.

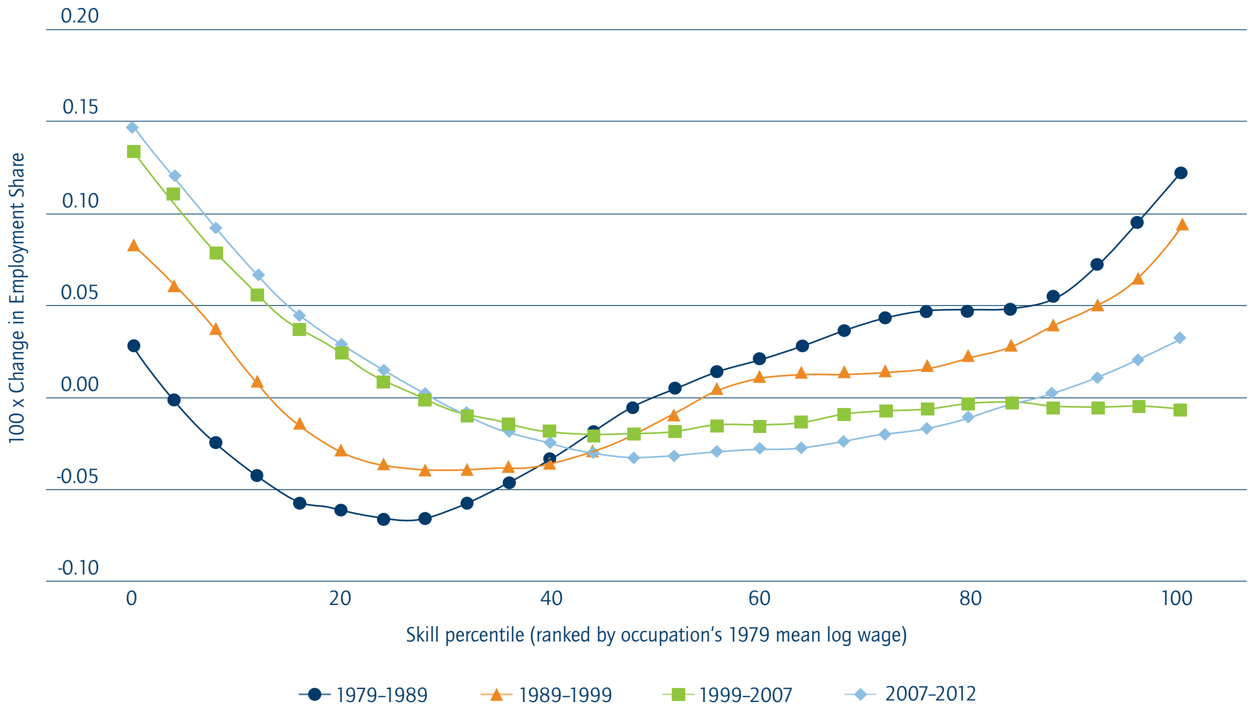



Figure 4: Smoothed employment changes by occupational skill percentile, 1979–2012
(Source: own presentation based on Autor 2015, p. 20)

Data: Autor (2015) calculated using 1980, 1990, and 2000 Census Integrated Public Use Microdata Series (IPUMS).
Autor defined "skill percentile" as follows: The figure plots by "skill percentile" rank using a locally weighted smoothing regression (bandwidth 0.8 with 100 observations), where "skill percentiles" are measured as the employment-weighted percentile rank of an occupation's mean log wage in the Census IPUMS 1980 5 percent extract. The sample includes the working-age (15–64) civilian non-institutionalized population with 48+ annual weeks worked and 35+ usual weekly hours. Weekly wages are calculated as annual earnings divided by weeks worked. And in the following, we use "low skill" or "inexperienced" to mean that the skill percentile is low, and so on.

In the United States, employees with middle-skilled occupations are replaced by computers due to ICT investment. The threat of employment loss is moving toward higher-skilled positions.

As the number of inexperienced workers continues to grow, ICT investments will increase the speed of substitution.. The number of highly skilled workers will continue to increase, but at a lower rate. It is possible to analyze this as follows: As technology progresses, the demand by companies for highly skilled workers grows rapidly, but the supply of highly skilled workers in the labor market to fulfill these companies' needs declines. When fewer highly skilled workers are available, wages increase. Most middle-skilled workers who lose their jobs transfer to lower-skilled jobs. The total number of lower-skilled jobs, however, remains constant, and as a result, wages continue to stay at a low level and employment status becomes unstable.

Autor also explains that "automation also complements labor, raises output in the ways that lead to higher demand for labor and interacts with adjustments in the labor supply"[26]. He argues that the polarization of the labor market is "unlikely to continue very far into the foreseeable future"[27].

26 | See Autor 2015, p. 5.
27 | See Autor 2015, p. 5.

## Case study in Germany: "The Future of Employment"

Frey and Osborne (2013) derive in their well-known study "The Future of Employment" that routine tasks will be substituted in the United States.[28] Moreover, they estimate that 47% of the total US employment is already in the risk category of >70%, which means potential automation in the next decade(s).[29] Two aspects should be noted in the results from Frey and Osborne: The first is to show the technical possibility. For example, if automatic driving technology is available, it would take decades until all professional drivers in the United States could be substituted. Nevertheless, these cases were counted as a possibility for substitution by machine. The second aspect is that new employment by new industries was not considered. Frey and Osborne's estimate extends to a practical number based on a calculation of workers who are presently employed and who may lose their jobs in the future. They did not include the number of new positions that will be created by new future industries.

Once the Frey and Osborne estimate was published, The Ministry of Labor and Social Affairs of the German Government started "Arbeit 4.0", or "Work 4.0". The ministry commissioned the ZEW – Leibniz Centre for European Economic Research to perform the analysis. Their paper indicated that the risk in Germany was 12% as of June 2015.[30] However, for the United States their indication was 9% compared to the 47% from Frey and Osborne. The reason for this variance was different estimation methods.

ZEW differentiates between jobs and tasks, whereby jobs are broken into a series of tasks. They assume that the portion of tasks performed by a machine will gradually increase, and that in the end a single human job may be replaced by machine. The estimation by Frey and Osborne differed because they presumed that a single human job will be substituted by a machine in a single stage, which is considered an overestimation.

As for the process of substitution of humans by machines, the Fraunhofer Institute for Industrial Engineering IAO (Fraunhofer IAO) conducted detailed research and analysis. Fraunhofer IAO first surveyed various German companies, but could not find consistency. Second, when Fraunhofer IAO surveyed trends of German companies, they found consistency as follows:

1. Machines are used to support humans.

2. Humans will make efforts to increase their skills with companies providing skill training to employees. However, as the progression of technology is rapid, several companies will substitute humans with machines in order to cut costs.

3. In the last stage, both humans and companies will cease making efforts to increase human skills.

## Case study in Japan: The future of employment

A phenomenon already happening is a separation of a series of tasks into those performed by a machine and those performed by a human. As separation progresses, the human receives tasks that must be done by a human. These tasks are generally very detailed, delicate, non-routine, and creative. Humans are therefore required to have higher skills. For several years, AI engineers have been developing technologies to carry out artistic, cultural, and sensitive activities, which were thought to be an output of human creativeness. But by monitoring these activities carefully, it was found that they contain many routine (cognitive and manual) tasks.

As technology has progressed, machines have been able to take on the routine (manual) tasks, physical strain, and hard labor that had once been the purview of humans. This is the history of technology and it will continue in the future. To prepare for these changes, humans must train by themselves during their entire lifetime.

After many interviews with Japanese companies, Senior Researcher K. Iwamoto from the Research Institute of Economy, Trade and Industry (RIETI) has formulated the following hypothesis regarding the process of substitution of humans by machines:

1. In the first stage, hard labor disliked by humans is substituted by machines. The aim of introducing machines is to support humans, who are then motivated to create further machines.

2. As more machines are introduced, humans are required to perform more highly skilled work, and companies promote investments in human resource development.

3. The rate of machines introduction increases; managers start to replace humans and layoffs commence.

4. Ultimately, all humans are replaced by machines.

28 | See Frey/Osborne 2013, Hirsch-Kreinsen 2018, p. 17.
29 | See Ittermann/Niehaus 2018, p. 43.
30 | See Bonin et al. 2015.

In a global perspective, according to estimates from McKinsey Global Institute (2017), 400–800 million jobs will be automated, and 75 million to 375 million workers (3 to 14 percent of the global workforce) will have to retrain or learn to do new jobs or acquire a new skill by 2030.[31]

The hypothesis from RIETI and the research results from Fraunhofer IAO both establish a similar process of machines replacing humans in Japan and Germany, respectively.

– – –

Overall, the research and analysis of future employment was based on three points:

1. As technology progresses, even more highly skilled routine cognitive tasks will be replaced by machines.

2. The number of low-skilled workers will continue to increase. If they are not able to skill up as quickly as machines' abilities increase, it is likely that they will be replaced by machines. Therefore, we have to design harmonized systems for humans and machines in which machines support inexperienced workers to keep pace in improving their skills. This will lead to a situation where humans develop alongside machines.

3. The number of highly skilled workers will continue to increase, as will companies' demand for highly skilled workers. If demand exceeds the supply of skilled workers, wage gaps will continue to increase.

## 3.2 Estimation of changes in labor structure due to digital transformation

Measurements of the rate of routine tasks are conducted by experts in countries around the world. De la Rica and Gortazar (2016) published the results of routine task intensity (RTI) of OECD countries.[32]

The RTI is defined as:

$$RTI_i = R_i - A_i - M_i$$

(Where $R_i$; $A_i$; $M_i$ correspond to the Routine (cognitive and manual routine), Abstract (cognitive and interpersonal non-routine), and Manual (non-routine manual) tasks indexes, respectively.[33]) RTI characterizes the countries' stages in the de-routinization process. The United States, for example, represents a highly de-routinized country (RTI=-0.39). Germany (RTI=-0.12), similar to other central European countries, is characterized as a medium de-routinized country. Japan (RTI=0.26), however, is positioned in the group of so-called low de-routinized countries.[34]

The most serious problem is how to deal with low-skilled workers who either are unwilling or unable to skill up, even after a series of retraining and relearning. Germany, as well as Japan, is looking for socially acceptable approaches to solving the problem.

### Case study in Germany: Potential substitution of parts of the human workforce

The assumptions of the potential substitution of parts of the human workforce have also been taken up in macroeconomic labor market studies for Europe, concluding that employment will decrease, since short-term compensation through novel activities wouldn't be feasible.[35]

Similar results can be found in the German context.[36] The risk of substitution generally falls when a higher knowledge level is required to complete a task.[37] Figure 5 shows which requirement levels of human work are most likely to be substituted by technical systems.[38] Between 2013 and 2016, the gap between the high and low requirement levels had become even larger.

Various studies also anticipate – at least from a short-term perspective – a potential risk of substitution for qualified, non-routinized jobs characterized by a high level of creativity and interaction. These jobs are not only on the shop-floor in the industrial sector, but also in administration, development, and management.[39] There are even scenarios that forecast a

31 | See McKinsey Global Institute 2017, p. VI.
32 | De La Rica/Gortazar 2016.
33 | De La Rica/Gortazar 2016, p. 7ff.
34 | De La Rica/Gortazar 2016, p. 10.
35 | See Ittermann/Niehaus 2018, p. 43, Bowles 2014.
36 | See Dengler/Matthes 2018.
37 | See Dengler/Matthes 2018, p. 1.
38 | The requirement levels are defined as follows Unskilled: Helpers with no vocational training or one-year vocational training; Skilled: Professionals with at least two years of vocational training or a professional qualification at a vocational school or college; Specialists: Master or technician education or advanced technical school/bachelor's degree; Experts: University degree of at least four years (Dengler/Matthes 2018, p. 5).
39 | See Hirsch-Kreinsen 2018, p. 17.

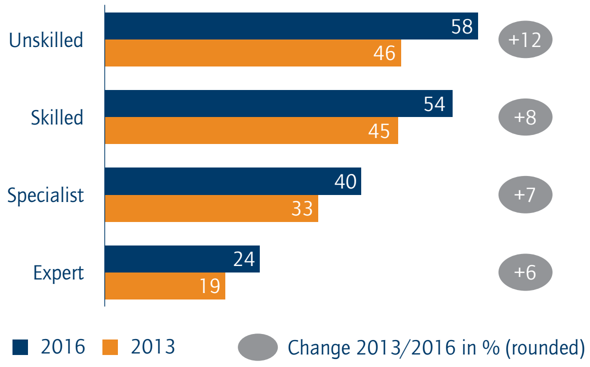



Figure 5: Substitution potential by requirement level in %, 2013–2016 (Germany) (Source: own presentation based on Dengler/Matthes 2018, p. 1)

potential decrease of nearly 60% of employment (mostly routine jobs) in Germany.[40] For an overview of estimated substitution potential by segment, see Figure 6. Again, it can also be seen that not only manufacturing processes in Industrie 4.0 are effected, but also the service sector.[41]

The digital transformation will enable companies to react faster and more precisely to changing customer needs and new market conditions. It is already well understood that a fast implementation of data-based business models and a high level of flexibility, adaptability, and willingness to change among organizations and its employees are crucial for success in the face of global competition.[42] Key factors in the successful introduction of Industrie 4.0 include the acceptance of new technologies by employees and the design of attractive forms of work.[43]

At the same time, the higher degree of flexibility, in turn, opens up the chance for workers to also achieve a higher level of work-life balance and to safeguard their long-term employability by personalized re- and up-skilling measures. In this context, the ability of workers to learn (and retrain) throughout the span of their careers is key to ensuring their future employability (lifelong learning). Companies share the responsibility by providing the corresponding education and training, and their employees obviously benefit from these measures.[44]

The phenomenon that not only routine jobs and tasks that require minimal qualifications potentially bear the risk of replacement is evident in the following Japanese case study, which refers to the application of AI in the Japanese health care sector.

## Case study in Japan: AI applied to health care

This case study in the 9th Academic Promotion Council Report by Japan Medical Association Academic Promotion Council describes the application of AI in hospitals.[45] AI "learns" treatment results from all over the world and advises doctors on the treatment of their patients. AI plays an "advice-giving" role for humans, whereby humans are responsible for the final assessment.

The report stated that Japan, which has an unprecedented aging population, may contribute to the world by pioneering cutting-edge medical care using AI. A further report shows that the misdiagnosis rate has decreased by 85% due to cooperation between doctors and AI. In the 2016 metastatic breast cancer diagnosis challenge (Camelyon Grand Challenge), the misdiagnosis rate of AI was 7.5% and the misdiagnosis rate of pathologists was 3.5%. Furthermore, with the cooperation of AI and pathologists, the misdiagnosis rate decreased to 0.5%.

The report also explained that "even if individual AI technology is developed, it should not be put to practical use unless the effectiveness and safety of AI are sufficiently secured. In particular, the health care field is related to human life, and ensuring effectiveness and safety is extremely important. And no matter how skillful [AI] is, the presence of a doctor will continue to be necessary. But what doctors do may vary greatly"[46]. In the report, Prof. Tsumoto of Shimane University noted that when AI supports a health care business, the business itself changes.

The same can be said for factories in which AI provides "advice", with the final assessment being made by humans. This type of scenario could establish a good relationship between AI and humans.

When the above-mentioned AI or robots replace the even "more skilled routine cognitive tasks" performed by humans, economic disparities in society will grow. That will give way to the phenomenon in which the total number of employees in the low-skilled, low-wage labor market increases, wages stagnate, and employment

40 See Ittermann/Niehaus 2018, p. 43, Brzeski/Burk 2015, p. 3.
41 See Allianz Industrie 4.0 Baden-Württemberg 2017.
42 See Jacobs et al. 2017, p. 9, Lanza et al. 2018.
43 See Abel et al. 2019.
44 See Jacobs et al. 2017, p. 9.
45 See JMA 2018.
46 See JMA 2018, p. 38.

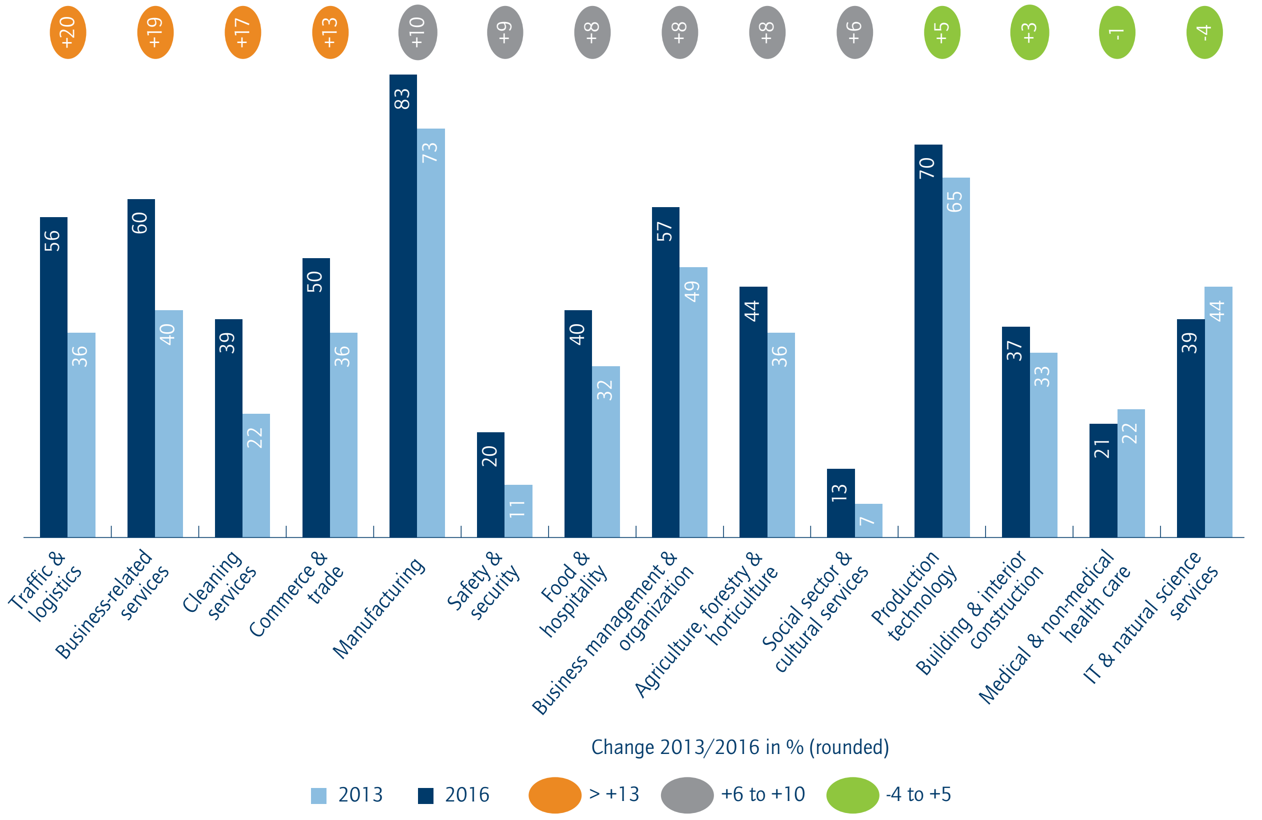



Figure 6: Substitution potential by occupational segment in %, 2013–2016 (Germany)
(Source: own presentation based on Dengler/Matthes 2018, p. 6)

becomes unstable. This happens when jobs for medium-skilled employees are lost, and they fall into lower-skilled positions, although the total amount of low-skilled jobs remains unchanged. The number of employees in occupations that require low skills has been rising continuously, as well as accelerating.

