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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

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NATIONAL ACADEMY OF SCIENCE AND ENGINEERING

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Outline

Foreword

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Global Representative & Advisor,
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Industrie 4.0 has been conceived as 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, a phase of sustainable growth should be established, in which ecological (e.g. circular economy), and social or societal challenges (e.g. the future of work) were addressed equally to the 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.

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 there are similar challenges the Japanese and German society is confronted with (e.g. aging population, skills shortage, etc.) there are also diverging societal trends and culturally related different problem-solving approaches that 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.

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Social subjects such as resource depletion, environmental burdens, declining birthrates and aging are global-wide challenges for the establishment of sustainable societies. Japan also focuses on those subjects since we have real affections and incidents due to operational errors and/or by machine deterioration in our society.

Furthermore, even in this 4th industry evolution era, we feel it is not enough to define the problems and impacts of those social subjects for our society of current and of the future. Many publications tend to introduce new technologies such as Artificial Intelligence (AI), Software Defined Control (SDC), 5G communications, etc., not to focus on challenges and policies based on sociological point of view and organizational point of view. This is the motivation of the German and Japanese colleagues gathered for this project.

Based on this motivation, this paper focuses on challenges and policies with some quantitative researches and assumptions with some use cases delivered from Germany and Japan. It was a quite valuable experience for us to feel the similarities and differences between the German and Japanese perspectives on how to grasp the problem, which is caused by the historical background and social structure of Germany and Japan, even though we aimed the same goal.

We expect that this paper will provide an opportunity to connect social subjects with the everyday issues confronting us. And we hope that our daily activities will contribute in a positive and better way in striving to establish 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 technology. 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 augmented human and self-learning machines collaboration – which is also referred to as human-machine collaborated 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 human 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 life-long 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 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.

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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 US 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 Cyber-Physical Systems (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 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?

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[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 the context of digitalization and Industrie 4.0[9], working methods are referred to as “Arbeit 4.0” or “Work 4.0” in Germany, in which other trends and drivers like globalization, demographic, cultural and societal changes are also considered, including aspects of training and co-determination.[10] As a consequence of the digital transformation, it can be assumed that employees are being confronted with significant changes in the way they work and collaborate – both with humans and with machines.[11] In Germany, social partners, such as work councils and management or trade unions, have realized that the future of work has a significant impact on employees, collaboration and on the company’s organization. Moreover, it also affects the quality of work, job satisfaction, health, qualifications along with interaction between humans and machines by creating new forms of collaboration.[12] Therefore, in this chapter, we focus on social issues revolving around employment, working methods and human resource development and provide some statistical data about labor population, quality and productivity, as well as some forecasts about changes in labor structure that are being induced by the digital transformation in society.

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

In Japan and Germany, a decrease in population of productive-age has already begun. In addition, a rapid advance in population decrease and aging of society by lower level of total fertility rate compared with a worldwide level is observable (Table 3-1).[13]

Table 3-1. Changes of populations in major countries (Source: Atkinson 2019, p.24).

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
World wide	7,466,964	10,165,231	36.1

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.

As the background, we observed the following:

- Germany has been demonstrated a trend of relatively small or even negative population growth since the early 70th.[14]
- Japan was the first country where the number of people of 64 was more than 20 percent.[15]
- Over time, both countries have learned to deal with the related social challenges.
- One of the differences between the two countries is the migration background. In Germany, more than 23 percent of the people have a migration background.[16] In Japan, however, less than two percent have a migration background.[17]

Generally, the process of the digital transformation changes our society rapidly, but according to the economic outlook published by OECD, the overall labor productivity growth decreased over the last few years in most OECD countries. A slightly decrease can also be identified both for Germany as well as for Japan (see Figure 3-1).

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

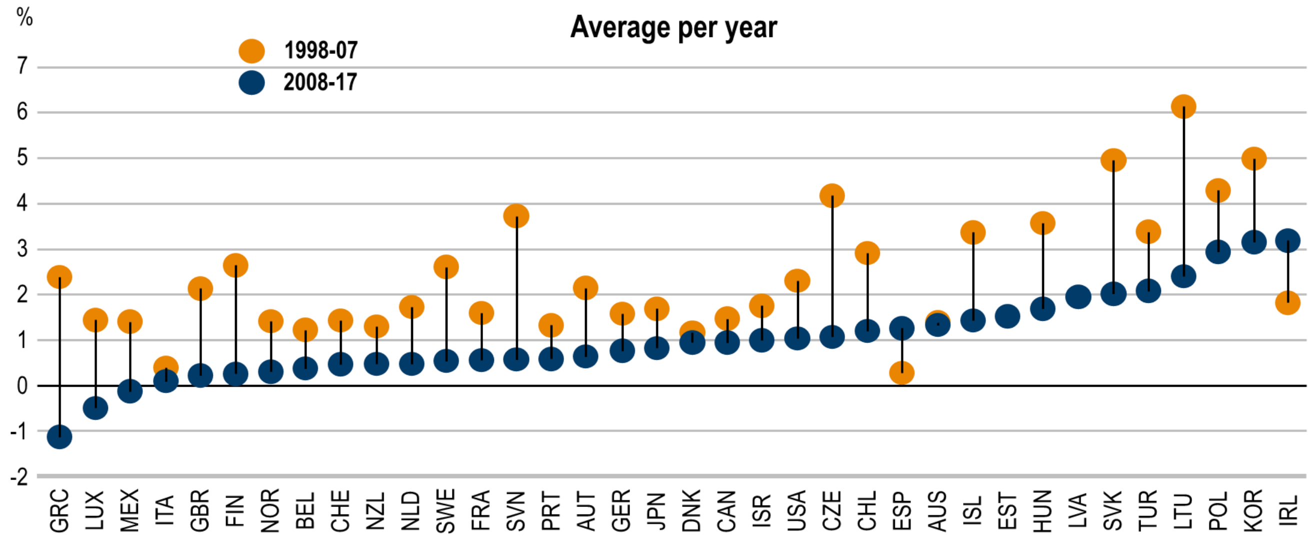

Figure 3-1. Labor productivity growth in OECD countries
(Source: OECD 2019, p. 57).

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 3-2 indicates the ranking of unit labor costs in the manufacturing industry.[19] It is a comparative index (Germany is standard = 100). It reveals the high unit labor costs in Germany, whereas 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 labor costs, that, in turn potentially threatens the 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]