## Case study in Japan: Potential substitution of parts of the human workforce

As for Japan, the Cabinet Office of the Japanese Government published an Economic and Financial White Paper in 2018 that included the results from a corporate survey held in February 2018. According to the paper, jobs are expected to increase or decrease with the introduction of IoT (Internet of Things) and AI (Figure 7).

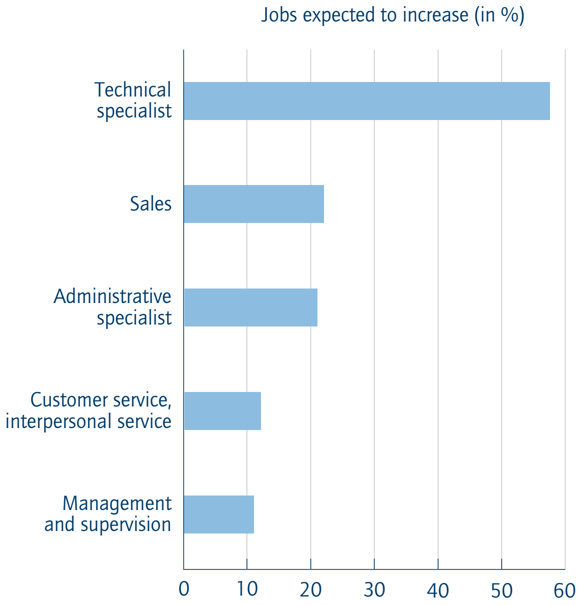
Occupations that companies expect to be replaced by AI are shown in Figure 8. With the progression of IoT and AI, managers of Japanese companies anticipate having to reduce skilled workers in factories, second to office clerks.

According to Gini coefficient of Japan,[47] the time-change for economic disparity has been relatively small until now in the trend of developed countries. But as the era of full dissemination of RPA (Robotic Process Automation) arrives, there is a possibility that the economic disparity will expand at once.

## Case study in Japan: Required skill change in office workers

Currently, the replacement of routine cognitive tasks with RPA is in progress in the administrative functions at Japanese companies. In particular, the banking and finance industry is the most heavily impacted. According to recent press announcements by three megabanks, ICT investments are expected to lead to the reduction of about 30,000 positions. Those who perform routine cognitive tasks are primarily regular and non-regular employees holding clerical jobs. As RPA progresses, Japanese companies will presumably protect regular employees through personnel re-alignments, where as non-regular employees will be dismissed.

47 | See METI 2017.



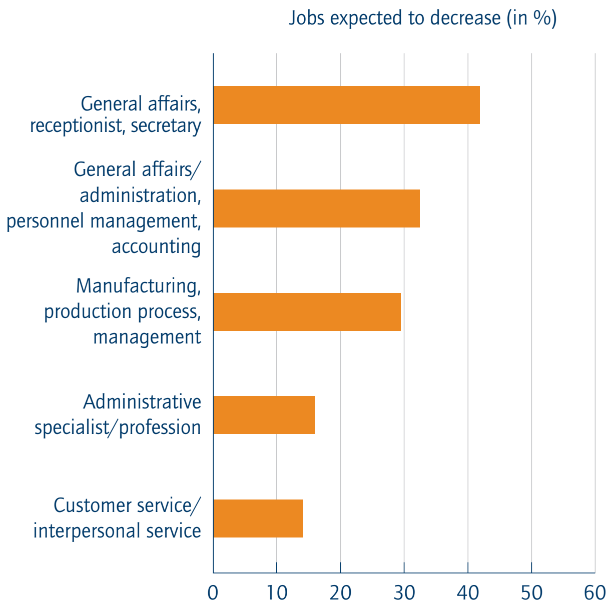




Figure 7: Expected increase and decrease in professions with the progression of AI and IoT implementation (Source: own presentation based on Cabinet Office 2018, p. 141)

*Administrative professions refer to survey analysis or legal, etc. Technical specialist refers to research and development, system design, etc. As for administrative specialist/profession and customer service/interpersonal service, companies expect both increases and decreases. Therefore, the categories appear in both charts.

A look at hiring statistics for new graduates in the spring of 2019 shows that banks have greatly reduced the recruitment of regular employees for clerical jobs.

In addition to the banking and finance industry, local governments are also active in implementing RPA. They have many routine cognitive tasks that deal with prescribed forms, many of which could be replaced by RPA. Local governments have strong needs to cut employment wages due to budget shortfalls.

RPA is now extending to manufacturing companies in Japan. An example is Nitto Denki, a manufacturer of switchboards with 150 employees. RPA has been introduced into the process of printing design drawings – a task previously performed by design engineers – thereby cutting printing time by 20 hours per month.[48] This example shows that even in manufacturing companies, some routine office work processes can be replaced by RPA.

Thus, in Japan, the banking and finance industry and the local governments are now leading in the implementation of RPA. Eventually, this development will expand to manufacturing and other industries. Higher-skilled routine cognitive office work is about to be replaced by computers. These employees are expected to enter the labor market looking for unskilled low-wage jobs just to make a living. In this low-skilled, low-wage labor market, unemployed Japanese workers will be competing against resident foreign workers for job opportunities.

## Case study in Germany: Required skill change in shop-floor workers

Autonomous systems potentially relieve human operators in certain areas, such as in monotonous daily job scheduling operations. Yet at the same time, the volume of complex tasks is increasing. Consequently, people have displayed a high willingness to acquire new skills in order to keep pace with the changed requirements, e.g., via various assistive systems or further qualification programs and concepts. All employees involved in the production process must increasingly adopt interdisciplinary forms of work. This is due to the fact that cooperation is required, especially with IT. Moreover, it is obvious that demand is likely to shift from foremen to IT specialists.[49]

In the past, nearly every technological development or progression was accompanied by new skills needs. In the context of the digital transformation, Industrie 4.0, and new forms of HMI, companies are particularly challenged by the fact that these

48 | See Iwamoto 2018.
49 | See BMWi/BMAS 2016, p. 14.

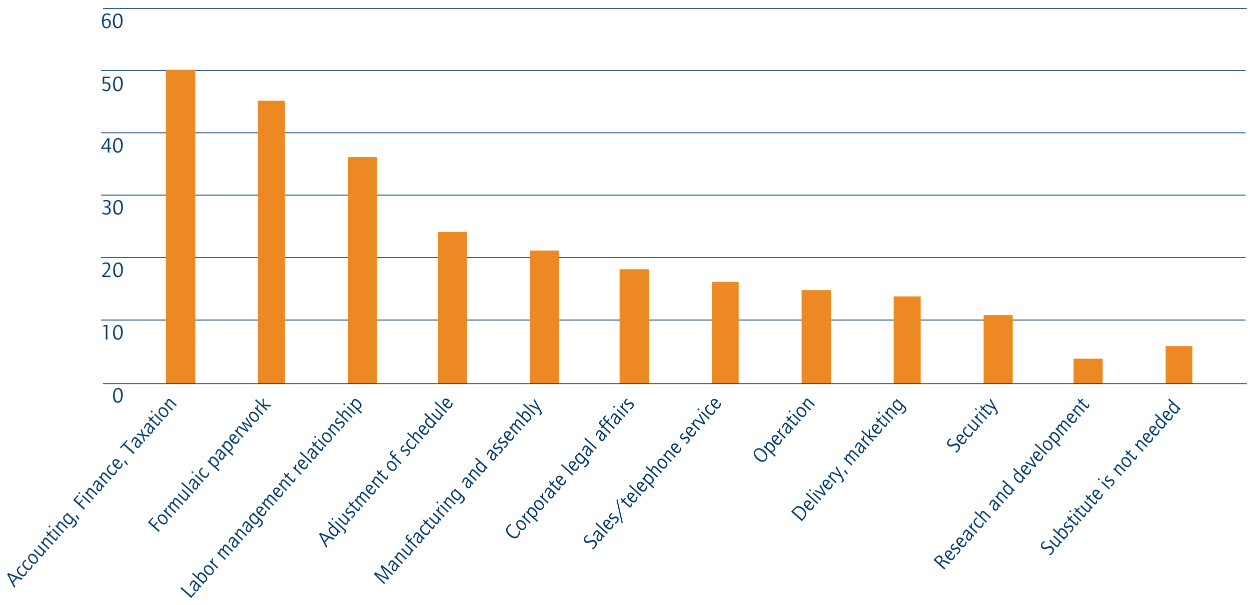



Figure 8:. Occupations likely to be replaced by AI (in %) (Source: own presentation based on Cabinet Office 2018, p. 142)

requirements are now changing at an accelerated rate. Additionally, almost all activities are affected.[50] As a consequence of the short innovation cycles and the changing requirements, tailored employee training activities are necessary. Therefore, a comprehensive analysis of the skills an individual worker or employee possesses is crucial. In a second step, necessary skills have to be identified. All learning measurements with respect to qualifications and education should be modified in order to guarantee systematic and individually tailored professional development methods that both meet the needs of the individual worker and the whole company.[51] While conceptualizing an adequate (re-) qualification and learning strategy, the potential diversity (especially between younger and older people) has to be considered.[52] In terms of technology-related skills, developing abilities for IT, and in particular AI, is a necessity.[53] This insight, however, has so far not been completely acknowledged across the German economy and in the workforce. While the spread of the term "Industrie 4.0" draws increasing attention to digitalization, there are still companies that are failing to grasp the need for action when it comes to fostering development in terms of skills and qualifications. Therefore, fast and well-founded training and retraining is crucial for a successful transformation into deployment, employability, and "good work".[54]

In order to enable and provide the workforce with greater qualifications (and also students as a future workforce), various strategies and measures can be undertaken (e.g., seminars, workshops, business games, and practice-related case studies). Moreover, during the last years, a promising approach has been developed called learning factory[55]. Especially in Europe, a variety of different learning factories has been established with specific forms, focuses, and purposes. However, a common element among all learning factories is hands-on qualification, which combines theory and practice.[56] A key advantage of learning factories, as opposed to real production environments, is that certain training and demonstration activities can be carried out without the risk of potential production downtime. Recently, more and more learning factories and labs have been focusing on Industrie 4.0-related topics. The approaches, however, mostly fail to combine both learning aspects of humans and machines.[57]

50 See Jacobs et al. 2018, p.27.
51 See Jacobs et al. 2017, p. 9.
52 See Majkovic et al. 2018.
53 See also PLS 2019.
54 See Jacobs et al. 2018, p.27.
55 See Schallock et al. 2018, p. 28, see also the "Case study in Germany: Learning Factory" in Chapter 5.
56 See Schallock et al. 2018, Elbestawi et al. 2018.
57 See Ansari et al. 2018a, Schallock et al. 2018.

## Case study in Japan: Required skill change in shop-floor workers

In Japan, there is a history of cherishing skilled shop-floor workers in factories. The new digital technologies now being introduced to the factories aren't replacing human work with computers; instead, these technologies make the best use of these skilled workers. When IoT is introduced, the workers acquire the new skill while receiving little training, so the problem of re-education or retraining of shop-floor workers has not become obvious in Japan. Rather, the focus is on the introduction of AI in a few years. The new digital technologies now being introduced to the factories in Japan are a "visualized" system, meaning that skilled workers are still responsible for looking at the displayed visualized data, exploring the cause of the failure of production machines, and devising countermeasures. However, in the near future the aspects of operations based on precedent (such as learning the precedent) and judging measures from the displayed data will be taken care of by AI.

In Japan, only a few large manufacturers are fully introducing new technologies to their factories and improving their output. According to Fujitsu executives[58], the emphasis is on "empowering humans" with new digital technology, which reduces the burden on employees. Furthermore, the company's IoT system compensates for the lack of shop-floor workers and their declining skills due to aging, and at the same time it supports workers with the rise in many various and small-volume products. Mitsubishi Electric's executives say that in the 1990s investments were focused on mechanization,[59] automation, and labor-saving measures. But now the focus is to replace jobs suitable for machines with machines, and to maintain other jobs suitable for humans, which is said to engender "harmony between humans and machines". The executives of DENSO,[60] a Toyota supplier, stress that "the concept for the IoT system of DENSO is human-centered". DENSO positions the skilled workers as a company asset to create competitiveness. It is worth pointing out that visualization by digital technology alone is insufficient for the skilled worker to provide sufficient performance on the shop-floor. And they state that it's important to actually measure shortcomings in production equipment and to formalize how the shortcomings can be solved by skilled workers. Both Mitsubishi Electric's e-F@ctory and Hitachi's Lumada,[61] which are representative IoT platforms in Japan, are designed on the same idea. In addition, the executives of Nippon Steel Co. emphasize[62] that they "continue to invest in [areas] where the number of skilled workers is rapidly decreasing in factories and it is difficult to ensure manufacturing quality". As can be seen from these cases, maintaining and expanding human capabilities is one of the main targets of digital investment in Japanese companies.

RIETI conducted a survey from August to October 2017 targeting 10,075 Japanese companies to understand the trend of IoT in Japanese industry; responses were collected from 1,372 companies for a recovery rate of 13.62%.[63] Through the introduction of new digital technologies, 34 companies replied that the number of employees is "decreasing", and 43 companies answered that it is "increasing". Technical experts, such as data engineers, are needed to operate new digital systems. The survey revealed an increasing need for technical experts as well as for administrators who manage them and office clerks who support them. Meanwhile, in the administrative divisions of the banking and finance industry and others, computerization of routine cognitive tasks is ongoing, leading to a continuous reduction in clerical office workers. A comparison of the present increases and decreases shows that the increases are greater than the decreases. It can be deduced that Japanese companies are more eager to digitalize factories than offices. In any case, going forward the trend needs to be monitored carefully.

58 | See Iwamoto 2018.
59 | See Iwamoto 2018.
60 | See Iwamoto 2018.
61 | See https://www.mitsubishielectric.co.jp/fa/sols/ and https://www.hitachi.co.jp/products/it/lumada/index.html.
62 | See Iwamoto 2018.
63 | See Iwamoto/Tanoue 2018.

### Case study in Germany: A positive scenario in contrast to the previous discussions

In Germany, there is a scenario that the substitution potential cannot be equated immediately with the probability of occurrence. In addition, the current implementation of modern technologies or Industrie 4.0 solutions and automated projects in the area of HMI shows that today's activities cannot be fully automated at reasonable costs.[64] The pessimistic view focuses on potential substitution effects in the human workforce and a devaluation of industrial work; the optimistic view highlights the potential aspects or consequences of the implementation of modern technologies and Industrie 4.0 systems, e.g., by referring to improvements in competitiveness, quality of life, work-life balance, etc.[65]

Therefore, in the context of this optimistic scenario, positive labor market effects are expected. This is forecasted, for example, in a study by the Boston Consulting Group that assumes employment growth of 6% in Germany within the next ten years. The positive effects are primarily based on the increasing demand for highly qualified industrial workers in mechanical engineering, the automotive sector, and electrical engineering.[66] A rather moderate technological change in the industry and the successive enrichment of work and production processes by new technologies is often regarded as a basis for this development.[67] Moreover, it is argued that even low-skilled workers will still be needed, and that nearly all kinds of routine work entail non-routine elements like experience-based knowledge that is hard to substitute with technical systems.[68] In addition, a general overestimation of technological potential and implications was stated, which in turn leads to potentially misleading conclusions as described in the pessimistic and optimistic scenarios.[69]

The optimistic scenario also features a new perspective on interactions between humans and machines, as well as on the related distribution of control and/or responsibility of the technical and personal systems. As orchestrators of technical systems, highly qualified and skilled people are in the center of the industrial production system. In case of problems or a breakdown, they are able to intervene, drawing on their past experience. All in all, qualified workers are supposed to be fully in control over the entire work and production processes. If necessary, technical assistance systems provide flexible and adequate support.[70]

As a result of changes in interactions between humans and technology brought on by novel forms of communication and collaboration, it is necessary to restructure work. Furthermore, lifelong learning needs to be implemented so that employees have the skills required to control the also changing CPS. Such assistance systems are a prerequisite to maintaining and continuously improving the physical and mental performance capabilities of humans.[71]

Today, it is generally accepted that a person's individual productivity does not primarily depend on the chronological but on the biological age. In particular, assistance systems allow machines interacting with workers to make work less strenuous.[72] Together with activities involving work design and initiatives for competency development, interactive collaboration between humans on one side and technological systems on the other create new opportunities for companies to benefit from demographic changes. In times of a shortage of skilled workers and an increasing diversity of employees (age, gender, cultural background), Industrie 4.0 enables diverse and flexible career models and thus sustainable productivity.[73]

In conclusion, the positive scenario is also supported by forecasts suggesting an upgrade in activities and qualifications. According to Ittermann/Niehaus (2018, p. 40), upgrading can be understood as a process of enriching activities and abilities that tends to affect all groups of employees.

64 | See Allianz Industrie 4.0 Baden-Württemberg 2017.
65 | See Ittermann/Niehaus 2018, p. 39f.
66 | See Ittermann/Niehaus 2018, p. 39f., BCG 2015.
67 | See Ittermann/Niehaus 2018, p. 40., Vogler et al. 2016.
68 | See Pfeiffer/Suphan 2015, See Ittermann/Niehaus 2018, p. 53.
69 | See Hirsch-Kreinsen 2018, p. 17.
70 | See Ittermann/Niehaus 2018, p. 41f.
71 | See Becker 2015, p. 25.
72 | See Becker 2015, p. 26.
73 | See acatech 2016, p. 16.

## Case study in Germany: Hybrid teams of humans, robots, and virtual agents in a production setting[74]

[Concept video available from below link; https://robotik.dfki-bremen.de/de/mediathek/videoarchiv/hysociatea-aus-gewaeh.html]

In Germany, the project *Hybrid Social Teams for Long-Term Collaboration in Cyber-physical Environments (HySociaTea)* demonstrates that – in contrast to any risks of substitution – recent developments in HMI are enabling new forms of cooperation in hybrid teams. In this project, funded by the German Federal Ministry of Education and Research (BMBF), specialists at the German Research Center for Artificial Intelligence (DFKI GmbH) aim to realize and examine the collaboration of humans with autonomous robots, virtual characters, and SoftBots to work out common tasks and to meet future production requirements characterized by a high degree of complexity and flexibility.

Not only the technical feasibility is analyzed, but also the development of (robotic) team competencies and intelligent multi-agent behavior. By proactively assisting workers in the production process, they are seen as partners without being directly instructed. This, in turn, has important implications on (future) decisions for team organization and configuration.

Characterized by the high level of cognitive abilities and flexibility, humans are at the center of the hybrid teams, while robots are responsible for the physically demanding tasks. The digitally available information, moreover, is provided on an interface of the virtual agents. The SoftBots[75] aggregate the data that is produced by the other team members, update databases, and provide meaningful, refined data.

74 | This case study is described in Schwartz et al. 2016.
75 | SoftBots can be defined as purely software-based agents or computer programs that can act autonomously in virtual worlds.

# 4 Emerging gap due to diversity and policies that promote sustainable innovations

This chapter discusses the anticipated increase in the diversity of workers and machines in the near future, and advocates for policies that promote sustainable innovations across the life cycle of products and services.

## 4.1 Emerging gap due to diversity

Since the industrial revolution, companies have striven to standardize production in order to achieve high production volumes at high speeds. However, standardization has reached its limits. The declining population has led to a diverse workforce with varied capabilities in the manufacturing sector. In addition, old machine tools are being used alongside AI robots (Figure 9).

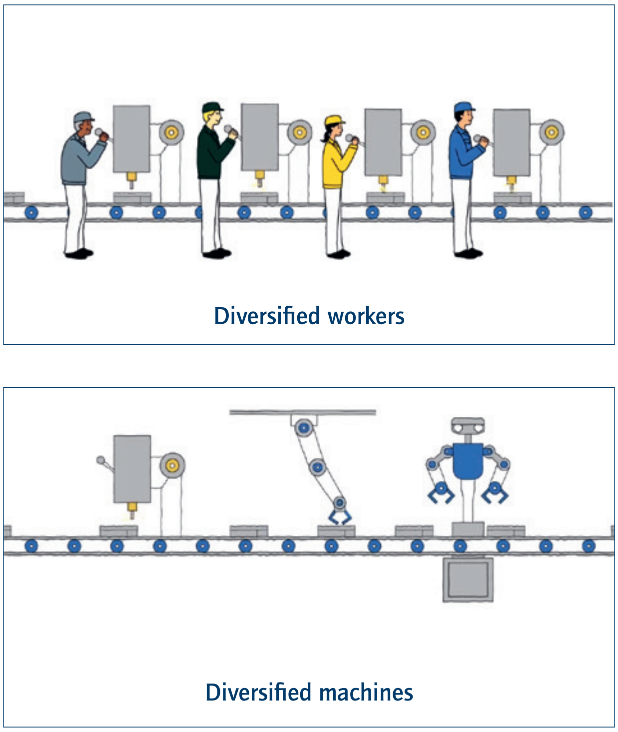



Figure 9: Possible changes on workers and machines in factories (Source: Hitachi Brand Channel 2019)

These developments have caused imbalances in tasks and the actual capabilities of workers and machines, which may lead to a loss of business opportunities.

In Japan, the declining population has been boosting workforce diversity, bringing more women, older people, and non-Japanese people into the employment market (see Table 3). At the same time, the advancement of automation that is currently taking place in the manufacturing sector is transforming job profiles and the way humans and machines interact at the workplace.

Additionally, many companies have been extending the life of their facilities annually. Especially, after 1990, the average life of a manufacturing facility was increased to over 16 years, as shown in Table 4.

Germany has also been facing several social and technical challenges, which have led to changes in employment as illustrated in Table 5. Furthermore, companies have been compelled to

| | Trends of the times | | |
|---|---|---|---|
| Employment ratio of women<br>(range of age: 25 to 44 years) | 61 [%]<br>(2000) | 66 [%]<br>(2010)<br>**+0.5 [%]/year** | 72.7 [%]<br>(2016)<br>**+1.1 [%]/year** |
| Employment ratio of older people<br>(range of age: 65 to 69 years) | 36.2 [%]<br>(2000) | 36.4 [%]<br>(2010)<br>**+0.02 [%]/year** | 44.3 [%]<br>(2017)<br>**+1.1 [%]/year** |
| Number of non-Japanese employees | 486k<br>(2008) | 718k<br>(2013)<br>**+50k/year** | 1279k<br>(2017)<br>**+140k/year** |

Table 3: Employment trends in Japan (Source: own presentation based on MIC 2019b, MHLW 2019)

| | Trends of the times | | |
|---|---|---|---|
| Average lifetime | 8 [years]<br>(1971) | 10 [years]<br>(1991)<br>**+2 [years]** | 16 [years]<br>(2016)<br>**+ 6 [years]** |

Table 4: Trends on the average lifetime of facilities in Japan (Source: own presentation based on Hamagin Research Laboratory 2016)

consider groups that were previously underrepresented in the job place, including people with disabilities, people with a migration background, and older people who have an extensive knowledge base.

Moreover, there is a shortcoming of skilled workers in science, technology, engineering, and mathematics (STEM), as well as in nursing. But these trends have been ongoing for some time now, having started long before Industrie 4.0 was introduced. While job profiles and requirements may change, it does not mean that workers with necessary qualifications cannot be found and that today's vocational training is inadequate. However, it's important that workers stay on track with the changing skill demands. Because of the adaptivity and flexibility of the German vocational training system, only slight adjustments are necessary in the vocational profiles.[76]

In the context of HMI, it is necessary to focus not only on how humans or machines learn, but also on how they improve their skills by learning from one another. Today humans and machines follow distinct learning concepts. In the future, however, hybridization of learning concepts will be necessary to achieve mutual learning success.

| | Trends of the times | | |
|---|---|---|---|
| Employment ratio of women<br>(range of age: 20 to 64) | 60.8 [%]<br>(2000) | 69.7 [%]<br>(2010)<br>**+0.89 [%]/year** | 75.2 [%]<br>(2017)<br>**+0.79 [%]/year** |
| Employment ratio of older people<br>(range of age: 65 to 69) | 3.9 [%]<br>(2010) | 5.9 [%]<br>(2015)<br>**+0.40 [%]/year** | 7 [%]<br>(2017)<br>**+0.55 [%]/year** |
| Number of non-German employees | 2219k<br>(2012) | 2919k<br>(2015)<br>**+233k/year** | 3470k<br>(2017)<br>**+275k/year** |

Table 5: Employment trends in Germany
(Source: own presentation based on Eurostat 2019, Destatis 2018b, Federal Employment Agency 2018)

| | | | Human | Machine |
|---|---|---|---|---|
| **Capability** | **Quality variation in** | **Mechanical job** | ▪ High inter-individual differences and diversities<br>▪ It can be improved by training and job satisfaction | ▪ Very low<br>▪ It can be degraded over time due to inappropriate maintenance |
| | | **Decision-making** | ▪ High inter-individual differences and diversities depending on problem-solving abilities, competences, experiences, and qualification level<br>▪ Personal, societal, and institutional interests may influence human decision-making<br>▪ The complexity and sensitivity (risk) of the decision may affect it | ▪ Low to high depending on the quality of data (affected by disturbances and noises), preciseness of algorithms, degree of preparation by humans, and complexity of the problem field<br>▪ Quality can be improved after training the system with (relatively large) datasets |
| | **Performance variation in** | **Carrying out a task** | ▪ Relatively high (depending on individual capacity, motivation, and commitment)<br>▪ High possibility of work fatigue and job dissatisfaction | ▪ Very low (depending on the lifetime, associated degradation rate, and service quality) |

Table 6: Comparing capabilities of humans and machines, based on quality and performance variation
(Source: own presentation based on Ansari et al, 2018a, p. 119)

76 | See Pfeiffer et al. 2016.

Ansari et al. 2018a define mutual learning as "a bidirectional process involving reciprocal exchange, dependence, action or influence within human and machine collaboration, which results in creating [a] new meaning or concept, enriching the existing ones[,] or improving skills and abilities in association with each group of learners"[77].

This is affected by different capabilities of humans and machines in performing different tasks as shown in Table 6.

The learning process may either be independent (distinct training for each group) or dependent (co-occurrence of learning by executing a common task). At present, there is a strong tendency to favor distinct training and a lack of exploration into co-occurrence of human-machine learning.

### Case study in Japan: Learned nonuse phenomenon in manufacturing

In the future, AI robot technology will be increasingly introduced into manufacturing systems in order to obtain high performance to produce high-quality goods at a low cost. But to what extent will AI robot technology influence humans in the long term? Taking the easy way of introducing AI robot technology may have a negative effect on the proficiency of humans. This could occur because humans might grow accustomed to a situation in that they do not need to employ any skills in the manufacturing process. We need to consider the possibility of this emerging vicious cycle of AI robot technology and a corresponding decline in human skills (left cycle in Figure 10).

In the field of brain science, substantial neurological injury usually leads to a vicious downward spiral that results in "learned nonuse" of the affected extremity.[78] Similar discussion has been conducted for the relationship between automation and humans.[79].

As for the methodology to overcome the learned nonuse phenomenon, in brain science and rehabilitation medicine constraint-induced movement therapy (CI therapy) has been proposed. Here, training procedures can be used to reward patients systematically for using the affected limb for a period of consecutive weeks.

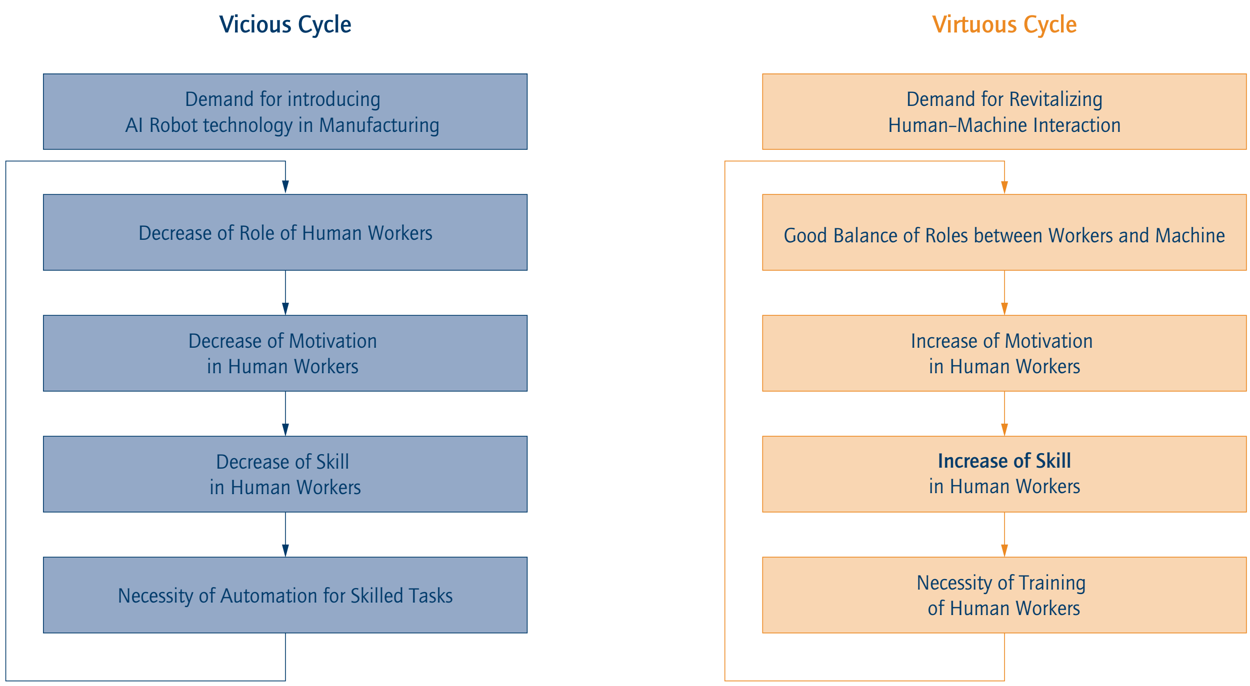



Figure 10: Vicious and virtuous cycles in humans and AI robot systems (Source: own presentation based on The University of Tokyo)

77 Ansari et al. 2018a, p. 119.
78 See Taub et al. 2002.
79 See for example Carr 2014.

In addition, use of the uninvolved limb can be restricted, so much so that the subject is rendered virtually helpless unless he/she tries to use the affected limb. A similar approach might be possible for manufacturing sites. So that humans and AI robots work together in future manufacturing sites, two requirements need to be fulfilled:

1. The efficient achievement of tasks with the cooperation of humans and AI robots and

2. the enhancement of skills in human workers through training. One possibility is to construct a management system (could be based on AI) to implement a systematic harmonization of HMI that can arbitrate the two sides (right cycle in Figure 10).

## 4.2 Managing the real world and the cyber world

Especially in research and development (R&D), manufacturing companies are traditionally dominated by classical engineering roles, particularly mechanical and electrical engineering. In fact, mechanical and electrical engineering have been at the core of innovation activities in manufacturing since the 19th century and have made a big impact on industry as we know it today.

Nevertheless, over the past few decades, software has become an important driver for innovation in machinery and electric/electronic products. Software innovations have mainly occurred within embedded systems, physically confined to a single machine.

Meanwhile, the software industry has grown significantly over the last decades at an ever-increasing speed to become ever more present in various aspects of daily life and business processes.

Software itself is an abstract entity, and understanding its inner workings requires a higher level of abstraction than a problem in mechanical engineering. Increasing complexity and the addition of new software layers have given way to the field of software engineering, which has its own methods, tools, unique processes, and organizational procedures.

The emergence of Industrie 4.0 heralds in the connecting and merging of both worlds. This leads to a whole new arena of innovation in an overlapping world that leverages the methods and procedures of the cyber world as well as classical engineering know-how.

Manufacturing companies are now faced with methods like agile development, scrum development, and pair programming that are different than waterfall approaches and detailed engineering specifications. On top of that, organizational principles like teams of ten and flat hierarchies are typical for software companies, and manufacturing firms need to adopt these principles in order to be agile (and to be perceived by potential software talents). Given the traditional approaches and the long and highly successful history of manufacturing companies, making this adjustment is a huge challenge. But these changes won't go away; companies must actively address them in their workforce, organizational principles, and management procedures.

Software development itself is a desktop-based activity, confined to the virtual world of computers and servers. This opens up careers to people who have hitherto been excluded from the workforce to a large degree. We will give an example of this in the following chapter. Furthermore, the development of software embedded in machinery requires not only software skills, but also a deep understanding of the production machines in which the software is to be integrated. Therefore, skilled workers who have earned additional qualifications in software development are particularly valuable with their insights and decades of experience in machinery and production technology.

To sum it up, the real and cyber worlds merge with Industrie 4.0 to give way to a new domain of innovations where a new set of tools, methods, and principles are the foundation to success. However, these new tools have to be combined with existing processes, technological paths, and valuable manufacturing qualifications and experiences. Manufacturing companies must actively acquaint themselves with new challenges and adopt new technologies while employing their unique manufacturing expertise.

## 4.3 Sustainable innovations with diversity

Both Germany and Japan face a shortage of skilled workers and an aging workforce, leading to more diverse workforce structures in industry in regard to age, gender, and skills. To attract the most talented employees in a tight labor market, inclusive working environments will become an even more significant competitive differentiator and a driver of business success. Inclusiveness has proven to boost engagement and creativity among employees. Moreover, when employee structures reflect the societal strata of customers, their needs can be better understood and met. And after all, collaboration among colleagues with different points of view generates a greater mix of ideas, and that spurs innovation.

## Case study in Germany: SAP – Autism at Work

[Concept video available from below link; https://www.sap.com/corporate/en/company/diversity/differently-abled.html?source=social-atw-mailto&sharedId=9e6909ee-6a7c-0010-82c7-eda71af511fa]

This case study describes how an organizational culture based on diversity and inclusion appreciation at SAP, Europe's largest software company, has laid the foundation for integrating people with autism into the workforce. SAP's program can serve as an example for other companies on how to expand the talent pool. Furthermore, it prepares manufacturing companies for the type of employee structures they may find in software companies such as SAP – a key partner for the transformation to Industrie 4.0.

The software industry has been a sector exposed to fast-paced change and characterized by speedy growth rates from the very beginning, making talent acquisition a crucial factor for success. In this "war for talents", SAP was faced with the prospect of labor shortages in the ICT sector early on. The need of both addressing volatile market trends as well as obtaining talented employees motivated the company to create an inclusive and accessible work environment for a diverse workforce. Diversity in employees, offering a broad range of perspectives, is seen as an important source of innovation and an unquestioned necessity for dealing with complex technological challenges. What is more, as SAP software is used by a wide breadth of societies around the globe, the benefit of having the workforce reflect the diversity of customers with different abilities and needs was an additional business driver for the recruitment strategy.

This open mindset was a crucial precondition for launching the Autism at Work program, which integrates people with autism into the company's workforce. It allows the company to tap into a talent pool that has thus far remained largely unaddressed by the labor market.

The Autism at Work program was officially launched in 2013. As per Q2 2019, SAP has over 155 employees from 13 countries with autism working in 26 different roles. The retention rate is above 90%. The program was initiated through a local project at SAP India, where first experiences with people on autism spectrum were gathered. Their outstanding performance convinced the company of the superb contribution to software development that people with autism can make.

Autism is a neurological disorder that can create challenges with social, emotional, and communication skills. It is estimated that an approximate 1% of the global population is affected, while 90% of them are un- or underemployed. People with autism are often attentive to routines and sameness, and have difficulties adjusting to unfamiliar surroundings or changes in routine. But this is only one side of the medal, as SAP's own experiences with colleagues on the autism spectrum have shown. Creating an environment in which the needs of employees with autism are addressed helps bring out their unique strengths and skills, including among others:

- a meticulous attention to detail and pattern recognition,
- the ability to remain focused on a task for a prolonged duration of time,
- analytical and logical thinking,
- and the skill to detect irregularities.

Stable and open work conditions are an important prerequisite to make employees with autism feel welcome. This is achieved, among other things, with a set group of internal and external people at each program location who hire, on-board, support, and coach their colleagues with autism while at work. Although this requires investment, most colleagues quickly become independent in their new workplace, creating a true return on investment – not only for the company, but for society at large with saved social welfare costs and strengthened social cohesion. After all, stable structures are crucial for running the program in a sustainable and scalable way.

But necessary adjustments already start in the recruitment phase: Mainstream processes frequently look for people who have good communication skills and who are team players – categories that candidates with autism typically do not fulfill. For that reason, SAP has attuned its recruitment practices, focusing on the passions of candidates with autism and incorporating practical tasks in the interview process.