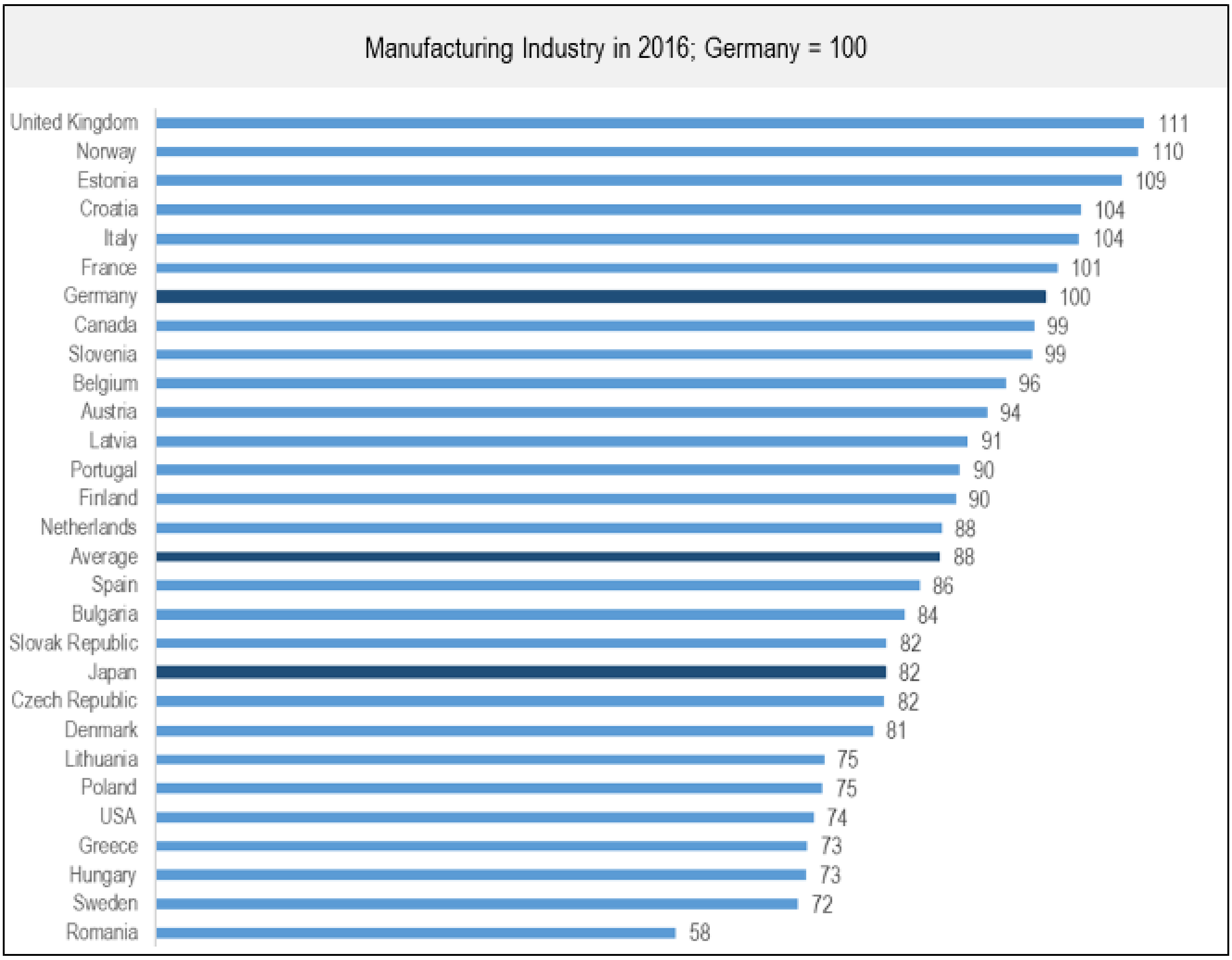

Figure 3-2. International Comparison of unit labor costs in manufacturing
(Source: Schröder 2018, p. 78).

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19 See Schröder 2017, p. 78.

20 See Schröder 2017, p. 75; 78.

21 See Nikkei Asian Review 2017.

In addition, Table 3-2 indicates the ranking of quality of human resources.[22] Hereby, Japan took the fourth place while Germany is ranked no. 11.

Table 3-2. Quality of human resources (Source: Atkinson 2018, p. 80).

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

Risk of change and risk of automation

According to Arntz et al. 2016, OECD, there are two types of risks for workers in 2016: 50-70% with "change in tasks", and 70 to 100% with "automation of tasks".[23] Nedelkoska and Quintini (2018) published the new estimation of risks for 70-100% and 50-70% in OECD countries (Figure 3-3). The portion of employment substitution risk is 70-100%, for 16% in Germany, 9% in US, 13% in Japan, and 14% in OECD average.[24]

This estimate was a consensus by experts throughout the world. As for Japan, according to the Work Force Survey 2017 by the Ministry of General Affairs, the number of work force was 67.2 million. As the risk of 70-100% is 13%, calculation of 67.2 million×0.13=8.7 million.

[22] See Atkinson 2019.

[23] See Arntz et al. 2016.

[24] See Nedelkoska/Quintini 2018.

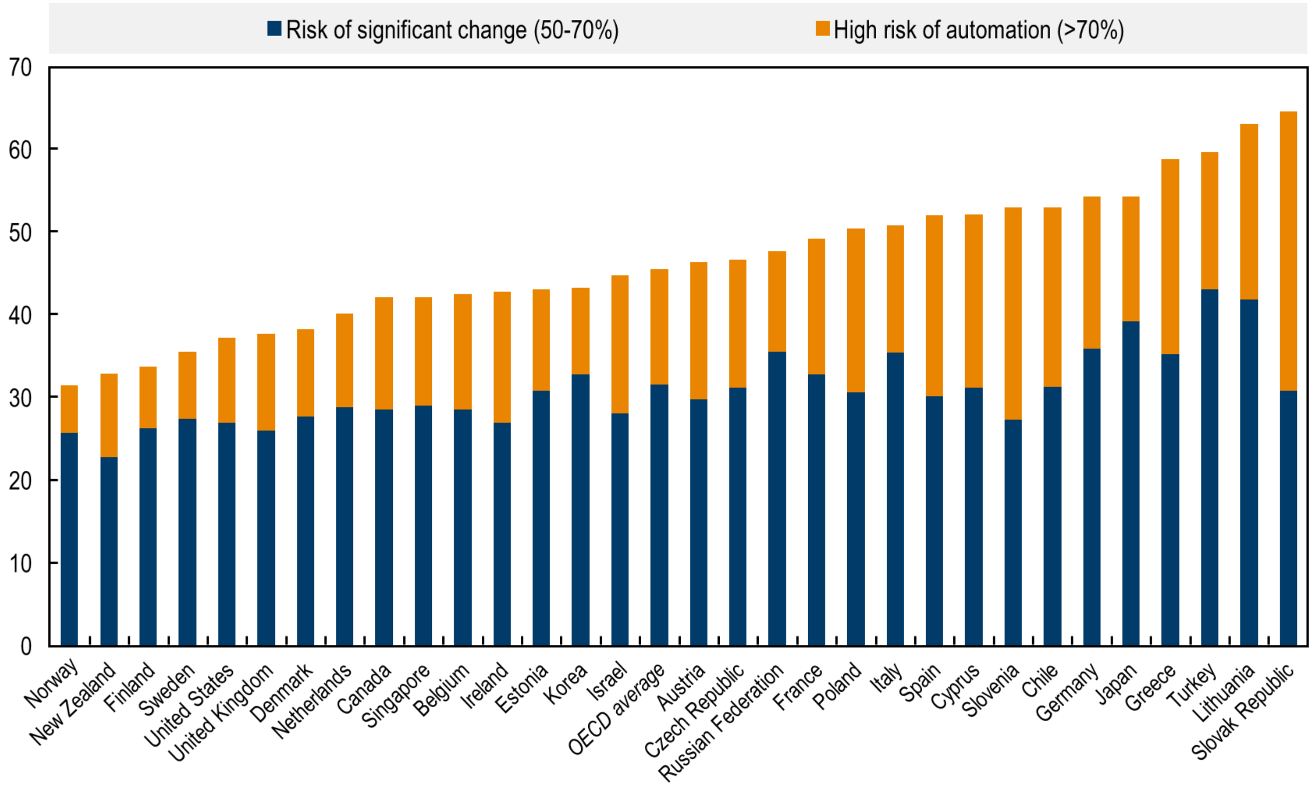

Figure 3-3. Cross-country variation in job automatability, %age of jobs at risk by degree of risk (Source: Nedelkoska/Quintini 2018, p. 49).