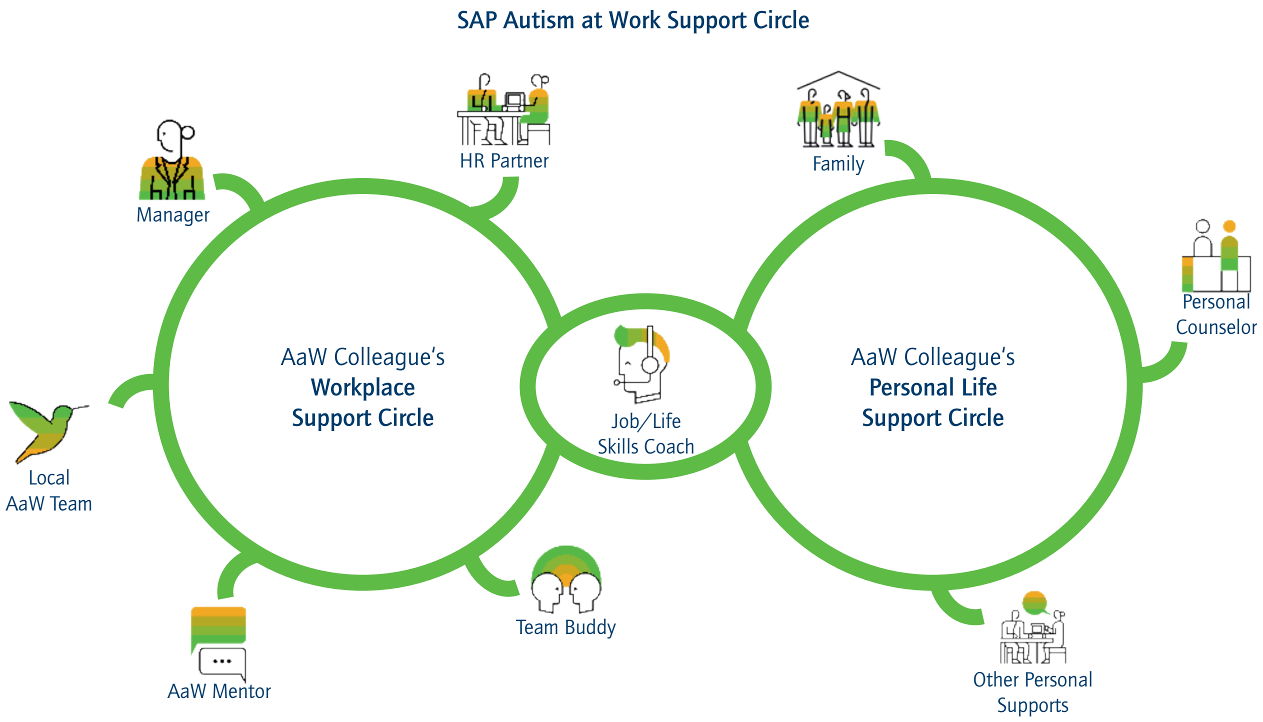



Figure 11: SAP's Autism at Work program (Source: SAP)

In order to help the program succeed, SAP has built a network of partners, including NGOs, research institutes, and government agencies, to support the company in reaching potential employees with autism. These stakeholders help identify possible candidates and advise the company on supporting colleagues with autism to integrate them smoothly. With the future stream of employees already in mind, SAP has also initiated cooperation with select high schools and universities to make students with autism aware of job opportunities at the company. Since many people with autism are used to being left out by conventional recruitment programs, it is essential that they are made aware of the fact that their skills are sought after.

– – –

Harmonizing interaction between a variety of humans and machines is more than just simply compensating for the lack of functions or synchronizing; it can also lead to attractive results by respecting individual characters and helping and enhancing one another.

To ensure sustainable economic growth, we must realize a world in which humans find fulfillment in their work while evolving hand in hand with machines. The corresponding transition for HMI is discussed by means of Figure 12.

The former model (left in Figure 12) is a traditional technology model, basically applied to humans, in which a master teaches a student. Scalability is a potential challenge due to the availability of appropriate masters.

## Case study in Japan: Technology traditions

In Japan, traditional crafts such as lacquer ware are still learned mainly through the apprenticeship system. The same applies to manufacturing processes, such as the brazing work required for a heat exchanger (the main component of an air conditioner). Soldering the thin copper tubes together is very difficult, and for skilled masters to train beginners efficiently has become a major issue.[80]

Today's manufacturing model (middle in Figure 12) is one in which machines assist humans. That means humans do not need to be trained to the same extent as before. Machines provide relevant instructions and automatic support to compensate for the gap in human skills. However, excessive computer aids could lead to an increase in the learned nonuse phenomenon, and humans in turn risk losing a key skill.

80 | See Hitachi Brand Channel 2018.

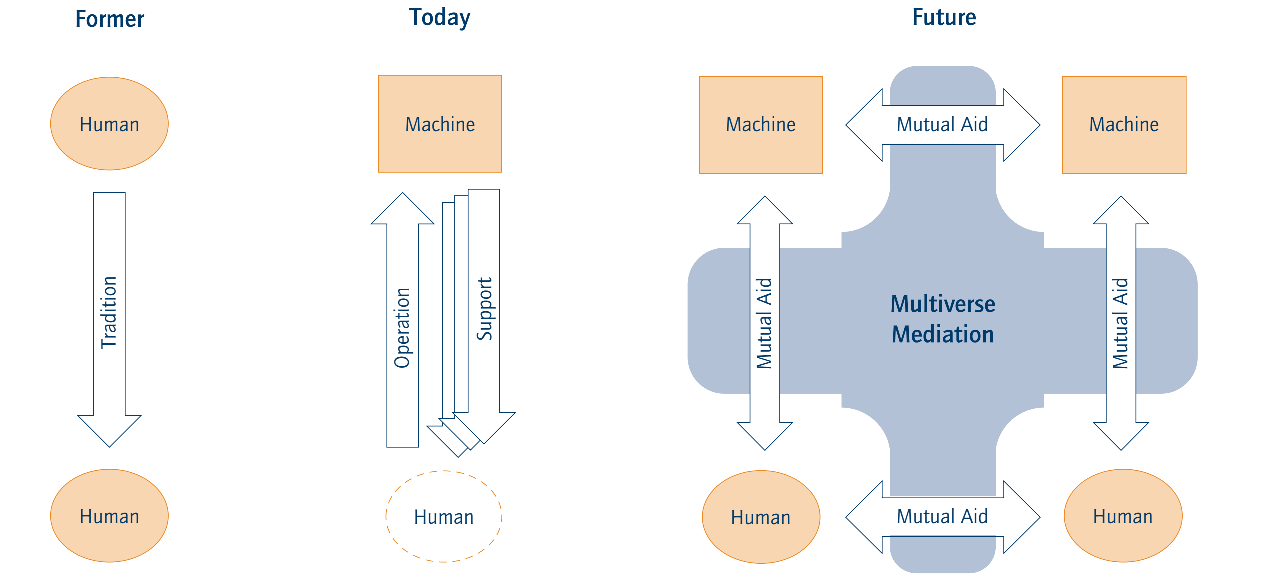



Figure 12: Transition of interaction models (Source: own presentation based on Hitachi)

## Case study in Japan: Issues of excessive assistance

In Japan, many machining processes such as drilling and turning are operated by numerical control (NC). Sometimes an operator can hardly understand the reasoning behind the parameters that have been set by the skilled operator or by the implemented AI, for example, the feed amount and cutting amount of the cutting tool.[81] Industrial robots are used in many cases to assemble home appliances and spot weld automobile bodies. Sometimes changes in a robotics program lead to a bottleneck in a process chain, again because it's difficult for an operator to understand the reasoning behind the program parameters set by the skilled operator or by the AI.[82]

– – –

So the future model for systematically harmonizing HMI would have a multiverse mediation process among humans and machines (right in Figure 12). Based on digitalized knowledge, the mediation would adjust interactions as mutual aids between humans, humans and machines, and machines. The result is a sustainable improvement for both humans and machines.

This future model not only observes human-human, human-machine, and machine-machine interactions, it also accumulates observed information. In the case of a skilled worker, the mediation process identifies potential improvements that could lead to adjustments in mutual aids.

Focusing on the interaction of 1) humans and 2) humans and machines based on this future model, companies need to adopt the following strategies:

1. Revisit traditional workforce structures and create an inclusive environment for a wider set of talented workers whose characteristics may differ from the majority in the current employee base.

2. Systematically measure the skills and capabilities of humans and machines in the same plant and, subsequently, harmonize task plans and adjust the programming of smart machines so that they can assist their human counterparts optimally.

In a first step, the mediation process and sharing data should happen within a company. In a second step, this procedure should be transferred to the whole of society. For a sustainable society focused on human well-being, knowledge acquired from interactions among humans and machines could be made available to the public – as long as there are no infringements on intellectual property.

81 See Nonaka 2019.
82 See Hitachi Brand Channel 2019.

The next case study describes Hitachi's activities in systematic harmonization of HMI, called Multiverse Barrier-Free.[83]

### Case study in Japan: Hitachi – Multiverse Barrier Free

[Concept video available from below link; https://www.youtube.com/watch?v=NWq6wQ_XzwQ]

In Japan, the diversity of workers is progressing, mainly due to the declining birthrate and aging population. In addition, diversity is also progressing in machines, meaning that old machines introduced during the period of high economic growth are used together in the factory with the latest robots introduced in recent years. Hitachi is promoting the development of a flexible production system utilizing human and robot cooperation[84] that optimizes work allocation between humans and robots.

At conventional worksites, workers are taught by an expert, and they perform according to the expert's model. However, as workers diversify, so too do their abilities. So even if they receive uniform work and instructions, their ability to do a job varies. As a result, they cannot work as instructed, and problems such as stress, a higher workload, a decrease in productivity, and a loss of growth opportunities may occur.

In factories with progressing machine diversity, there is a potential risk that human work is substituted by machines.

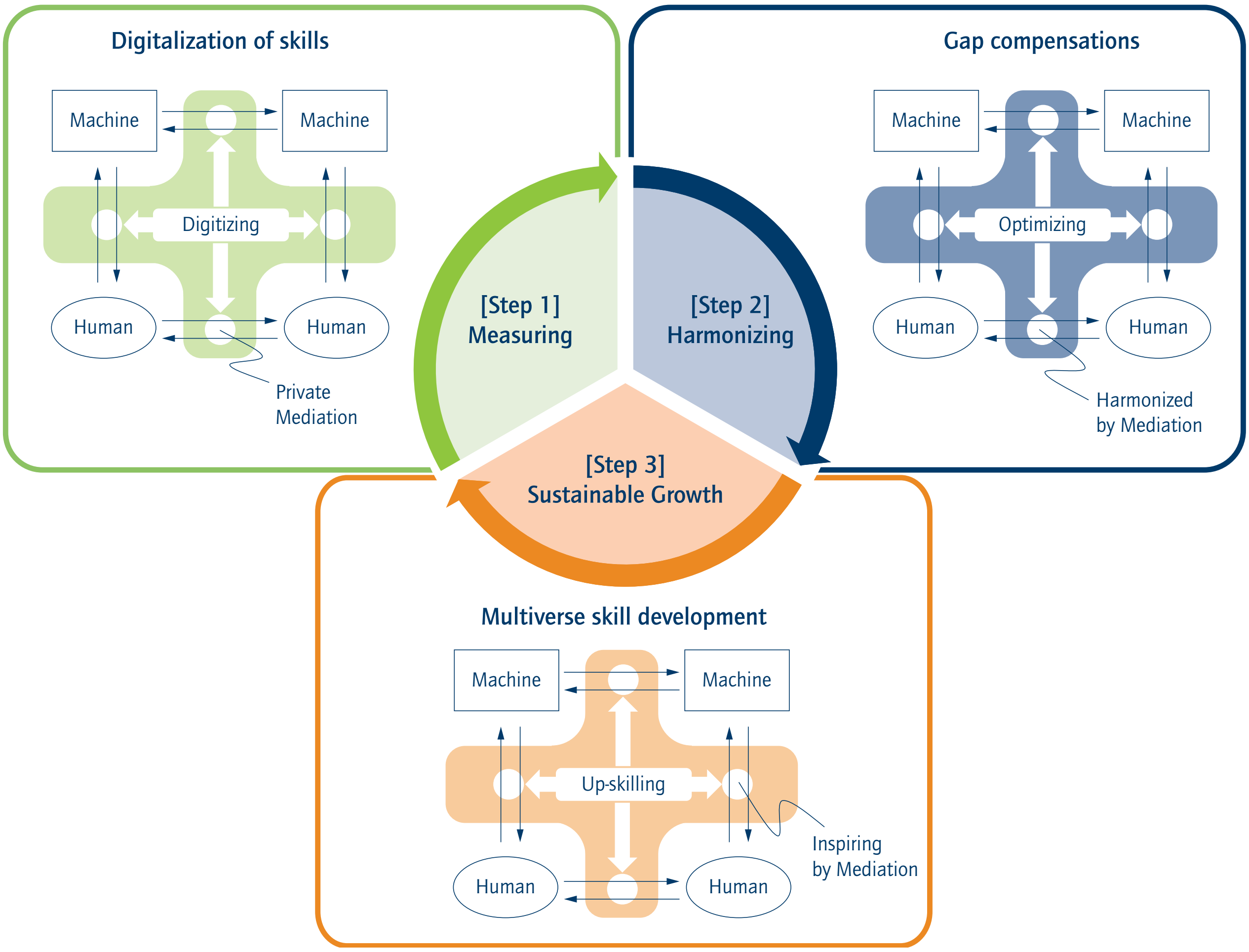



Figure 13: Key three steps of Hitachi's Multiverse Barrier Free (Source: own presentation based on Hitachi)

83 | See Hitachi Brand Channel 2019.
84 | Hitachi R&D Group 2017.

That, in turn, could lower the workers' motivation. In addition, there is also the problem that the machine supports the workers excessively, which causes the workers' ability to fall behind and prevents growth opportunities, as mentioned in the case study on the learned nonuse phenomenon in manufacturing.

Given these problems, Hitachi proposed the concept of Multiverse Barrier Free. It is a mechanism to promote sustainable growth rather than over-supporting one another, and it takes advantage of the individual characteristics of a diverse set of humans and machines. In this concept, a mediation (which is mentioned in Figure 12) is created for interactions between humans, humans and machines, and machines with the following three steps as shown in Figure 13.

- First step: Measuring
  The characteristics of HMI are digitalized and a private mediation is created for each interaction. Hitachi assumes the HMI consists of 4M (Man, Machine, Material, and Method) entities, and a cross-analysis of 4M behavior can extract key tips of HMI. Hitachi then collaborates with OKUMA to extract key tips of machine tool manufacturing for manufacturing efficiency maximization.[85]

- Second step: Harmonizing
  In this step, the mediation generates an appropriate policy of HMIs to compensate for performance bottlenecks. For example, the mediation promotes an optimized organization plan for humans and machines to achieve a task, an appropriate support menu from machines to humans, and an appropriate operation policy from humans to machines. Factors such as a machine's condition are taken into consideration. With this policy, Hitachi has developed technology to optimize both the production line configuration and product design.[86] Since product design specifications assign some production capabilities to workers, robots, etc., and since the capabilities of workers and robots limit product design specifications in terms of weight, fineness, etc., a harmonization technology was established and examined in automotive device manufacturing.

- Third step: Sustainable growth
  For the purpose of achieving growth in humans and machines, mutual aids need to be provided for each human and each machine. With this policy, Hitachi is collaborating with Daikin for the sustainable growth of HMI for brazing.[87] In the collaboration, a new process visualization function was added to the existing brazing system for copper tubes in heat exchangers for air conditioners, and an improvement program for worker's brazing skills was established with the function.

In summary, the essential value of Hitachi's Multiverse Barrier Free is:

1. Help humans and machines develop their creativity continuously.

2. Replace operations that become obsolete with automatic control as much as possible to free humans from having to perform tedious tasks.

3. This continuous expression of creativity contributes to maintaining and developing machines in a sustainable society.

Hitachi launched this Multiverse Barrier Free concept at the Hitachi Social Innovation Forum 2018[88] and has released concept videos on YouTube[89]. Hitachi contributes to the creation of a society where diverse humans and machines grow together.

85 See Nonaka 2019.
86 See Tsutsumi et al. 2018.
87 See Hitachi Brand Channel 2018.
88 For more information regarding the Hitachi Social Innovation Forum, see http://hsiftokyo.hitachi/en/.
89 See Hitachi Brand Channel 2019.

# 5 Challenges in the new paradigm of human-machine collaboration

The impact of the digital revolution on industry and society is already evident. With the projected growth in population and increase in prosperity, a rise is expected in the overall global market volume for products and services. Demand could even develop toward increasingly customized products. However, manufacturing labor is expected to decrease globally.

To address the societal trends mentioned above, industry in general is changing, becoming increasingly diverse and complex.

Industrie 4.0, for example, is not based on the vision of the complete automation of the manufacturing process, but on an adaptable and individualizable process even for small batch sizes, making next-generation HMI a necessity in the manufacturing sector.

The new paradigm of industrial manufacturing can rapidly adjust cyber-physical systems (CPS) to changes in customer requirements. Responsiveness to the customer is most visible with human-machine collaboration, which is more productive and presents opportunities for companies to gain a new competitive advantage. However, how will humans and machines interact with each other, and what role will our thoughts play?

In this chapter, we focus on the human-machine collaboration in the context of smart manufacturing and the impact it will have on manufacturing work in the future. Potential solutions may give rise to new styles of interaction. Additionally, integrating humans and self-learning machines will call for operations and management to be flexible and adaptable. A possible result could be the creation of better and more satisfying work.

## 5.1 Current situation

Many efforts have been taken to equip machines with sensing technology or AI to function more intelligently and self-learn. The current situation is shown in Figure 14, whereas advanced machines or robots are more efficient in adapting routine cognitive tasks, traditional machines require more effort. In addition, workers have to adjust to the upgraded machines, and management needs to be prepared for fast-changing manufacturing processes.

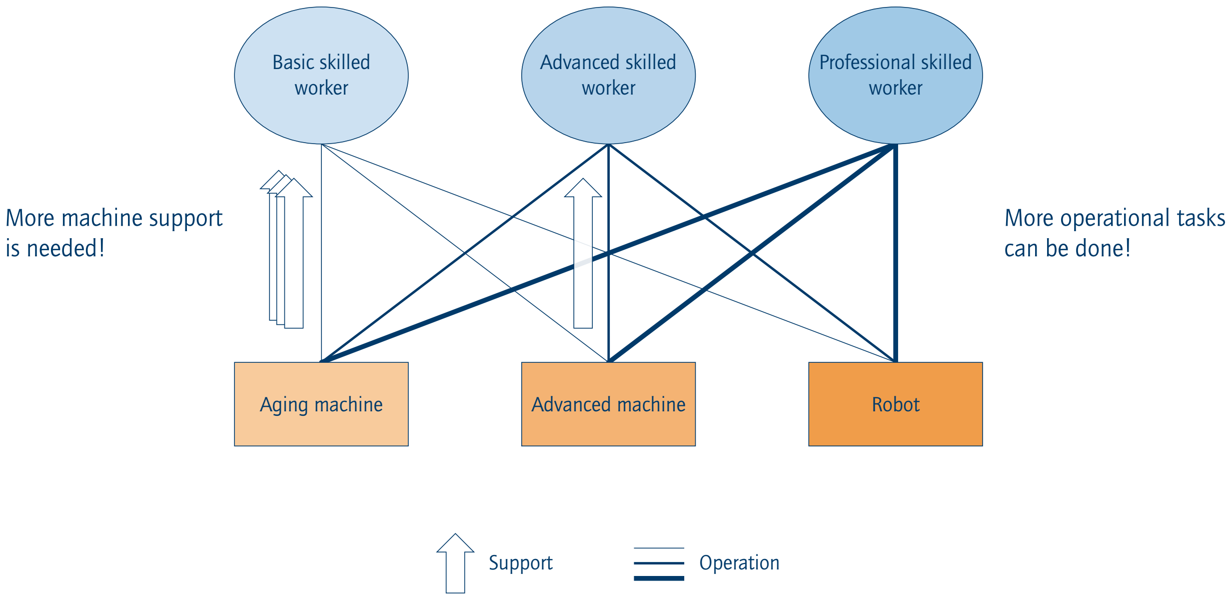



Figure 14: Current situation in manufacturing (Source: own presentation based on Mitsubishi Electric Corporation)

## 5.2 Future development

To properly address the challenges, the following approaches are recommended:

- Increase the intensity of cognitive technology and HMI.
- Enable the collection of human intelligence on the shop-floor along with knowledge-sharing management.
- Merge human intelligence with CPS and learning in process management.
- Foster collaborative robotics and activity recognition for highly skilled workers (see "Case study in a collaboration between Germany and Japan: DFKI and Hitachi – worker activity recognition, evaluation, and transfer").
- Increase the intensity of supervising skills to utilize the workers' potential and increase management's visibility of the company.