When we see these tables, it turns out that when it comes to productivity, Japan and Germany have a great deal of room for improvement. Improving human skill-sets and the related changes in the quality of human work are an area of high potential. Such human skills can be developed by digitalization as an enabler for the competitiveness of industries in the situation of a decreasing population and a changing workforce.

In order to achieve real sustainable growth, it's important to raise the potential growth rate by increasing the investment and innovation.

For Germany and Japan, boosting digitalization is a favorable option to gather thought potentials. Digitalization can help offer potential employees more high-value-added jobs and add higher value to the industry itself in that human beings can assign to machines that can be better performed by those machines.

Society has to drive these changes so that humans and machines can develop together in a harmonized way in terms of sharing of work-related tasks and supporting them. We have to ask ourselves what such a change in the world of work 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 US, 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 the replacement of human workers by machines and economic disparity resulting therefrom are caused by active investment in information and communication technology (ICT, see Figure 3-4).[25] In Japan, there is no comparable analysis, but the mechanism and process that structural change of employment, the process of the replacement of machine to human and economic disparity is thought to be almost the same as US. This research output was the most significant output of a series of "the future of work" research works, and a great deal of subsequent research has been strongly influenced by this research.

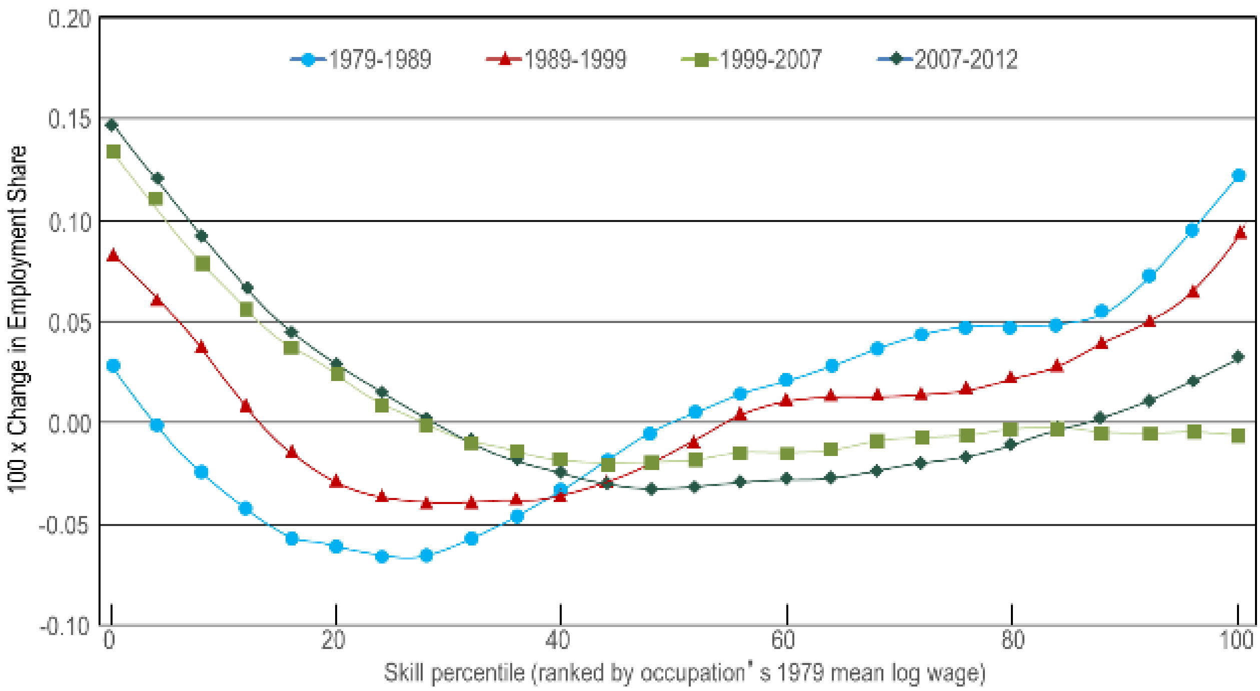

Figure 3-4. Smoothed employment changes by occupational skill percentile, 1979-2012 (Source: Autor 2015, p. 20).

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 (1–64) 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 followings, we call "low skill" or "inexperienced" as meaning of that the skill percentile is low, and so on.

[25] See Autor 2015.

Autor explains that the active ICT investments changed employment structure for more than thirteen 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 many years of training for human is necessary to learn, it can be programmed as it is 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 is being replaced by robots). In the U.S., employees with middle skilled occupations are replaced by computers due to ICT investment. The boundaries of continuing decrease of employment loss is moving towards higher skill positions.

As the number of inexperienced workers continues to grow, so too will the speed. The number of highly skilled workers will continue to increase, but the speed of the increase will decline. 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 for the labor market that fulfill company needs declines. The increasing speed of highly skilled workers declines and wage increase. Most middle-level skilled workers who lose their jobs transfer to inexperienced jobs. The total number of inexperienced jobs, however, remains constant, and as a result, wages continue to stay at a low level and the 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].

Case study in Germany: The future of employment

Frey and Osborne (2013) derive in their well-known study "the future of employment" that routinized tasks will be substituted in the US.[28] Moreover, they estimate that 47% of the total US employment is already in more than 70% risk category, which could potentially be automated in the next decade(s).[29] The result by Frey and Osborne has two important conditions. 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 U.S. may be substituted. Nevertheless, these cases were counted as a possibility for substitution by machine. The second condition is new employment by new industries were not considered. Frey and Osborne's estimate extends to a practical number, based on calculation, of employed workers who exist present and who may lose jobs in the future. They did not include the number of new employments that will be created by new future industries.

Once the Frey and Osborne estimate was published, The Ministry of Labor and Social Affairs of German Government started the "Arbeiten 4.0" or "Work 4.0" project to confirm the numbers of the estimation in Germany. The Ministry commissioned the analysis to Zentrum für Europäische Wirtschaftsforschung GmbH (ZEW). ZEW recalculated under the same condition of Frey and Osborne.

[26] See Autor 2015, p. 5.

[27] See Autor 2015, p. 5.

[28] See Frey/Osborne 2013, Hirsch-Kreinsen 2018, p. 17.

[29] See Ittermann/Niehaus 2018, p. 43.

Their paper indicated that the risk in US was 9% and in Germany 12% as of June 2015.[30] The estimation by Frey and Osborne was 47% but 9% by ZEW. How did this difference occur? The reason was the difference of estimation method.