## 5.3 New paradigm of human-machine collaboration

The new paradigm (Figure 15) can be interpreted as a generalization of Figure 13.

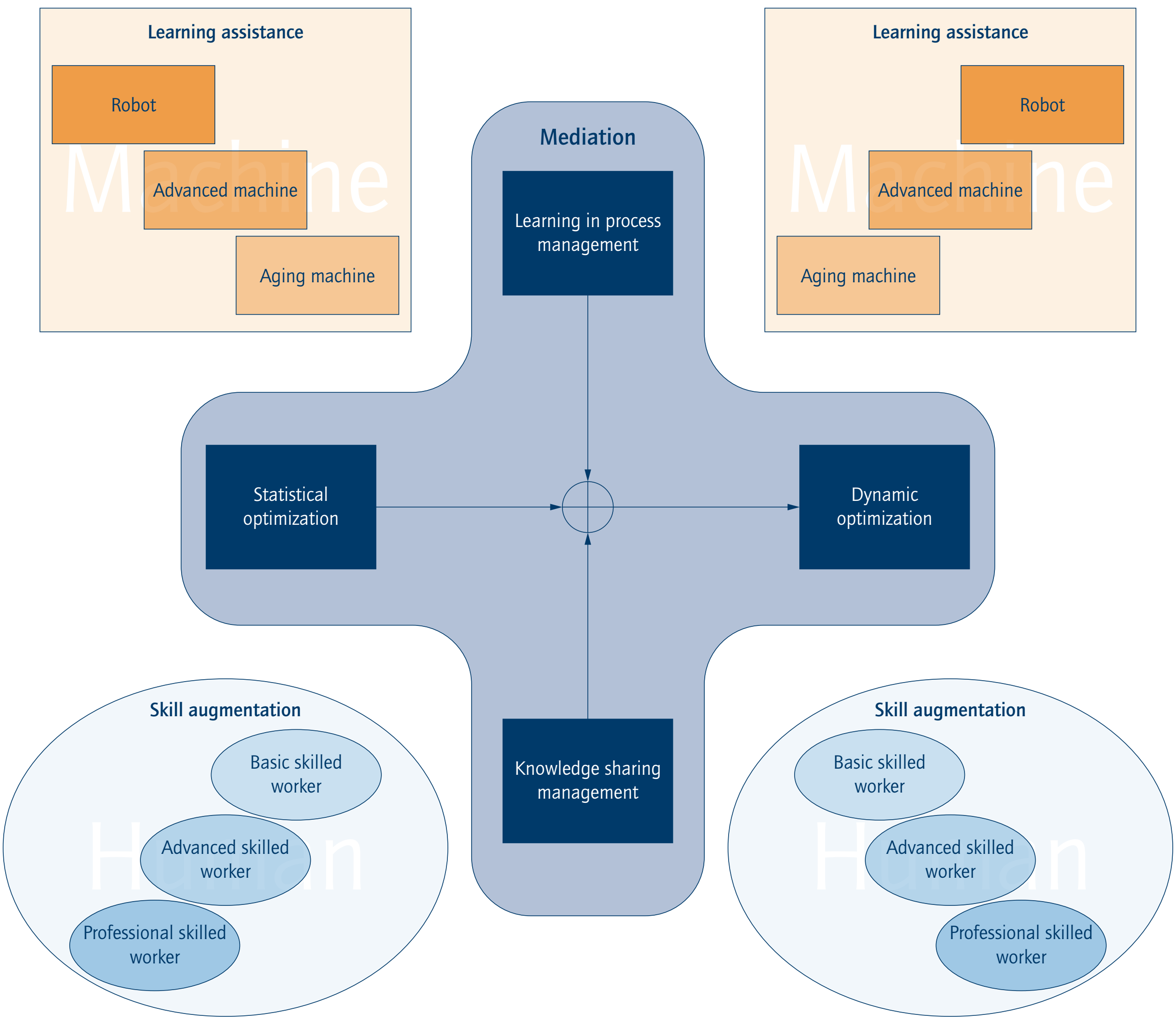



Figure 15: New paradigm of human-machine collaboration (Source: own presentation based on Mitsubishi Electric Corporation)

In a workplace in which self-learning machines are being increasingly introduced, employees who work with these technical systems must become adept at statistical and dynamical optimization, learning in process management, and knowledge sharing management supported by digital technologies. It is therefore imperative that enterprises embrace the new paradigm of human-machine collaboration.

The following case studies introduce some of the new aspects.

### Case study in Japan: Mitsubishi Electric – collective intelligence

Collective intelligence, which is based on lessons-learned and ideas gathered by members of a company, an organization, or society, contributes not only Kaizen (successive improvement of products and productions), but also to innovations, as shown in lateral thinking[90] and Theory of Inventive Problem Solving (TRIZ)[91].

However, a reduction in the productive population leads to the deceleration of Kaizen and innovation, because less knowledge and fewer lessons-learned and ideas can be collected from worksites. In the future, workers will have to come to terms with increasingly complex manufacturing processes. In manufacturing, the ability to adapt and efficient operations will grow in importance.

In addition, less productive populations prevent companies from providing for long-term skills development in their workplaces. This also concerns, first and foremost, efforts aiming to establish a culture that is more accommodating in regard to the approaches implemented in a workplace itself. However, considering the drastic and dramatic changes occurring in the current business

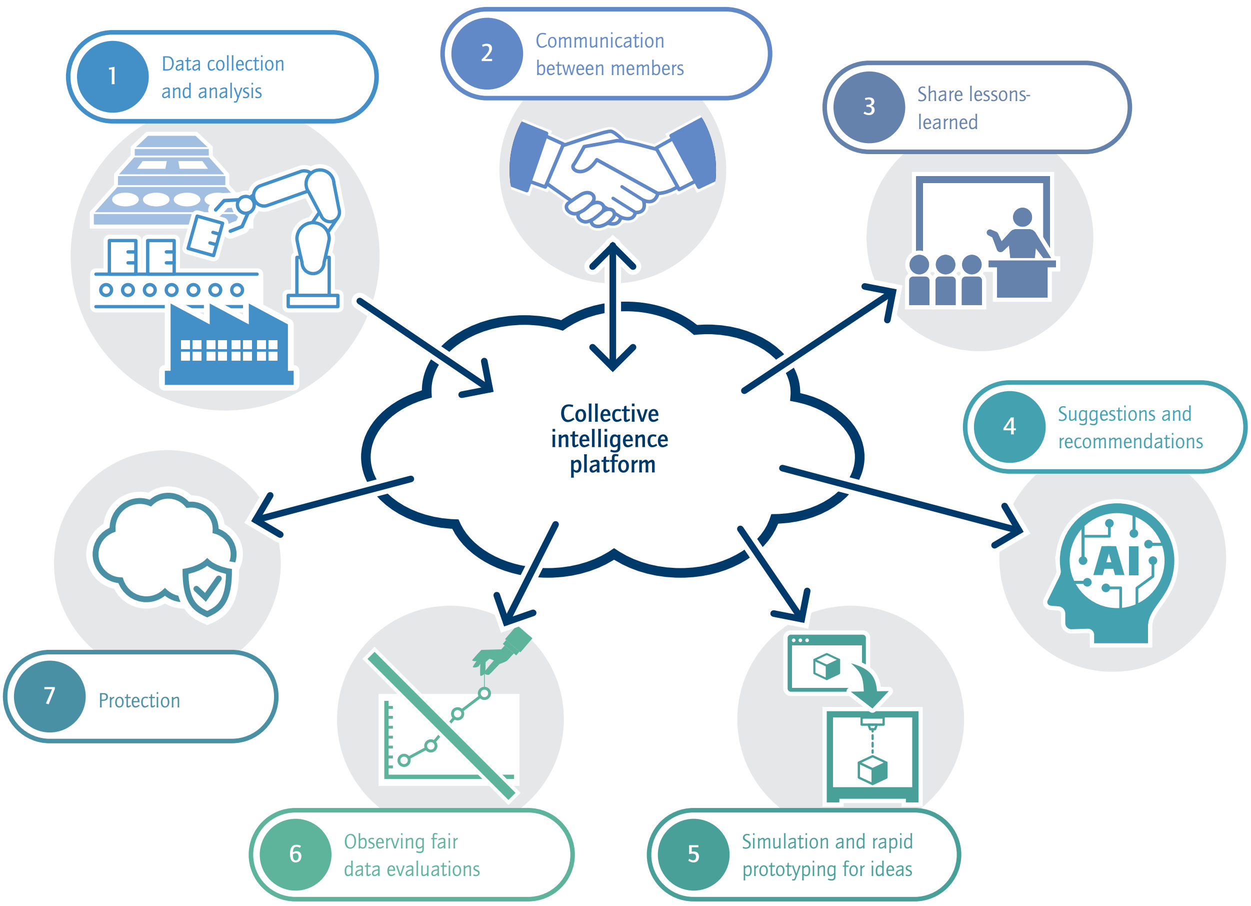



Figure 16: Collective intelligence platform (Source: Mitsubishi Electric Corporation & the University of Tokyo)

90 | See de Bono 1967.
91 | TRIZ is a Russian acronym for the "Theory of Inventive Problem Solving". See Altshuller/Shapiro 1956.

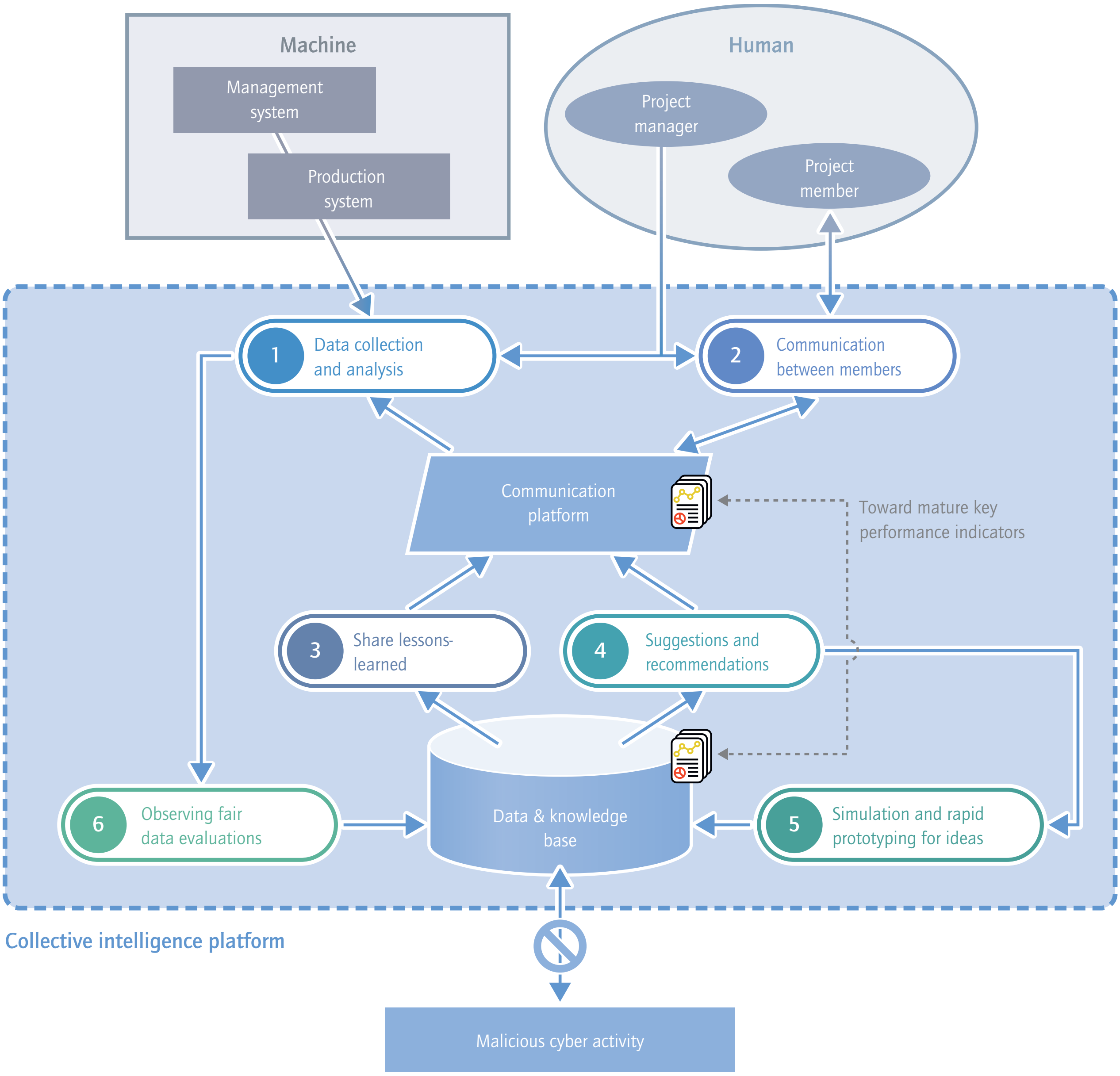



Figure 17: Use of a collective intelligence platform (Source: Mitsubishi Electric Corporation)

environment, it is key to have employees' latest feedback on their working environment and to ensure that cutting-edge training is introduced as quickly as possible.

In order to overcome the barriers, collective intelligence (Figure 16) is a goal worth striving for. Collective intelligence seeks to ensure that the lessons learned and the ideas collected in the workplace can continue to be implemented and explored. This is done via a collective intelligence platform that reflects the increasing diversity of manufacturing and the accelerating processes in the actual manufacturing environment. Such a platform can also assist in utilizing data and leveraging skills and knowledge efficiently to contribute to the collaboration and training of humans on worksites to enable them to focus on more creative and value-adding tasks.

As shown in Figure 17, the collective intelligence platform gathers data not only from machine systems, but also from humans via a communication platform that explains the lesson-learned idea and makes suggestions and recommendations based on data in the growing knowledge base. AI is integrated into the platform to evaluate and correlate data, compare methods, and prototype ideas. The information gained from AI analysis is highlighted as skills and knowledge, and it is stored as use cases in the knowledge database. The skills and knowledge will be shared by humans who are involved as members via a communication platform for on-demand education, idea evaluation, and simulations. As a result, ideas developed by members will be accelerated. Furthermore, categorizing skills and knowledge regarding key performance indicators in the collective intelligence platform can provide guidance and accommodate the actual transformation cycles of skills and knowledge with the goal to successfully promote smart manufacturing maturity.[92]

Enabling the diversity of manufacturing with collective intelligence exploits breakthroughs in a company, such as a cell-style production system. For Mitsubishi Electrics electromagnetic switch assembly[93], one worker who collaborates with robots takes charge of a broader range of manufacturing processes to accomplish the assembly. Here, robots compensate for the worker's weaknesses, whereby the worker's value lies in process judgment. The knowledge gained from one cell can be put into practice faster through collective intelligence management. Management can evaluate the return on investment and the time plan.

With the support of a collective intelligence platform, humans on the worksite can leverage skills and knowledge effectively to create innovative product manufacturing.

### Case study in Japan: The University of Tokyo – Digital Triplet

An important approach to promote human-centered manufacturing is to encourage on-site engineers and technicians to develop new ways of executing engineering activities at their own initiative, in addition to routines specified in manuals and by supervisors. This is the traditional way of Kaizen with Japanese manufacturers. While this means that cyber-physical production systems (CPPS) should be equipped with this functionality, this is not yet the case. Digital Triplet as discussed in this subsection is the concept to add this functionality to CPPS.

Although continuous improvement (Kaizen) by manufacturing engineers and shop-floor technicians to pursue lean production is important for high-quality manufacturing, activities of continuous improvement are not digitalized to be "smart" in CPPS[94], since many engineers and technicians cannot follow the digital transformation. With the growing digitalization of manufacturing systems, the question is what kind of next-generation system we need to support engineers in creating maximum value in manufacturing, rather than just "automate" engineers' activities.

This section deals with situations, as seen in typical Japanese manufacturing companies, in which manufacturing system engineers are always stationed at the shop-floor and continuously improve manufacturing systems with workers. They conduct engineering activities, including operating manufacturing systems, problem solving when troubles occur, Kaizen for pursuing lean production, and developing new manufacturing systems.

In order to solve this problem, we are proposing "Digital Triplet".[95] Digital Triplet aims to support engineers to solve problems and to create value throughout a product life cycle. As a type of CPPS,[96] Digital Triplet encourages engineers to develop new methods of executing engineering activities on their own initiative.

As can be seen in Figure 18, engineering activities consist of data collection, information analysis, decision by the engineer, and execution of a plan in the physical world. We call this the "engineering cycle". When an engineer executes a cycle, value from the data is created. The terms in the rounded rectangles in Figure 18 are represented in the traditional CPPS. But important aspects to support manufacturing system engineers in constructing engineering cycles are included in rectangles in this figure (such as Selection of data to be monitored and Selection of Analysis Methods and Tools). They are not described in the traditional CPPS, but they are main players in Digital Triplet. In other words, the manufacturing system engineers targeted in this section execute Kaizen by constructing their own engineering cycles based on their own initiatives. Digital Triplet aims to support this process. Among others, human-centered CPPS[97] is a good reference for this framework. The main difference between human-centered CPPS and Digital Triplet is the subject who develops engineering cycles: in human-centered CPSS, it's the developer; in Digital Triplet, it's the manufacturing system engineers on the shop-floor.

We are going to describe these engineering cycles as reusable process knowledge. In other words, we would like to formalize,

92 | See Shi et al. 2019.
93 | See Mitsubishi Electric's concept of the e-F@ctory. URL: https://us.mitsubishielectric.com/fa/en/solutions/efactory.
94 | See Monostori et al. 2016, Geisberger/Broy 2014.
95 | See Umeda et al. 2019.
96 | See Monostori et al. 2016, Geisberger/Broy 2014.
97 | See Ansari et al. 2018b, 2018c.