Frey and Osborne presumed a substitution of humans by machines in the context of jobs. However ZEW distinguishes between jobs, work and tasks where jobs are broken into a series of tasks.They assume that the portion of tasks done by machine will gradually increase and finally 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 machine in a single stage, which is considered as overestimated.

As for the process of substitution of humans by machines, the Institute of Arbeitswirtschaft und Organisation, Fraunhofer (Fraunhofer IAO) has conducted a detailed research and analysis. Fraunhofer IAO first surveyed various numbers of German companies, but could not find consistency. Second, when Fraunhofer IAO surveyed the trends of German companies, they found consistency of the same activities as follows: 1) Machines are used to support humans. 2) Humans will make efforts to increase their skills, and companies provide skill training to employees. However, as the progress 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 happening in reality is a separation of a series of tasks divided into tasks done by machine or human. As the separation progress, the human role becomes to do tasks which must be done by human: It may be very detailed, delicate, non-routine, and creative. Human will be requested to have more and more high skills. For these several years, AI engineers are developing the technologies to replace the human artistic, cultural, and sensitive activities. These activities were thought to be an output of human creativeness. But by monitoring these activities carefully, it was found that these activities contained many routine tasks.

As technology progressed, routine tasks and physical strain and hard labor once had to be done by human, were eventually substituted by machine. This is the history of technology and will continue in the future. To prepare for these changes, human must self-train during their entire life-time.

In Japan, Senior Researcher K. Iwamoto, the Research Institute of Economy, Trade and Industry (RIETI) has the following hypothesis regarding the process of substitution of humans by machines, after many interviews of Japanese companies. 1) The first stage is, hard labor disliked by human is substituted by machines. The aim of these introductions of machines is to support human, then human raise their motivation. 2) The introduction of machine progresses. Then humans are requested to perform more high skilled work and companies promote human resource development investment. 3) The rate of machines being introduced increases. Managers start to replace humans and layoffs will start. 4) Ultimately, all humans are replaced by machines.

[30] See Bonin et al. 2015.

In a global perspective, according for the estimation by 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 learn a new skill by 2030.[31]

It is surprising that the hypothesis RIETI has and results of research output by Fraunhofer IAO are the same, that is, the process of machines replacing humans is the same in both countries.

Overall, the research and analysis of estimation for employment in the future was drawn from three parts. 1) The decreasing tendency of routine tasks will continue. As technology progresses, more high skilled routine tasks will be replaced by machines. 2) The number of unexperienced workers will continue to increase, but as the technology progresses, the volume of tasks replaced by machines will increase. We must argue that as machines' abilities increase over time and at a faster rate than the increase in that of inexperienced workers, it's likely that workers will be replaced by machines. Therefore, we have to design harmonized systems for humans and machines, wherein machines support inexperienced workers who are striving to improve their skills. By the support of the technology, the worker can follow the skill growth and grow faster than machines or other workers. This will lead to a situation where humans grow side by side with machines. 3) The number of highly skilled workers will continue to increase, but the need for highly skilled workers by companies will also grow. However, since the supply of highly skilled workers in the employment market will be unable to match companies' needs, wages will continue to increase.

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

According to the research and analysis worldwide, there is a trend that as technology progresses, machines will replace humans for routine tasks. Measurements for the rate of routine tasks in each country are conducted actively by experts around the world. Such a rate is expressed by what is referred to as Routine Task Intensity (RTI). De la Rica and Gortazar (2016) published the results of RTI of OECD countries.[32]

Hereby, the RTI is defined as follows:

$$RTI_i = R_i - A_i - M_i$$

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]

The RTI differentiates the countries, focusing on different stages in the de-routinization process. The U.S., for example, represents a highly de-routinized country (RTI=-0.39). Similar to other central European countries, Germany (RTI=-0.12) is characterized as medium de-routinized country. Japan (RTI=0.26), however, is positioned in the group of so called *low* de-routinized countries.[34]

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.

The study of De la Rica and Gortazar (2016) also shows that e.g. workers in the U.S. have adopted technology more intensively in comparison to central European workers. Moreover, the ICT-adoption in Japan is slightly faster compared to the PIAAC (Programme for the International Assessment of Adult Competencies) sample.[35]

As a result, the total number of workers does not seem to change much in Japan. However, when looking at the type of labor, there is a possibility that the required skills will not correspond to the supply and demand of labor. For example, many workers may lay off before the emergence of new labor demand due to the rise of new industries.

It is a case of whether the total number of workers of a company will increase or decrease, and if humans doing routine work are ultimately replaced by machines. There is a possibility that as the competitiveness of the company and sales increase, the company may expand. Then the total number of workers may increase by introducing machines. On the other hand, even when technology progress, a company may continue to keep the old-fashioned work style by not introducing new technology. Then the productivity and the competitiveness of the company may decrease, and a large scale of layoff may happen.

When new technology is introduced, the phenomenon of workers loss is mainly focused. But introducing new technology has another effect that creates new jobs. For example, a young person who did not have the skill to work under the old technology, such as using an oil tooling machines in a factory, may be able to work under the new technology, such as development of application software by personal computer. For the conclusion of this matter, the most serious problem is how to deal with the person who never caught up with the new technology, after a series of re-training and re-learning. For this problem, Japan, same as Germany has not yet reached to an answer.

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 as a short-term compensation through novel activities wouldn´t be feasible.[36]

Similar results can be found in the German context.[37] The risk of substitution generally falls with the requirement level of the task.[38] Figure 3-5 shows which requirement levels of human work are most likely to be substituted by technical systems.[39] Between 2013 and 2016 that the gap between high and low levels of requirement had become even larger.

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35 De La Rica/Gortazar 2016, p. 11.

36 See Ittermann/Niehaus 2018, p. 43, Bowles 2014.

37 See Dengler/Matthes 2018.

38 See Dengler/Matthes 2018, p. 1.

39 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).

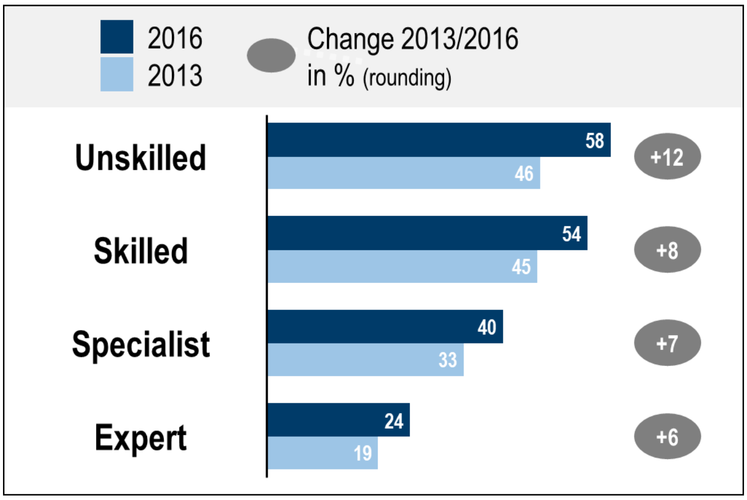

Figure 3-5. Substitution potentials by requirement level in %, 2013-2016 (Germany)
(Source: Dengler/Matthes 2018, p. 1).

Various studies also anticipate – at least from a short term perspective – a potential risk of substitution for qualified, non-routinized occupations, characterized by a high level of creativity and interaction – not only on the shop-floor in the industrial sector but also in the context of administration, development and management.[40] There are even scenarios, which forecast a potential decrease of nearly 60% of the employment (mostly routine jobs) in Germany.[41] For an overview of estimated substitution potentials by occupational segments, see Figure 3-6. Again, it can also be seen, that not only the occupations within the production processes in the context of Industrie 4.0 are affected but also the service sector.[42]

[40] See Hirsch-Kreinsen 2018, p. 17.

[41] See Ittermann/Niehaus 2018, p. 43, Brzeski/Burk 2015, p. 3.

[42] See Allianz Industrie 4.0 Baden-Württemberg 2017.

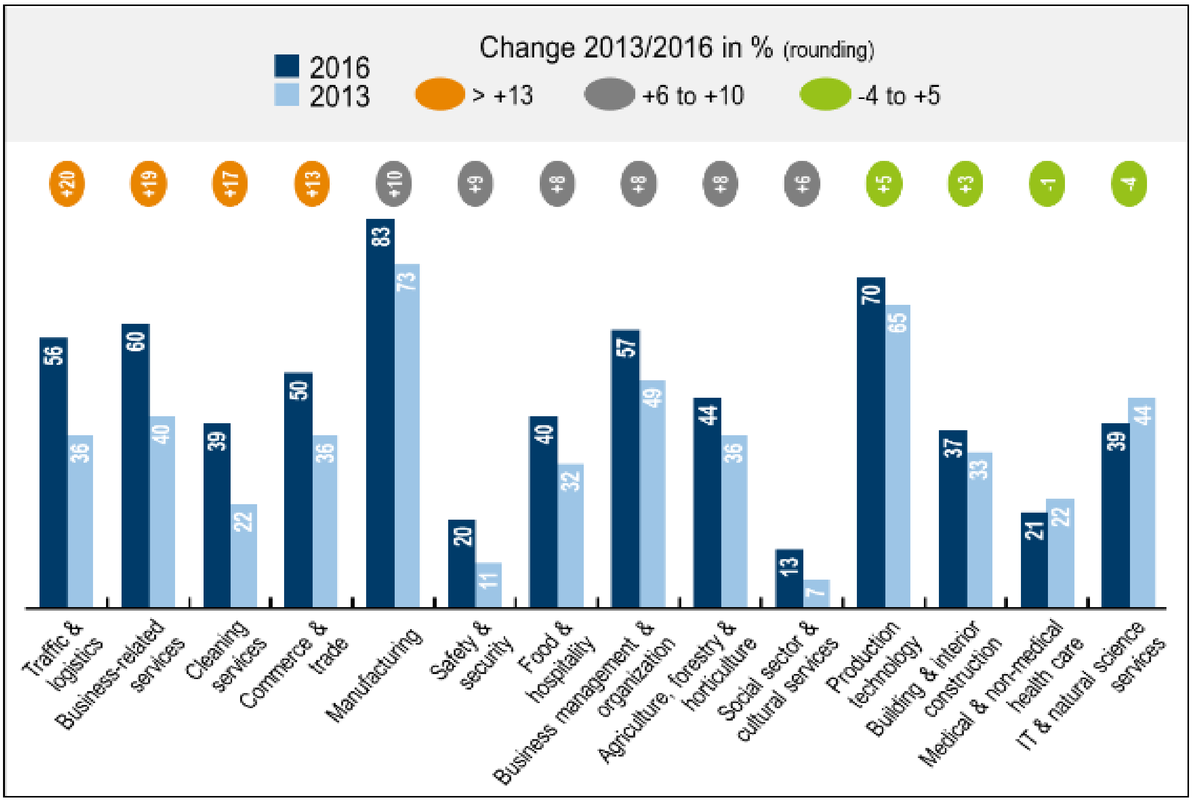

Figure 3-6. Substitution potentials by occupational segments in %, 2013-2016 (Germany) (Source: Dengler/Matthes 2018, p. 6).

In the course of the digital change, however, companies are also able to react faster and more precisely to changed and 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 willingness to change, flexibility and adaptability of organizations and its employees is crucial for success in the face of global competition.[43] Key factors in the successful introduction of Industry 4.0 include the acceptance of new technologies by employees and the design of attractive forms of work.[44]

At the same time, the higher degree of flexibility, in turn, opens up the potential chance for workers also to 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 a key to ensuring their future employability (lifelong learning). For this, both companies that provide the corresponding educational and training offers and their employees that are meant to benefit from these measures have a shared responsibility.[45]

The phenomenon that it is not only routine occupations and tasks that require minimal qualifications are potentially the ones that 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.

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43 See Jacobs et al. 2017, p. 9, Lanza et al. 2018.

44 See Abel et al. 2019.

45 See Jacobs et al. 2017, p. 9.

Case study in Japan: AI applied into medical care

This case study describes an AI application to medical hospitals in 9th Academic Promotion Council Report by Japan Medical Association Academic Promotion Council.[46] AI learns treatment results from all over the world and advises doctors of the treatment policy for 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 Artificial Intelligence. There is a report that the misdiagnosis rate has decreased by 85% due to cooperation between doctors and AI. In the 2016 metastatic breast cancer diagnosis contest (Camelyon Grand Challenge), the misdiagnosis rate of Artificial Intelligence was 7.5% and the misdiagnosis rate of pathologists was 3.5%. The misdiagnosis rate decreased to 0.5%.

The report also explained "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 it is, the presence of a doctor will continue to be necessary. But what doctors do may vary greatly"[47]. In the report, Prof. Tsumoto, Shimane University mentioned that it is noticed that Artificial Intelligence to support the business is changing the way of the business itself.

The same can be said for the factories, where the cycle of receiving "advice" from AI, with the final assessment being made by humans, could establish a good relationship between AI and human.

When the above-mentioned AI or robots replace the even "more skilled routine cognitive tasks" performed by human beings, economic disparities in society will grow. Then the phenomenon occurs where the total number of employees increase in low skilled low wage labor market, wages do not rise, and employment becomes unstable. This happens when jobs for medium-skilled employees are lost, and fall into the lower skilled positions, although the total amount of low skill jobs remains unchanged. The number of employees employed in occupations that require low skills has been rising continuously, as well as accelerating.

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[46] See JMA 2018.

[47] See JMA 2018, p. 38.

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

As for Japan, the Cabinet Office of Japanese Government published Economic and Financial White Paper 2018 with a corporate consciousness questionnaire survey in February 2018. According to the results, concerning the work expected to be reduced when IoT (Internet of Things) and AI are introduced, the order of “general affairs, receptionist, secretary”, “general affairs, personnel management, accounting”, “manufacturing, production process, management” (Figure 3-7).