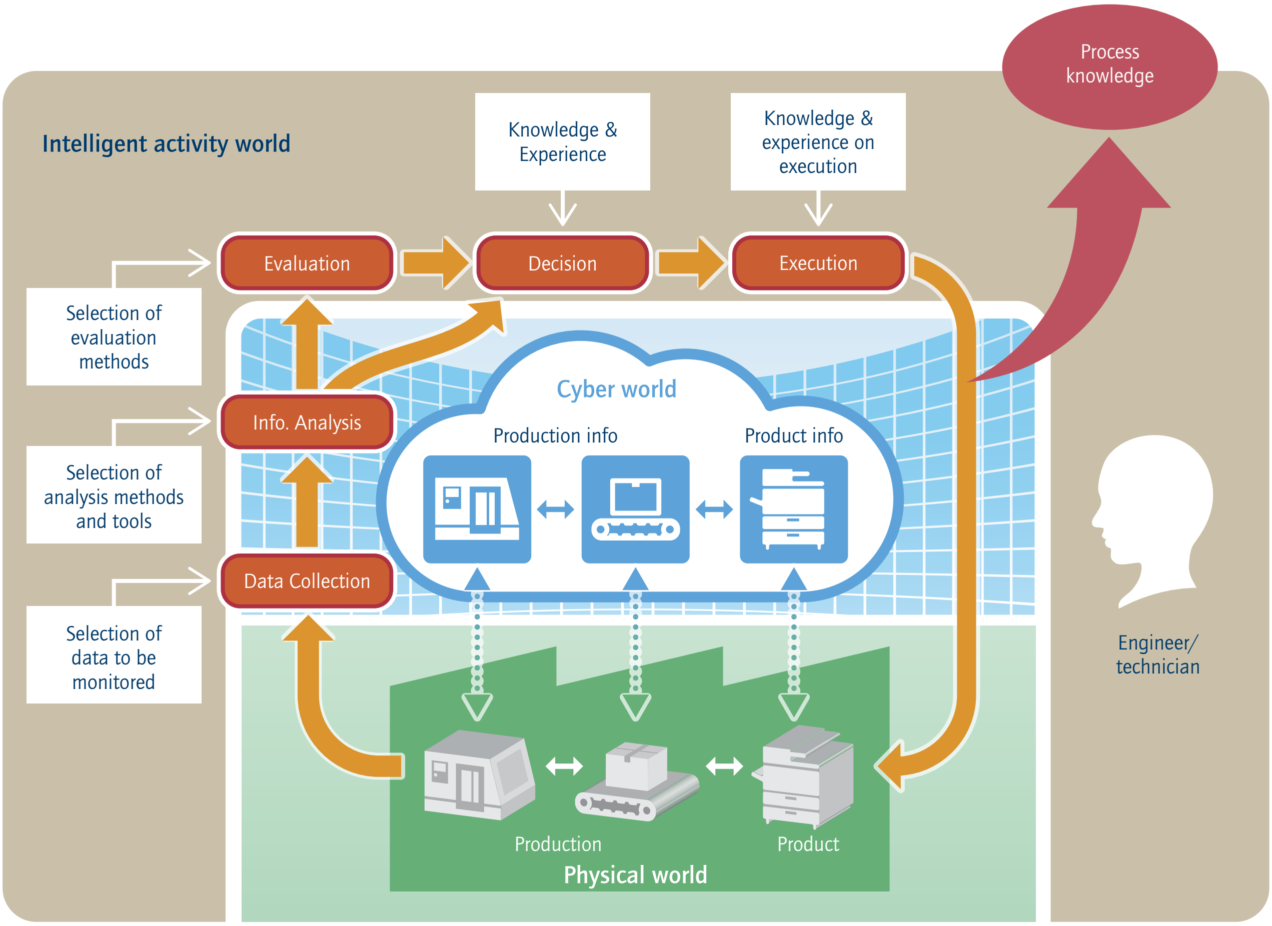



Figure 18: An engineering cycle on Digital Triplet (Source: Mitsubishi Electric Corporation)

collect, and archive the process knowledge of manufacturing system engineers; support human activities by reusing, deploying, and sharing the knowledge; and employ the knowledge for education. By utilizing this process knowledge, we can improve engineering cycles, including the HMI method. This is a new form of knowledge transfer from experts to novice engineers. When an expert engineer develops an engineering cycle for a specific problem (e.g., to increase productivity of a manufacturing system), Digital Triplet records this engineering cycle as a process of data collection; the use of several AI tools, simulators, and other software; and the execution of actions by the engineer. By tracking this process record, a novice engineer can study an expert's approach to solving a problem.

Digital Triplet is an extension of CPPS, focusing on the integration of Kaizen, which encourages engineers to construct and execute various engineering cycles based on their own initiatives, into CPPS. This also facilitates and enables knowledge transfer from experts to novice engineers, and aids in training novices in smart manufacturing. In other words, Digital Triplet makes a smart manufacturing system possible that fully utilizes the varied abilities of diverse manufacturing system engineers to create value in a respectful manner, thus improving their skills and abilities.

## Case study in Germany: Infineon – collaborative robotics

The latest generation of collaborative robots (CoBots) demonstrates that the benefits outweigh the risks of humans collaborating with robots. Moreover, these risks can be minimized or even nearly eliminated with the right combination of semiconductor solutions and advanced algorithms. First and foremost, CoBots need advanced safety and security capabilities as well as the ability to scan their surroundings with utmost precision.

Unlike conventional industrial robots, CoBots operate without safety cages and interact directly with humans. The lack of cages, however, significantly increases the safety risks for humans and production materials. If you want to liberate robots from their cages, you also have to ensure that human beings are protected from entering the critical reach of a robot operating at high speed in the first place and risking injury, either through their own negligence or a malfunction. Making robots sufficiently sensitive only works with sophisticated sensor technology. Basically, the area between humans and robots, but also between the robots themselves, must be made safer. The aim is to make protection zones more flexible so that, for example, a much smaller protection zone moves dynamically with a moving robot arm. A zone concept is used to implement virtual fences. If a human enters the outer perimeter, a warning signal is emitted, but the robot continues to operate at full speed. If the human gets closer, the speed is reduced, and a warning is issued accordingly. The CoBot stops if the human is directly about to enter the danger zone.

Although both terms, safety and security, sound similar at first, there is a clear distinction: While safety deals with human protection, security embraces data protection and thus aims at protecting robots from cyberattacks. Only systems that are appropriately safe in terms of data security can also be functionally safe – an aspect that is becoming increasingly important in the context of Industrie 4.0 and IoT. Encryption systems protect the commands sent to the robot from manipulations, whereas authorization mechanisms protect the robot from executing wrong commands. Security mechanisms also aim to prevent the robots as part of the production process against manipulation during wired or remote software updates. Secured authentication of users and newly added components is also required to prevent unauthorized access.

In order to function correctly, robots must also be calibrated. However, if an attacker manipulates the calibrations, for example, the robot could exceed its programmed motion limits.

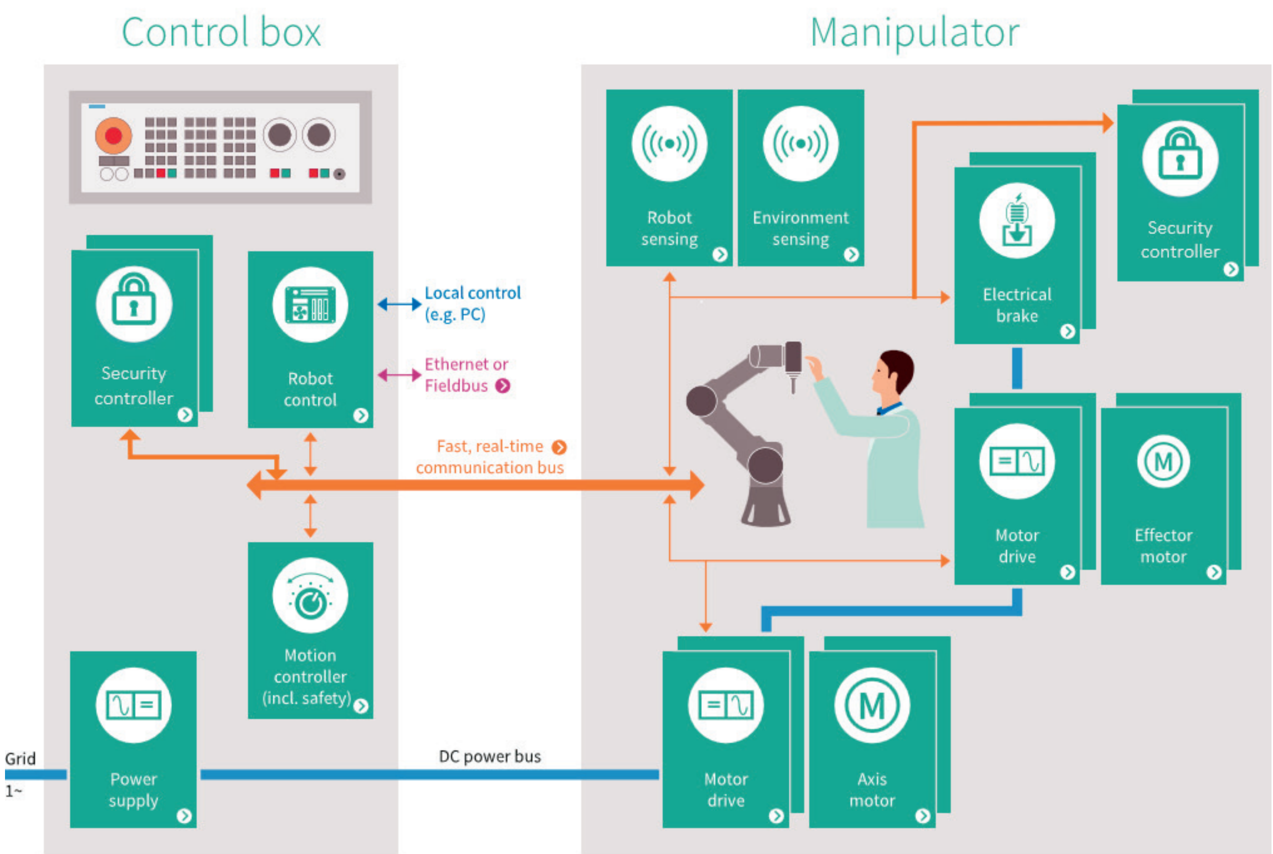



Figure 19: Structure of a CoBot including sensing and security components (Source: Infineon)

This is where safety and security converge – without efficient security protection, functional safety doesn't exist. This is a key requirement for future systems and is being addressed by special security controllers or microcontrollers with functions such as Hardware Security Module (HSM). Since the security functions are implemented in the hardware, users need only minimum knowledge of encryption technologies. In addition, the impact on existing software is extremely low.

The automation equipment and robots employed can only get work done when they fully function. In order to do so, they need to be maintained regularly. However, turning these machines off to perform maintenance takes away valuable time from production activities. In addition, automation teams might replace parts that are still fully functional because of the specific load profile within the production process. This may cause significant costs that could be avoided.

Robots provide us with a wide range of signals that we can use to diagnose their "health". For instance, a change in their whirring sound or a slight shuddering motion are signs that a motor, gearbox, or bearing is in need of repair or maintenance. For instance, power consumption that goes up slightly but steadily could be an indication of increased mechanical resistance. This can result from close-to-failing bearings that cause the electrical system to draw more current than usual. The semiconductor industry has used the unique properties of silicon to create inexpensive, tiny sensors to measure a wide variety of signals. With this wealth of low-cost but high-quality sensing capability, there is little reason to not integrate a range of sensors into robots to monitor their health. For example, temperature, vibration, noise, positioning and motion, acceleration, and force sensors could be integrated into the joints of a robot. Many of them can be found there already, as they are required to enable the intended function of the robot or any other machine. But in addition, monitoring all these sensors together would, like an intuitive human, recognize signs of potential early failure.

If this continual sensing is to be of use, it also needs to be evaluated immediately in order to highlight pending failures. Microcontrollers can be used to collect, pre-process, and evaluate the data. Featuring all the necessary data interfaces to connect to such sensors, these tiny number crunchers can also be integrated inside robotic joints. This fusion of sensor information can be evaluated on-chip or passed on to a central computer using Industrie 4.0 data networks. By continuously reviewing the robot's signals, AI could later easily highlight when some of these parameters are starting to fall outside their expected range. This would be the trigger for the maintenance team to inspect the robot for excessive wear. The combination of continuous sensing and data analysis by AI systems enables condition monitoring and predictive maintenance solutions in robotic as well as other production systems, thus enabling high availability for all types of equipment. Therefore, robots need to be equipped with sensors that detect their surroundings. Technologies like radar or 3D imagers are based on the time-of-flight principle that might function as "eyes". MEMS microphones might give "ears" to machines and pressure sensors provide a kind of "feeling" to them. This reliable "understanding" of the environment improves the safety of human coworkers.

## Case study in Germany: Learning factory

Learning factories typically are factories that are designed and implemented to educate and train workers on new skills necessary to create an advanced production environment.[98] Production technologies rapidly adopt the concepts of information and communication technologies, as well as new production paradigms such as additive manufacturing and collaborative robotics. In the future, the frequency of changes in production will increase. Competence building in a production environment is required increasingly, which in turn also has implications on new forms of human-machine interaction.

Learning factories provide a new education and training approach, complementary to the traditional education and training concepts of higher education and industrial training. The approach combines both concepts and integrates research-driven state-of-the-art solutions with industrial strategies for competitive production. The main goal is to strengthen the human role in advanced value chains.

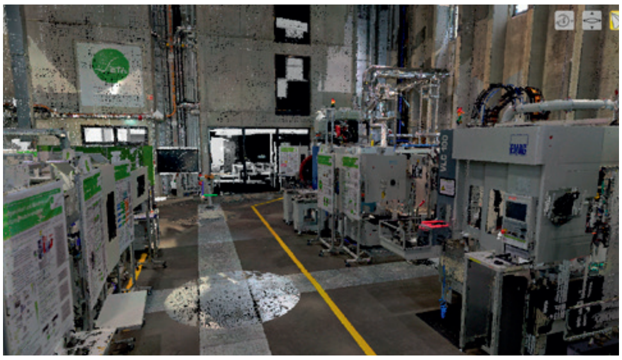


Figure 20: Cyber-physical education and training environment (Source: ETA-factory, Darmstadt)

98 | See Abele et al. 2018.

As ICT increasingly impacts production technologies, it becomes more and more important to train workers to keep pace with the high development dynamics in an ICT-driven production environment and with new forms of human-machine interaction.

For society 4.0, lifelong learning and a high level of flexibility in education or up-skilling play a key role. Lifelong learning, however, also requires places where skills are updated and further competences created. Such places need to be established either physically or in cyberspace, or a combination of both to create a cyber-physical education and training environment. Learning factories represent such a cyber-physical education and training environment, dedicated to support lifelong learning.

One practical example of a learning factory is the ETA factory, which was initiated by the interdisciplinary research group Energy Technologies and Applications in Production (ETA) of the Institute of Production Management, Technology and Machine Tools at TU Darmstadt. As a real research tool, the ETA factory offers not only excellent opportunities for research, but also serves as a learning environment in which the insights gained in industry and teaching are transferred. The production hall of the ETA factory consists of two complete value chains in which small-scale, market-ready products can be produced (see Figure 20).[99]

In recent years, more and more learning factories or labs have been established. In Germany, too, the concept of learning factories has already been taken up and put into practice. For example, Map Industrie 4.0 provided by Plattform Industrie 4.0 lists use cases, test beds, and support services that have already been realized in the context of Industrie 4.0. It demonstrates various initiatives, activities, and implementations of learning factories initiated by companies (e.g., SAP, Festo) or scientific and public institutions (e.g., the wbk Institute of Production Science at the Karlsruhe Institute of Technology, Fraunhofer IGCV).[100]

Generally, the concept of learning factories is not restricted to qualification measures on production sites, as it also can be transferred, e.g., to so-called learning labs, learning laboratories, and learning groups. Therefore, the term can be generalized to learning places where human-machine interaction topics play an important role.

## Case study in a collaboration between Germany and Japan: DFKI and Hitachi – worker activity recognition, evaluation, and transfer

An aging society and declining birth rates are some of the biggest social issues in mature societies such as Europe and Japan. Especially for manufacturing companies, the retirement of

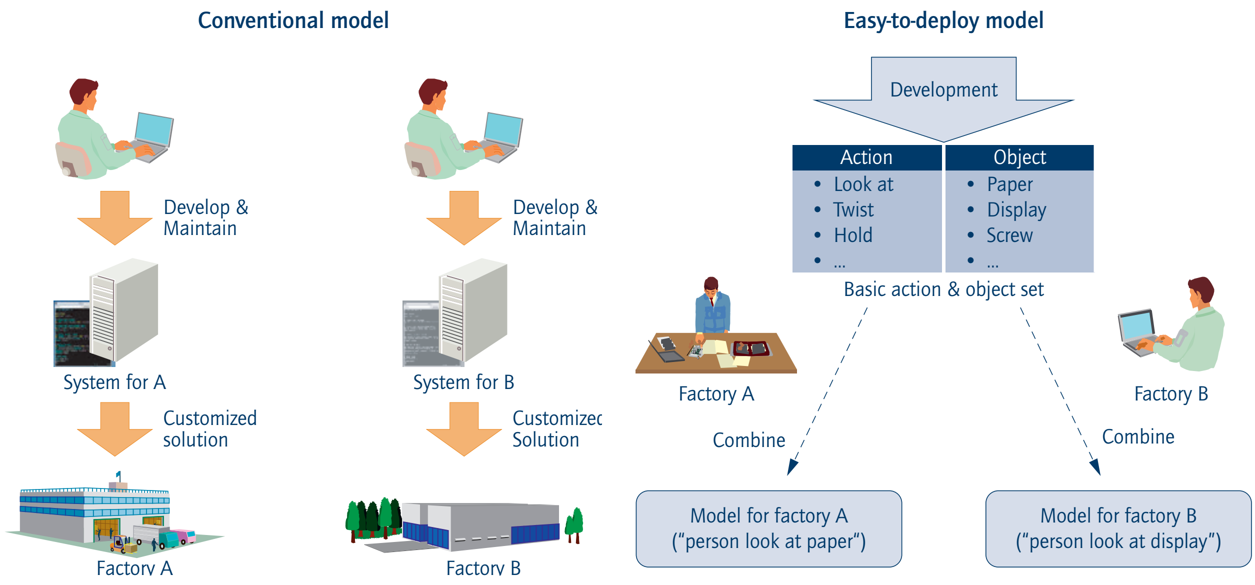



Figure 21: Conventional model vs. Easy-to-deploy activity recognition model (Source: DFKI)

99 See further https://eta-fabrik.de/bildung/lernfabrik/.
100 For the "map Industrie 4.0" of the German Plattform Industrie 4.0, see https://www.plattform-i40.de/PI40/Navigation/Karte/SiteGlobals/Forms/Formulare/karte-anwendungsbeispiele-formular.html.

experienced workers, who are the backbone of a strong industry, is a serious problem. Therefore, there is an immense need for technology that can benefit from experts to support novice workers. Worker (either human or machine) activity recognition can play a vital role to support workers in factories, for instance, for quality control, reducing accident risks, maintaining worker health, and transferring knowledge between machines, experts, and novices.

The main difficulty in applying an activity recognition model to different factories is the diversity of the activities between these factories. Since the important activities to be recognized vary from factory to factory, the target activities are different depending on the factories. In addition, even if the target activities are the same among some factories, their representation in each factory may be different. For example, in factory A the activity of "check manual" may refer to a situation where a worker is reading from paper, but in factory B it may describe a situation where a worker keeps looking at a display (to read a digitalized manual). In this case, the conventional methods used need to create separate recognition models for these factories, because the model created for one factory cannot be used for the other factory, even though in both factories the target activity has the same name of "check manual". In other words, with conventional methods a customized model has to be created for every individual customer.

In addition, even if a customized model is successfully developed, it lacks the flexibility of further modification. For example, if a display to read a digitalized manual is introduced in factory A after a customized model was developed, a lot of data for the new "check manual" activity needs to be collected, and a new customized solution needs to be developed. Similarly, any decision made by these systems is not supported with the explanation, i.e., why a particular decision was made, which is critical, especially in environments where human-machine collaboration is indispensable.

The goal of this research is to develop an easy-to-deploy human-activity recognition model,[101] which can be applied to different factories as a standard solution with limited or no customization, which makes it deployable at a low cost. In addition, explaining a machine's decisions to a human is a vital component of this approach.

The key idea is to recognize complex activities based on the combinations of simpler components,[102] like the actions and objects involved in the activities, and explain the recognition to humans in both visual[103] and textual form[104].

We used two wearable sensors: One is smart glasses, or an eye-tracker, with a camera that provides the view of the worker. The other is motion-tracking sensor on the body, either in the

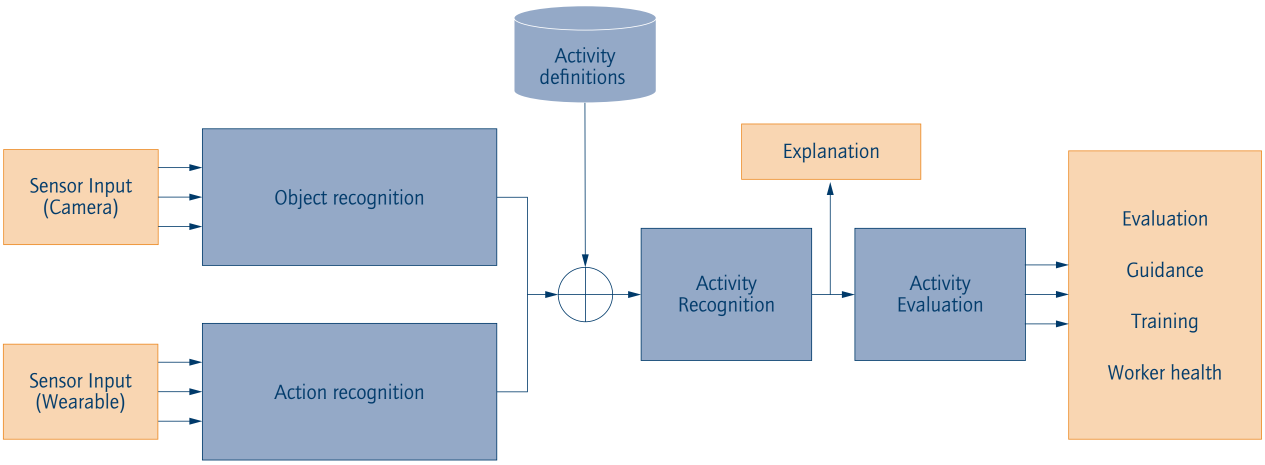



Figure 22: Overview of the framework (Source: DFKI)

101 | See Al-Naser et al. 2018.
102 | See Al-Naser et al. 2018.
103 | See Palacio et al. 2018, Siddiqui et al. 2018.
104 | See Ohashi et al. 2017.

form of an armband sensor or full-body sensor. These sensors are used to recognize gazed objects and basic actions, respectively.[105] Although many conventional systems use fixed cameras as sensors, wearable sensors are more appropriate in a complex industrial environment because fixed cameras are often limited by occlusion and view angle.

We assume that even though the representation of the activities may differ from factory to factory, the differences are in how actions and objects are combined (after they are collectively called "basis"). In other words, we assume that the recognition modules for the basis, namely the action and object, can be commonly used in different factories.

Figure 22 provides an overview of the proposed model.[106] This framework enables recognition of new activity without time-consuming retraining processes, assuming that a new activity can be represented by a combination of predefined basic actions and objects. Here, "action" is defined as a simple motion of body parts such as "raise arm" or "bend down", while "activity" is defined as a combination of a basic action and an object. Recognition decisions of both actions, as well as gaze-guided object detection, are supported both with visual[107] and textual explanations[108]. These explanations play a vital role in building trust in machines in situations in which humans and machines work in close proximity.

In the above-mentioned example of "check manual" activity, the possible action is "look at", and the possible object in factory A is "paper" and in factory B "display". By breaking the complex activity into simpler actions and involved objects, the intermediate recognition module of "look at" can be used for both factories. This framework enables the recognition of many activities in various factories without customization but with a sufficient level of explanation.

This system introduces a deep neural network (DNN) based on an explainable action recognition method that utilizes wearable sensors and a gaze-guided object recognition method[109] to recognize activities. The experimental results showed comparable performance to conventional methods with an accuracy of over 90%.

By developing an easy-to-deploy explainable activity recognition system, we will support many workers in various manufacturing factories in terms of training, guiding, quality control, and reducing risk.

105 | See Al-Naser et al. 2018, Ohashi et al. 2017, 2018.
106 | See Al-Naser et al. 2018, Ohashi et al. 2017, 2018.
107 | See Palacio et al. 2018.
108 | See Ohashi et al. 2017.
109 | See Al-Naser et al. forthcoming, Munir et al. 2019.

# 6 Conclusion

This paper focused on social challenges associated with factors such as a maturing workforce and aging machines and infrastructure, discussed how these problems should be defined, and explored new approaches in HMI through use cases in Germany and Japan. Digital technologies like CPS, AI, and robotics are expected to help solve these social challenges. Applying these technologies also impacts social transformation, since the technologies perform routine cognitive tasks that were previously the domain of humans.

In order to establish a sustainable society, it's necessary for humans to be able to continuously create high-value-added work, and to be able to shift from non-high-value-added work to high-value-added work at any time. It's also necessary for machines to not only carry out non-high-value-added work, but to also be a mechanism to create high-value-added work by constant interaction with humans. According to these requirements, the digital transformation can enable a novel, human-centered manufacturing system in which humans concentrate on lifelong skill improvement and continuously create high-value-added work. Essentially, this system revitalizes human-machine interaction, allowing both humans and machines to play a role in digital society.

Ultimately, we should work to strengthen the public interest in digital society, share knowledge acquired from interactions between humans and machines, and establish a sustainable society that focuses on human well-being. In this paper we called for a mediation process, and we encourage society start considering and discussing the scenarios and actions together for the future.

Based on various country-specific case studies, we observed how Germany and Japan are changing traditional HMI with digital technologies. It appears that a new HMI model – a social mediation process that adjusts for mutual aids, as explored in the previous chapter – is under development. However, a mechanism for storing the experiences of HMI as social collective intelligence and attempts to improve the performance of humans and machines using the collective intelligence have not been explored in both countries. In order to realize this potential, it is necessary to establish a mechanism and rules to share experiences at various levels, such as the individual, regional, factory, company, country, world, etc.

This collaborative project between Germany and Japan is quite valuable, as we have recognized similarities and differences among the two countries on how to deal with the issue at hand. Although both countries are aiming for a similar goal, their historical backgrounds and social structures are impacting their methodologies and focal areas. In closing, we encourage keeping discussions open among multiple countries in the effort to establish a sustainable society.

# References

**acatech 2016**
acatech (Ed.): *Innovation Potential of Human-Machine Interaction.* acatech IMPULSE-Executive Summary. This summary is based on: acatech (Hrsg.): Innovationspotenziale der Mensch-Maschine-Interaktion (acatech IMPULS), Munich: Herbert Utz Verlag 2016.

**Abel et al. 2019**
Abel, J./Hirsch-Kreinsen, H./Steglich, S./Wienzek, T.: *Akzeptanz von Industrie 4.0 (acatech, Research Council of the Plattform Industrie 4.0).* 2019. URL: https://www.plattform-i40.de/PI40/Redaktion/DE/Downloads/Publikation/akzeptanz-industrie40.pdf?__blob=publicationFile&v=4 [as at: 02.09.2019].

**Abele et al. 2018**
Abele, E./Metternich, J./Tisch, M. (Eds.): *Learning Factories – Concepts, Guidelines, Best-Practice Examples*, Cham: Springer International Publishing, 2018.

**Akaishi 2018**
Akaishi, K.: "Strategic Plan toward Society 5.0 – Entering into Next Stage –". In: *7th International Cybersecurity Symposium*, November 29th, 2018.

**Al-Naser et al. 2018**
Al-Naser, M./Ohashi, H./Ahmed, S./Nakamura, K./Akiyama, T./Nguyen, P./Sato, T./Dengel, A.: "Hierarchical Model for Zero-shot Activity Recognition Using Wearable Sensors". In: *Proceedings of the 10th International Conference on Agents and Artificial Intelligence* - Volume 2: ICAART, 2018, pp. 478–485.

**Al-Naser et al. forthcoming**
Al-Naser, M./Siddiqui, S. A./Ohashi, H./Ahmed, S./Nakamura, K./Sato, T./Dengel, A./Gaze, O.: "Gaze Prediction in Egocentric Videos for Attentional Object Selection". In: *PLOS ONE*, forthcoming.

**Allianz Industrie 4.0 Baden-Württemberg 2017**
Allianz Industrie 4.0 Baden-Württemberg (Hrsg.): *Arbeit in der Industrie 4.0 in Baden-Württemberg (Kurzstudie)*, 2017. URL: https://www.i40-bw.de/wp-content/uploads/Kurzstudie_Arbeit-4.0_BW-1.pdf [as at: 19.08.2019].

**Altshuller/Shapiro 1956**
Altshuller, G. S./Shapiro, R. B.: "О Психологии изобретательского творчества (On the Psychology of Inventive Creation)". In: *Вопросы Психологии (The Psychological Issues)* (in Russian), 6: 1956, pp. 37–39.

**Ansari et al. 2018a**
Ansari, F./Erol, S./Sihn, W.: "Rethinking Human-Machine Learning in Industry 4.0: How Does the Paradigm Shift Treat the Role of Human Learning?". In: *Procedia Manufacturing*, 23: 2018, pp. 117–122.

**Ansari et al. 2018b**
Ansari, F./Khobreh, M./Seidenberg, U./Sihn, W.: "A Problem-Solving Ontology for Human-Centered Cyber Physical Production Systems". In: *CIRP Journal of Manufacturing Science and Technology*, 22: 2018, pp. 91–106.

**Ansari et al. 2018c**
Ansari, F./Hold, P./Sihn, W.: "Human-Centered Cyber Physical Production System: How Does Industrie 4.0 Impact on Decision-Making Tasks?". In: *2018 IEEE Technology and Engineering Management Conference*, 2018.

**Arntz et al. 2016**
Arntz, M./Gregory, T./Zierahn, U.: "The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis". In: *OECD Social, Employment and Migration Working Papers*, No. 189: 2016, OECD Publishing.

**Atkinson 2019**
Atkinson, D.: *Nihonjin no Shousan (Chance of Winning for Japanese)*, TOYO KEIZAI INC (Published in Japanese), 2019. URL: https://str.toyokeizai.net/books/9784492396469/ [as at: 19.08.2019].

**Autor 2015**
Autor, D. H.: "Why Are There Still So Many Jobs? The History and Future of Workplace Automation". In: *Journal of Economic Perspectives*, 29:3, 2015, pp. 3–30.

**Becker 2015**
Becker, K.-D.: "Arbeit in der Industrie 4.0 – Erwartungen des Instituts für angewandte Arbeitswissenschaft e.V". In: Botthof, A./Hartmann, E. A. (Hrsg.): *Zukunft der Arbeit in Industrie 4.0*, Berlin, Heidelberg: Springer Vieweg, 2015, pp. 23–30.

**BCG 2015**
Boston Consulting Group (BCG) (Ed.): *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries*, 2015. URL: https://www.bcg.com/de-de/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries.aspx [as at: 27.05.2019].

**BMAS 2017**
Federal Ministry of Labour and Social Affairs (BMAS): *Weißbuch Arbeiten 4.0*, 2017, p. 18ff. URL: https://www.bmas.de/SharedDocs/Downloads/DE/PDF-Publikationen/a883-weissbuch.pdf?__blob=publicationFile [as at: 19.08.2019].

**BMWi/BMAS 2016**
Federal Ministry for Economic Affairs and Energy (BMWi)/Federal Ministry of Labour and Social Affairs (BMAS) (Eds.): *Working in the Digital World: People, Organisation, Technology*, 2016, URL: https://www.digitale-technologien.de/DT/Redaktion/EN/Downloads/Publikation/autonomik-arbeiten%20in%20der%20digitalen%20welt-engl.pdf?__blob=publicationFile&v=6 [as at: 19.08.2019].

**Bonin et al. 2015**
Bonin, H./Gregory, T./Zierahn, U.: Übertragung der Studie von Frey/Osborne (2013) auf Deutschland – Endbericht –. Forschungsbericht 455, Zentrum für Europäische Wirtschaftsorschung GmbH, 2015. URL: https://www.bmas.de/SharedDocs/Downloads/DE/PDF-Publikationen/Forschungsberichte/fb-455.pdf?__blob=publicationFile&v=2 [as at: 26.08.2019.]

**Botthof/Hartmann 2014**
Botthof, A./Hartmann, E. A. (Hrsg.): *Zukunft der Arbeit in Industrie 4.0*, Berlin, Heidelberg: Springer Vieweg, 2014.

**Bowles 2014**
Bowles, J.: *The Computerisation of European Jobs – Who Will Win and Who Will Lose from the Impact of New Technology onto Old Areas of Employment?*, 2014. URL: http://bruegel.org/2014/07/the-computerisation-of-european-jobs/ [as at: 26.05.2019].

**Brzeski/Burk 2015**
Brzeski, C./Burk, I.: *Die Roboter kommen. Folgen für den deutschen Arbeitsmarkt*. INGDiBa, Economic Reserach, 2015. URL: https://www.ing.de/binaries/content/assets/pdf/ueber-uns/presse/publikationen/ing-diba-economic-analysis-die-roboter-kommen.pdf [as at: 26.05.2019].

**Cabinet Office 2018**
Cabinet Office, Government of Japan (Ed.): "Chapter 2 Human Capital and Work Styles in the Era of the 100-Year Life". In: *Annual Report on the Japanese Economy and Public Finance 2018 – White Paper: Toward The Economy of Society 5.0*, 2018. URL: https://www5.cao.go.jp/j-j/wp/wp-je18/pdf/all_02.pdf [as at: 19.08.2019].

**Carr 2014**
Carr, N.: *The Glass Cage: Automation and Us*, New York, NY: W.W. Norton & Company, 2014.

**De Bono 1967**
De Bono, E.: *New Think: The Use of Lateral Thinking in the Generation of New Ideas*, 3rd Edition, University of Michigan 1967.

**De La Rica/Gortazar 2016**
De La Rica, S./Gortazar, L.: "Differences in Job De-Routinization in OECD Countries: Evidence from PIAAC". In: *IZA Discussion Paper*, No. 9736, 2016. URL: http://ftp.iza.org/dp9736.pdf [as at: 15.08.2019].

**Dengler/Matthes 2018**
Dengler, K./Matthes, B.: "Substituierbarkeitspotenziale von Berufen in Deutschland – Weniger Berufsbilder halten mit der Digitalisierung Schritt". In: *IAB Kurzbericht*, 4:2018. URL: http://doku.iab.de/kurzber/2018/kb0418.pdf [as at: 19.08.2019].

**Destatis 2018a**
Statistisches Bundesamt (Destatis): *Bevölkerung und Erwerbstätigkeit – Bevölkerung mit Migrationshintergrund – Ergebnisse des Mikrozensus 2017* –, 2018. URL: https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Bevoelkerung/Migration-Integration/Publikationen/Downloads-Migration/migrationshintergrund-2010220177004.pdf?__blob=publicationFile [as at: 15.08.2019].

**Destatis 2018b**
Statistisches Bundesamt (Destatis): *Statistisches Jahrbuch 2018*. URL: https://www.destatis.de/DE/Themen/Querschnitt/Jahrbuch/jb-arbeitsmarkt.pdf?__blob=publicationFile&v=7 [as at: 19.08.2019].

**Elbestawi et al. 2018**
Elbestawi, M./Centea, D./Singh, I./Wanyama, T.: "SEPT Learning Factory for Industry 4.0 Education and Applied Research". In: *Procedia Manufacturing*, 23: 2018, pp. 249–254.

**Eurostat 2019**
Eurostat: *Employment Rate by Gender, Age Group 20-64*, 2019. URL: https://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=t2020_10&language=de [as at: 20.08.2019].

**Federal Employment Agency 2018**
Federal Employment Agency (Bundesagentur für Arbeit): *Labor Market for Foreigners (Monthly Figures)*, 2018. URL: https://statistik.arbeitsagentur.de/Statistikdaten/Detail/201807/analyse/analyse-d-arbeitsmarkt-auslaender/analyse-d-arbeitsmarkt-auslaender-d-0-201807-pdf.pdf [as at: 20.08.2019].

**Frey/Osborne 2013**
Frey, C.B./Osborne, M.A.: "The Future of Employment: How Susceptible are Jobs to Computerisation?" In: *Oxford Martin School Working Paper*, No. 18, 2013.

**Geisberger/Broy 2014**
Geisberger E./Broy, M. (Eds.): *Living in a Networked World. Integrated Research Agenda Cyber-Physical Systems* (agendaCPS) (acatech STUDY), Munich: Herbert Utz Verlag 2014.

**Gorecky et al. 2014**
Gorecky, D./Schmitt, M./Loskyll, M./Zühlke, D.: "Human-Machine-Interaction in the Industry 4.0 Era". In: *12th IEEE International Conference on Industrial Informatics (INDIN)*, July 27–30 Porto Alegre, Brazil, 2014. URL https://ieeexplore.ieee.org/document/6945523/versions [as at: 04.09.2019].

**Hamagin Research Laboratory 2016**
Hamagin Research Laboratory: *The Way of Renewal Investment Due to Corporate Equipment Age Increase* (in Japanese), 2016. URL: https://www.yokohama-ri.co.jp/html/report/pdf/ev002.pdf [as at: 19.08.2019].

**Hirsch-Kreinsen 2018**
Hirsch-Kreinsen, H.: "Einleitung: Digitalisierung industrieller Arbeit". In: Hirsch-Kreinsen, H./Ittermann, P./Niehaus, J. (Hrsg.): *Digitalisierung industrieller Arbeit – Die Vision Industrie 4.0 und ihre sozialen Herausforderungen*, 2. Auflage, Baden-Baden: Nomos Verlagsgesellschaft, 2018, pp.13–32.