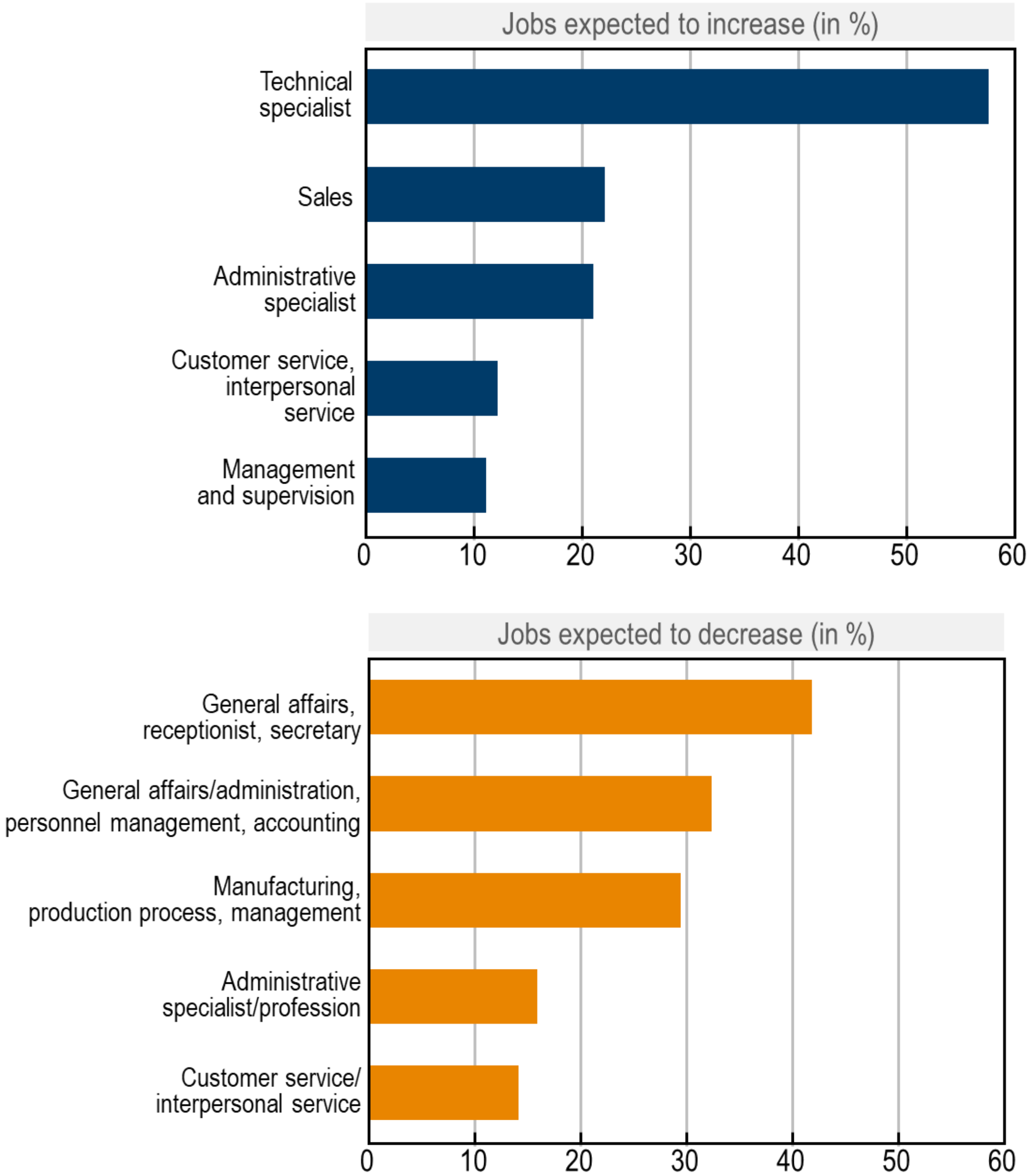

Figure 3-7. Expected increase and decrease in professions in terms of the progression of AI and IoT implementation (Source: Cabinet Office 2018, p. 141).

*administrative profession refers to survey analysis or legal etc. Technical specialist refers to research and development, system design etc. As for administrative specialist, customer service, interpersonal service, companies responded both to expectations for increase and decrease. Therefor the categories appear in both.

The business that the company is considering to substitute for AI is in the order of “Accounting, Finance, Taxation”, “Constant Document Production”, “Labor Management Relationship”, “Adjustment of Schedule etc.”, “Manufacturing and Assembly” (Figure 3-8). When the introduction of IoT and AI progress, the management of Japanese companies expect to reduce skilled workers in the factories second to office clerks, in regard to personnel reduction.

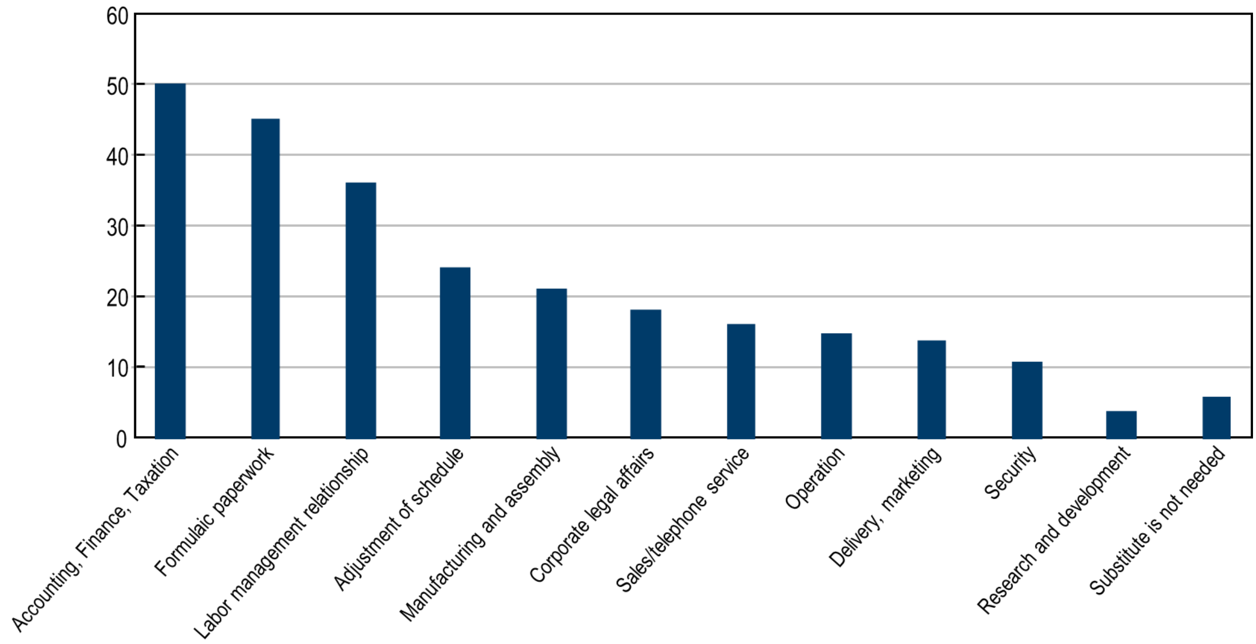

Figure 3-8. Occupations likely to be replaced by AI (in%)
(Source: Cabinet Office 2018, p. 142).

According to Gini coefficient of Japan,[48] 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 task to RPA is in progress in the administrative division of Japanese company’s offices. In particular, the banking and finance industry is most active in this respect. From recent press announcements by three megabanks, all three megabanks reported that about 30,000 personnel were to be reduced by ICT investments. Those who take part in the routine cognitive task are primarily regular employees responsible for clerical jobs and non-regular employees. As RPA progresses, presumably, Japanese companies will protect employment by realign personnel for regular employees where as non-regular employees will be dismissed. Just by taking a look at recruitment of new graduates in the spring of 2019, we can see that the banks have greatly reduced the recruitment of regular employees for clerical jobs.