**Hitachi Brand Channel 2018**
Hitachi Brand Channel: *Taking the Skills of Experts to the World through Collaborative Creation between Daikin and Hitachi*. Online Video on YouTube, 2018. URL: https://www.youtube.com/watch?v=hNu-zcxWPNw [as at: 19.08.2019].

**Hitachi Brand Channel 2019**
Hitachi Brand Channel: *Multiverse Barrier Free - Revitalize Human-Machine Collaboration*. Online Video on YouTube, 2019. URL: https://www.youtube.com/watch?v=fKjN3PPbUhk [as at: 19.08.2019.]

**Hitachi R&D Group 2017**
Hitachi R&D Group: *Flexible Production System Utilizing Human and Robot Cooperation*, Development Story, May 29, 2017. URL: https://www.hitachi.com/rd/portal/contents/story/cobot/index.html [as at: 19.08.2019].

**Hoose 2018**
Hoose, F.: "Digitale Arbeit – Strukturen eines Forschungsfeldes". In: *IAQ-Forschung – Aktuelle Forschungsberichte des Insitituts Arbeit und Qualifikation*, 2018. URL: http://www.iaq.uni-due.de/iaq-forschung/2018/fo2018-03.pdf [as at: 19.08.2019].

**Ittermann/Niehaus 2018**
Ittermann, P./Niehaus, J.: "Industrie 4.0 und Wandel von Industriearbeit – revisited: Forschungsstand und Trendbestimmungen". In: Hirsch-Kreinsen, H./Ittermann, P./Niehaus, J. (Hrsg.): *Digitalisierung industrieller Arbeit – Die Vision Industrie 4.0 und ihre sozialen Herausforderungen*, 2. Auflage, Baden-Baden: Nomos Verlagsgesellschaft 2018, pp. 33–60.

**Iwamoto 2018**
Iwamoto, K: "Impact of Employment by Artificial Intelligence and Social Policies". In: Managi, S. (Ed.): *The Economics of Artificial Intelligence: How Our Lives, Our Work and Our Society Will Change*, RIETI Books, Minerva Publishing, 2018, pp. 19-45.

**Iwamoto/Tanoue 2018**
Iwamoto, K./Tanoue, Y.: "Digitization, Computerization, Networking, Automation, and the Future of Jobs in Japan." In: RIETI (Ed.): *RIETI Policy Discussion Paper Series*, 18-P-013: 2018. URL: https://www.rieti.go.jp/jp/publications/pdp/18p013.pdf [as at: 19.08.2019].]

**Jacobs et al. 2017**
Jacobs, J. C./Kagermann, H./Spath, D. (Eds.): *The Future of Work in the Digital Transformation – Agility, Lifelong Learning and the Role of Employers and Works Councils in Changing Times*. A paper by the acatech and Jacobs Foundation Human Resources Working Group – Forum for HR Directors on the Future of Work (acatech DISCUSSION), Munich: Herbert Utz Verlag 2017.

**Jacobs et al. 2018**
Jacobs, J. C./Kagermann, H./Sattelberger, T./Lange, T./Depiereux, P./van Alphen, C./Greve, A./Lohmann, T./Bruckner, L./Werther, S.: "Aktuelle Studien zur Zukunft der Arbeit". In: Werther, S./Bruckner, L. (Hrsg.): *Arbeit 4.0 aktiv gestalten – Die -Zukunft der Arbeit zwischen Agilität, People Analytics und Digitalisierung*, 2018, Berlin: Springer-Verlag, pp. 23-46.

**JMA 2018**
Japan Medical Association (JMA), Academic Promotion Council: *AI and Medical Care, 9th Academic Promotion Council Report*, 2018. URL: http://dl.med.or.jp/dl-med/teireikaiken/20180620_3.pdf [as at: 23.08.2019].

**Kagermann et al. 2013**
Kagermann, H./Wahlster, W./Helbig, J.: *Recommendations for implementing the strategic initiative INDUSTRIE 4.0" (Final report of the Industrie 4.0 Working Group)*, 2013. URL: https://www.acatech.de/wp-content/uploads/2018/03/Final_report__Industrie_4.0_accessible.pdf [as at: 19.08.2019].

**Lanza et al. 2018**
Lanza, G./Nyhuis, P./Fisel, J./Jacob, A./Nielsen, L./Schmidt, M./Stricker, N.: *Wandlungsfähige, menschzentrierte Strukturen in Fabriken und Netzwerken der Industrie 4.0* (acatech, Research Council of the Plattform Industrie 4.0), München: Herbert Utz Verlag 2018.

**Majkovic et al. 2018**
Majkovic, A.-L./Werkmann-Karcher, B./Gundrum, E./Birrer, J./Genner, S./Probst, L./Huber, R./Pfister, A.: *IAP Studie 2017 – Teil 2. Der Mensch in der Arbeitswelt 4.0*. Ergebnisse der qualitativen Interviews, Zürich: IAP Institut für Angewandte Psychologie der ZHAW Zürcher Hochschule für Angewandte Wissenschaften, 2018. URL: https://www.zhaw.ch/storage/psychologie/upload/iap/studie/IAP-Studie_Teil-2_Bericht.pdf [as at: 28.08.2019].

**McKinsey Global Institute 2017**
McKinsey&Company, McKinsey Global Institute: *Jobs Lost, Jobs Gained: What the Future of Work Will Mean for Jobs, Skills, and Wages*, 2017. URL: https://www.mckinsey.com/~/media/mckinsey/featured%20insights/Future%20of%20Organizations/What%20the%20future%20of%20work%20will%20mean%20for%20jobs%20skills%20and%20wages/MGI-Jobs-Lost-Jobs-Gained-Report-December-6-2017.ashx [as at: 27.08.2019].

**METI 2017**
Ministry of Economy, Trade and Industry (METI): *Trade White Paper 2017*. URL: https://www.meti.go.jp/report/tsuhaku2017/whitepaper_2017.html [as at: 18.08.2019].

**MHLW 2019**
Ministry of Health, Labor and Welfare (MHLW): *Employment Situation of Foreigners* (in Japanese), 2019. URL: https://www.mhlw.go.jp/stf/houdou/0000192073.html [as at: 19.08.2019].

**MIC 2019a**
Ministry of Internal Affairs and Communications (MIC), Statistics Bureau: *Japan Statistical Yearbook 2019, Chapter 2: Population and Households*, 2019. URL: http://www.stat.go.jp/english/data/nenkan/68nenkan/1431-02.html [as at: 23.08.2019].

**MIC 2019b**
Ministry of Internal Affairs and Communications (MIC): *Labor Force Survey Results* (in Japanese), 2019. URL: http://www.stat.go.jp/data/roudou/longtime/03roudou.html [as at: 19.08.2019].

**Monostori et al. 2016**
Monostori, L./Kádár, B./Bauernhansl, T./Kondoh, S./Kumara, S. R./Reinhart, G./Sauer, O./Schuh, G./Sihn, W./Ueda, K.:"Cyber-Physical Systems in Manufacturing". In: *CIRP Annals-Manufacturing Technology*, 65:2, 2016, pp. 621-641.

**Munir et al. 2019**
Munir, M./Siddiqui, S. A./Küsters, F./Mercier, D./Dengel, A./Ahmed. S.: "TSXplain: Demystification of DNN Decisions for Time-Series Using Natural Language and Statistical Features". In: *28th International Conference on Artificial Neural Networks (ICANN)*, 2019.

**National Intelligence Council 2012**
National Intelligence Council: *Global Trends 2030: Alternative Worlds*, 2012. URL: https://www.dni.gov/index.php/who-we-are/organizations/mission-integration/nic/nic-related-menus/nic-related-content/global-trends-2030?highlight=WyJnbG9iYWwiLCJnbG9iYWxpemF0aW9uIiwiZ2xvYmFsbHkiLCJnbG9iYWxpemVkIiwiZ2xvYmFsaXplIiwiZ2xvYmFsJ3MiLCJnbG9iYWxpemluZyIsInRyZW5kcyIsInRyZW5kIiwidHJlbmRpbmciLCJnbG9iYWwgdHJlbmRzIl0= [as at: 19.08.2019].

**Nikkei Asian Review 2017**
Nikkei Asian Review: *Japan Falls to 14th in Manufacturing Productivity: Survey*, 2017. URL: https://asia.nikkei.com/Economy/Japan-falls-to-14th-in-manufacturing-productivity-survey [as at: 21.08.2019].

**Nonaka 2019**
Nonaka, Y.: *Navigation Scheme of Smart Manufacturing System Development for Each Maturity Level Enterprise – An Activity of German-Japan IoT Collaboration PJ*. Presentation at Forum Industrie 4.0, Hannover Messe 2019. URL: http://files.messe.de/abstracts/91524_uni_0204_1600_Y_Nonaka_Hitachi.pdf [as at: 19.08.2019].

**Nedelkoska/Quintini 2018**
Nedelkoska, L./Quintini, G.: "Automation, Skills Use and Training". In: *OECD Social, Employment and Migration Working Papers*, No. 202: 2018. URL: https://doi.org/10.1787/1815199X [as at: 04.09.2019].

**OECD 2019**
Organisation for Economic Co-operation and Development (OECD): *Economic Outlook, Volume 2019, Issue 1*, 2019. URL: https://doi.org/10.1787/b2e897b0-en [as at: 15.08.2019].

**Ohashi et al. 2017**
Ohashi, H./Al-Naser, M./Ahmed, S./Akiyama, T./Sato, T./Nguyen, P./Nakamura, K./Dengel, A.: "Augmenting Wearable Sensor Data With Physical Constraint For Dnn-Based Human-Action Recognition". In: *ICML 2017 Times Series Workshop*, Sydney, Australia, 2017. URL: https://www.dfki.de/web/forschung/projekte-publikationen/publikationen/publikation/9676/ [as at: 04.09.2019].

**Ohashi et al. 2018**
Ohashi, H./Al-Naser, M./Ahmed, S./Nakamura, K./Sato, T./Dengel, A.: "Attributes' Importance for Zero-Shot Pose-Classification Based on Wearable Sensors". In: *Sensors*, 18(8): 2018. URL: https://www.mdpi.com/1424-8220/18/8/2485 [as at: 19.08.2019].

**Palacio et al. 2018**
Palacio, S./Folz, J./Hees, J./Raue, F./Borth, D./Dengel, A.: "What do Deep Networks Like to See". In: *The IEEE Conference on Computer Vision and Pattern Recognition (CVPR). International Conference on Computer Vision and Pattern Recognition (CVPR-2018)*, June 18-22 Salt Lake City, Utah, United States IEEE, 2018. URL: https://ieeexplore.ieee.org/document/8578426 [as at: 04.09.2019].

**Pfeiffer/Suphan 2015**
Pfeiffer, S./Suphan, A.: "Industrie 4.0 und Erfahrung: Statt vager Prognosen zu technologischer Arbeitslosigkeit morgen, heute das Gestaltungspotenzial der Beschäftigten nutzen und anerkennen". In: Hirsch-Kreinsen, H./Ittermann, P./Niehaus, J. (Hrsg.): *Digitalisierung industrieller Arbeit*. Baden-Baden, 2015, S. 205–230.

**Pfeiffer et al. 2016**
Pfeiffer, S./Lee, H./Zirnig, C./Suphan, A.: *Industrie 4.0 – Qualifizierung 2025*. VDMA Study, 2016. URL: https://www.sabine-pfeiffer.de/files/downloads/2016-Pfeiffer-Industrie40-Qualifizierung2025.pdf [as at: 22.08.2019].

**PLS 2019**
Lernende Systeme – Die Plattform für Künstliche Intelligenz (PLS) (Hrsg.): *Arbeit, Qualifizierung und Mensch-Maschine-Interaktion – Ansätze zur Gestaltung Künstlicher Intelligenz für die Arbeitswelt*. Whitepaper. AG Arbeit/Qualifikation, Mensch-Maschine-Interaktion. URL: https://www.plattform-lernende-systeme.de/files/Downloads/Publikationen/AG2_Whitepaper_210619.pdf [as at: 05.09.2019].

**Schallock et al. 2018**
Schallock, B./Rybski, C./Jochem, R./Kohl, H.: "Learning Factory for Industrie 4.0 to Provide Future Skills Beyond Technical Training". In: *Procedia Manufacturing 23*: 2018, pp. 27–32.

**Schröder 2017**
Schröder, C: "Lohnstückkosten im internationalen Vergleich". In: Institut der Deutschen Wirtschaft Köln (Hrsg.): *IW-Trends Nr. 4*: 2017. URL: https://www.iwkoeln.de/fileadmin/user_upload/Studien/IW-Trends/PDF/2018/IW-Trends_4-2017_Lohnstueckkosten.pdf [as at: 19.08.2019].

**Schwartz et al. 2016**
Schwartz, T./Feld, M./Folz, J./Hevesi, P./Hutter, D./Kiefer, B./Lüth, C./Mronga, D./Spieldenner, T./Wirkus, M./Zinnikus, I./Straube, S.: "Hybrid Teams of Humans, Robots and Virtual Agents in a Production Setting". In: *Proceedings of the 12th International Conference on Intelligent Environments. International Conference on Intelligent Environments*: 2016. URL: https://ieeexplore.ieee.org/document/7723506 [as at: 04.09.2019].

**Shi et al. 2019**
Shi, X./Baba, N./Osagawa, D./Fujishima, M./Ito, T.: "Maturity Assessment: A Case Study Toward Sustainable Smart Manufacturing Implementation". In: *2019 IEEE International Conference on Smart Manufacturing, Industrial & Logistics Engineering*, April 19–21, 2019.

**Siddiqui et al. 2018**
Siddiqui, S. A./Mercier, D./Munir, M./Dengel A./Ahmed, S.: "TS-Viz: Demystification of Deep Learning Models for Time-Series Analysis". In: *IEEE Access 2018*. DOI:10.1109/ [as at: 19.08.2019].

**Taub et al. 2002**
Taub, E./Uswatte, G./Elbert,T.: "New Treatments in Neurorehabilitation Founded on Basic Research". In: *Nature Reviews Neuroscience*. 3(3): 2002, pp. 228-236.

**Tsutsumi et al. 2018**
Tsutsumi, D./Gyulai, D./Kovács, A./Tipary, B./Ueno, Y./Nonaka, Y./Monostori, L.: "Towards Joint Optimization of Product Design, Process Planning and Production Planning in Multi-product Assembly". In: *CIRP Annals - Manufacturing Technology*, 67(1): 2018, pp. 441–446.

**Umeda et al. 2019**
Umeda, Y./Ota, J./Kojima, F./Saito, M./Matsuzawa, H./Sukekawa,T./Takeuchi, A./Makida, K./Shirafuji, S.: "Development of an Education Program for Digital Manufacturing System Engineers Based on 'Digital Triplet' Concept". In: *Procedia Manufacturing*, 31: 2019, pp. 363–369.

**UN 2017**
United Nations (UN), Department of Economic and Social Affairs: Population Division (2017). *World Population Prospects: The 2017 Revision, Volume I: Comprehensive Tables*, 2017. URL: https://population.un.org/wpp/Publications/Files/WPP2017_Volume-I_Comprehensive-Tables.pdf [as at: 23.08.2019].

**UN 2019**
United Nations (UN): *17 Goals to Transform Our World*, 2019. URL: https://www.un.org/sustainabledevelopment/ [as at: 19.08.2019].

**Vogler et al. 2016**
Vogler-Ludwig, K./Düll, N./Kriechel, B.: *Arbeitsmarkt 2030 Wirtschaft und Arbeitsmarkt im, digitalen Zeitalter – Prognose 2016*, 2016. URL: https://www.arbeitenviernull.de/fileadmin/Downloads/arbeitsmarktprognose-2030.pdf [as at: 27.05.2019].

**World Bank 2019**
The World Bank.: *Population growth (annual %)*, 2019. URL: https://data.worldbank.org/indicator/SP.POP.GROW [as at: 23.08.2019].

# acatech – National Academy of Science and Engineering

acatech advises policymakers and the general public, supports policy measures to drive innovation, and represents the interests of the technological sciences internationally. In accordance with its mandate from Germany's federal government and states, the Academy provides independent, science-based advice that is in the public interest. acatech explains the opportunities and risks of technological developments and helps to ensure that ideas become innovations – innovations that lead to greater prosperity, welfare, and quality of life. acatech brings science and industry together. The Academy's Members are prominent scientists from the fields of engineering, the natural sciences and medicine, as well as the humanities and social sciences. The Senate is made up of leading figures from major science organisations and from technology companies and associations. In addition to its headquarters at the acatech FORUM in Munich, the Academy also has offices in Berlin and Brussels..

Further information is available at www.acatech.de

**Editor:**

**Prof. Dr. Dr.-Ing. E. h. Henning Kagermann**
**acatech – Deutsche Akademie der Technikwissenschaften**
**Pariser Platz 4a**
**10117 Berlin**
**Germany**

**Ph.D. Youichi Nonaka**
**Center for Technology Innovation – Production Engineering**
**Research & Development Group**
**Hitachi, Ltd.**
**292, Yoshida-cho, Totsuka-ku, Yokohama**
**244-0817 Japan**

**Series editor:**

**acatech – National Academy of Science and Engineering, 2019**

Munich Office
Karolinenplatz 4
80333 Munich | Germany
T +49 (0)89/52 03 09-0
F +49 (0)89/52 03 09-900

Berlin Office
Pariser Platz 4a
10117 Berlin | Germany
T +49 (0)30/2 06 30 96-0
F +49 (0)30/2 06 30 96-11

Brussels Office
Rue d'Egmont/Egmontstraat 13
1000 Brussels | Belgium
T +32 (0)2/2 13 81-80
F +32 (0)2/2 13 81-89

info@acatech.de
www.acatech.de



Recommended citation:
Kagermann, H., Nonaka, Y. (Eds.): *Revitalizing Human-Machine Interaction for the Advancement of Society. Perspectives from Germany and Japan* (acatech DISCUSSION), Munich 2019.



Coordination: Joachim Sedlmeir, acatech, Lisa Hubrecht, acatech
Edited by: Alexander Chavez
Layout-concept: Groothuis, Hamburg
Conversion and typesetting: Fraunhofer IAIS, Sankt Augustin

The original version of this publication is available at www.acatech.de

In recent years, countries such as Germany and Japan are being faced with social challenges such as a maturing workforce or aging machines and infrastructure. Also, productivity declines can be expected in an older population due to diminishing physical and reactive capabilities. Digital technologies like cyber-physical systems (CPS), artificial intelligence (AI), and robotics may help solve these social challenges. However, applying these technologies also impacts social transformation, since the technologies perform primarily routine cognitive tasks that were previously the domain of humans.

This acatech DISCUSSION seeks to establish how these problems should be defined and what new approaches in human-machine interaction (HMI) can contribute to achieving the goal of sustainable societies. Against the background of a qualitative change of humans and machines, it proposes that the digital transformation can enable a novel, human-centred manufacturing system in which humans concentrate on life-long skill improvement and continuously create high-value-added work.