48 See METI 2017.

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

RPA is now extending to manufacturing companies in Japan. For example, Nitto Denko manufactures switchboards and has 150 employees; design engineers have many time to print out design drawings currently, but Nitto Denko has introduced RPA into the printing process, amounting to 20 hours cut in printing time per month.[49] As it can be seen in this example, even in manufacturing companies, some process are routine office work which can be replaced by RPA.

Thus, in Japan, the banking and finance industry and the local government are now leading ahead in the implementation of RPA and eventually expanding to manufacturing and other industries, the "higher skilled routine cognitive office work tasks" are about to be replaced by computer.

These employees are expected to enter the labor market looking for unskilled low wage jobs just to make a living, and in this low skilled low wage labor market, the unemployed Japanese will be competing for job opportunities against the resident foreign workers. In Germany, more foreign people are employed than in Japan.

Case study in Germany: Required skill change in field workers

Although autonomous systems potentially relieve the human operators in certain areas, such as in quite monotonous daily job scheduling operations, the volume of complex tasks is increasing at the same time. Consequently, there is a higher demand for willingness to learn – e.g. via various assistive systems or further qualification programs and concepts in order to keep pace with the changed requirements. All employees involved in the production process must increasingly adopt interdisciplinary forms of work. This is due to the fact that co-operation is required, especially with IT. Moreover, it is obvious that demand is likely to shift from foremen to IT specialists.[50]

In the past, nearly every technological development or progress has been accompanied by new skills needs. In the context of the digital transformation, Industrie 4.0 and new forms of HMI, companies are especially challenged by the fact that these requirements are now changing at an accelerated rate and, in addition, almost all activities are affected.[51] As a consequence of the short innovation cycles and the changing requirements, precisely tailored employee training measures are necessary. Therefore, a comprehensive analysis of the skills an individual worker or employee possesses is crucial. In a second step, those skills that are needed 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 measures that both meet the needs of the individual worker and the whole company.[52] While conceptualizing an adequate (re-)qualification and learning strategy, the potential

[49] See Iwamoto 2018.

[50] See BMWi/BMAS 2016, p. 14.

[51] See Jacobs et al. 2018, p.27.

[52] See Jacobs et al. 2017, p. 9.

diversity (esp. between younger and older people) has to be considered.[53] In terms of the technology-related skills, developing skills across IT, and especially AI is a necessity.[54] This insight, however, has been far from acknowledged across the entire German economy and across the board in the workforce. While the spread of the term "Industrie 4.0" certainly lends an enormous amount of attention to digitalization, there are still companies that are failing to systematically grasp the need for action when it comes to fostering development in terms of skills and qualifications. The fast and well-founded training and retraining is, however, crucial for a successful transformation into deployment, employability and "good work".[55]

In order to enable and provide the workforce with greater qualifications (and students as a future workforce), there are various strategies and measures that can be undertaken (e.g. seminars, workshops, business games or practice-related case studies). Moreover, during the last years, a promising approach has been developed, called learning factory[56]. Especially in Europe, a variety of different learning factories has been established that have taken specific forms, focuses and purposes. All learning factories, however, have in common, that a hands-on qualification for the human worker is pursued.[57] A key advantage of a learning factory is the fact that certain training and demonstration activities can be carried out without the risk of potential production downtime, as would be possible in the real production environment. Recently, more and more learning factories or labs have been focused on Industrie 4.0-related topics. The approaches, however, mostly fail to combine both learning aspects of humans and machines.[58]

Case study in Japan: Required skill change in field workers

In Japan, there is a history of cherishing skilled field workers in the factories. The new digital technology now being introduced to the factories isn't replacing working with computers but makes the best use of these skilled field workers. When IoT is introduced, the workers acquire the new skill while receiving little training, so the problem of re-education or retraining of field workers has not become obvious in Japan, rather, the issue of AI that is to be introduced in a few years. The new digital technology now introduced to the factories in Japan is the "visualized" system. Therefore, skilled field workers are still responsible for looking at the displayed visualized data, exploring the cause of the failure of production machines and devising countermeasures. However, the operations that is based on the past precedent, such as learning the precedent, then judging measures from the displayed data, should be replaced by AI in the near future.

In Japan, the number of large manufacturers that are fully introducing new technologies to their factories and proving the output results is still a few. According to Fujitsu executives,[59] emphasis is

53 See Majkovic et al. 2018.

54 See also PLS 2019.

55 See Jacobs et al. 2018, p.27.

56 See Schallock et al. 2018, p. 28, see also the "Case study in Germany: Learning Factory" in Chapter 0.

57 See Schallock et al. 2018, Elbestawi et al. 2018.

58 See Ansari et al. 2018a, Schallock et al. 2018.

59 See Iwamoto 2018.

placed upon the purpose of new digital technology to "empower humans" and lessen the burden of the employees, the company's IoT system support a lack of skills of field workers due to skilled field workers' population decline and support a decline the level of skills of field workers due to aging, and support field workers as many-various and small-volume products is increasing. Mitsubishi Electric's executives say that in the 1990's investment for mechanization,[60] automation and labor saving in the factories were active, but now the atmosphere is introduced to leave jobs suitable for machine (human) work to machine (human), which is said as "harmony between human and machine". The executives of DENSO,[61] (a supplier of Toyota) stress the fact that "the concept for the IoT system of DENSO is human-centered". DENSO positions the skilled field workers as company treasure to create competitiveness. It is worth pointing out that visualization by digital technology alone is insufficient for the skilled person to provide sufficient performance in the field. And they state that it's important to actually measure shortcomings in production equipment and to formalize how the shortcomings are solved by skilled workers. Both Mitsubishi Electric's e-F@ctory and Hitachi's Lumada,[62] which are representative IoT platforms in Japan, are designed on the same idea. In addition, the executives of Nippon Steel Co. emphasize[63] "we continue to invest in issues 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 the questionnaire survey to comprehend the trend of IoT in Japanese industry from August to October 2017 targeting 10,075 Japanese companies, and collected responses from 1,372 companies (recovery rate 13.62%).[64] Through the introduction of new digital technology, 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 system. The survey revealed, not only the technical experts but also the needs for administration who manage them and office clerks who support the technical experts are increasing. Meanwhile, in the administrative divisions of the banking and finance industry etc., computerization of routine cognitive tasks is ongoing and clerical office workers is reduced continuously. When calculating the present increases and decreases, the increases are greater than the decreases, which means that, Japanese companies are more eager to digitalize factories in the manufacturing sector than the office. This may apparently be the case, we will need to monitor this trend carefully in the future.

[60] See Iwamoto 2018.

[61] See Iwamoto 2018.

[62] See https://www.mitsubishielectric.co.jp/fa/sols/ and https://www.hitachi.co.jp/products/it/lumada/index.html.

[63] See Iwamoto 2018.

[64] See Iwamoto/Tanoue 2018.

Case study in Germany: A positive scenario against the previous discussions

In Germany, there is a scenario that the substitution potential can not immediately be equated 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 activity cannot be fully automated at reasonable costs.[65] In contrast to an pessimistic view, that i.e. refers to potential substitution effects of human workforce and a devaluation of industrial work, the positive scenario highlights the potential aspects or consequences of the implementation of modern technologies and Industrie 4.0 systems from an optimistic perspective, e.g. by referring to improvements in competitiveness, quality of living, work-life balance etc.[66]

Therefore, in the context of this optimistic scenario, positive labor market effects are expected. This is i.e. forecasted in a study by the Boston Consulting Group, which 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 work, in mechanical engineering, in the automotive sector and in electrical engineering.[67] A rather moderate technological change in the industry and the successive enrichment of work and production processes by new technologies is often regarded as basis for this development.[68] Moreover, it is argued that even the low skilled workers are still needed and that nearly all kinds of routine work entail non-routine elements like experience-based knowledge that is hard substitute by technical systems.[69] In addition, a general overestimation of technological potentials and implications is stated, that in turn lead to potentially misleading conclusions as described in the pessimistic or negative scenario.[70].

This positive scenario also features a new look or perspective at the interactions between humans and machines and 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 industrial production system. In case of problems or breakdown, they are able to intervene, thanks to their previous experience. All in all, the qualified workers are supposed to be fully in control over the entire work and production processes. If necessary, a flexible and adequate support by technical assistance systems is provided.[71]

Together with the change in the interactions of humans and technology in novel forms of communication and collaboration, the restructuring of work and lifelong learning that is necessary to control the also changing Cyber-Physical Systems (CPS), such assistance systems create the prerequisites to maintain and continuously improve the physical and mental performance capabilities of humans.[72]

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65 See Allianz Industrie 4.0 Baden-Württemberg 2017.

66 See Ittermann/Niehaus 2018, p. 39f.

67 See Ittermann/Niehaus 2018, p. 39f., BCG 2015.

68 See Ittermann/Niehaus 2018, p. 40., Vogler et al. 2016.

69 See Pfeiffer/Suphan 2015, See Ittermann/Niehaus 2018, p. 53.

70 See Hirsch-Kreinsen 2018, p. 17.

71 See Ittermann/Niehaus 2018, p. 41f.

72 See Becker 2015, p. 25.

Today, it is generally accepted that the individual productivity of the people does not primarily depend on the chronological, but from the biological age. In particular, assistance systems allow machines that interact with people to make the work demographically sensitive and to reduce strain.[73] Together with specific measures of work design and initiatives for competency development, an interactive collaboration between humans on the one side and technological systems on the other side creates new opportunities for companies even to benefit from the process of demographic change. In times of a prevailing 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 through work.[74]

In summary, one can conclude that the positive scenario is also supported by forecasts, which suggest an upgrading of 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.

Case study in Germany: Hybrid teams of humans, robots & virtual agents in a production setting[75]

[Concept video available from below link;
A concept video is available from below link: https://robotik.dfki-bremen.de/de/mediathek/videoarchiv/hysociatea-ausgewaeh.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 the human-machine interaction are enabling new forms of cooperation in hybrid teams. In this project, funded by the German Federal Ministry of Education and Research (BMBF), researchers at the German Research Center for Artificial Intelligence (DFKI GmbH) aim at realizing and examining the collaboration of augmented humans with autonomous robots, virtual characters and SoftBots in order to work out common tasks and to meet future production requirements that are characterized by a high degree of complexity and flexibility.

Hereby, not only the technical feasibility is analyzed, but also the development of (robotic) team-competencies and intelligent multi-agent behavior. By proactively assisting the humans in the production process, they are seen as partners without being directly instructed. This, in turn, has important implications on (future) decisions on 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 and the SoftBots[76] aggregate the data that is produced by the other team members, update databases and are responsible for providing meaningful, refined data.

73 See Becker 2015, p. 26.

74 See acatech 2016, p. 16.

75 This case study is described in Schwartz et al. 2016.

76 SoftBots can be defined as purely software-based agents or computer programs that can act autonomously in virtual worlds.

4. Gap emerged due to diversities & approaches of sustainable innovations

This chapter discusses the anticipated increase in the diversification of workers and machines in the near future and promotes solution policies with sustainable innovations across the life cycle of products and services.

4.1. Gap emerged due to diversities

Since the industrial revolution, companies have striven to standardize production in order to achieve high production volumes at high speeds. However, nowadays, standardization has reached its limits. The declining population has led to a diversified workforce with varied capabilities in the manufacturing fields. Even in the case of machines, old machine tools are being used alongside AI robots (Figure 4-1).

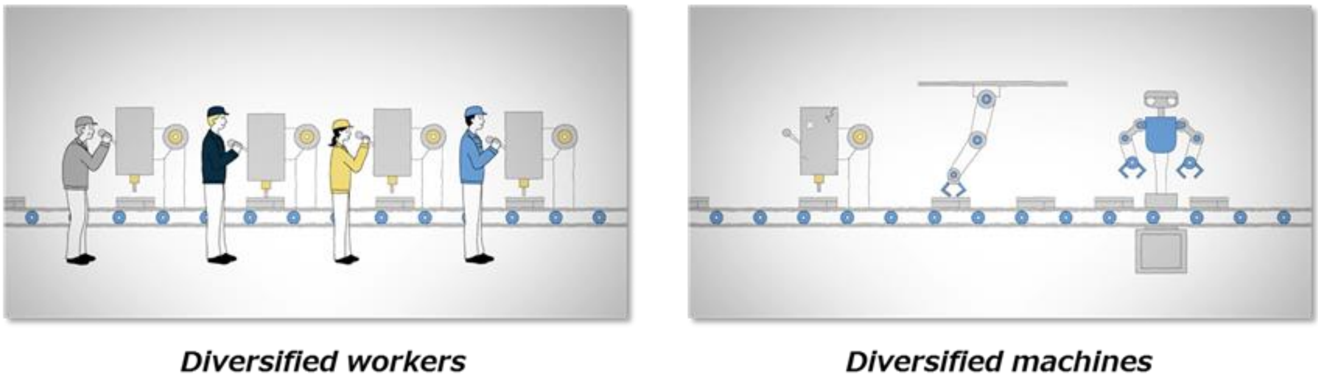

Figure 4-1. Possible changes on workers and machines in factories.
(Source: https://www.youtube.com/watch?v=fKjN3PPbUhk).

In manufacturing, increasing diversity has created gaps that have been causing imbalances between the planned task and actual capabilities of workers and machines. This imbalance might exhaust workers and/or machines or lead to an opportunity loss.

Regarding to growth in diversity, in Japan, the declining population has been boosting workforce diversity. Table 4-1 shows increasing trends of diversity, such as woman, elderly people and non-Japanese employee. This diversity comes along with new requirements for the working environment.

Table 4-1. Trends on employment in Japan (Source: MIC 2019b, MHLW 2019).

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

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 4-2.

Table 4-2. Trends on the average life of facilities in Japan (Source: Hamagin Research Laboratory 2016).

	Trends of the times		
Average life	8 [years] (1971)	10 [years] (1991) **+2 [years]**	16 [years] (2016) **+ 6 [years]**

Germany is also facing several social and technical challenges, as illustrated in Table 4-3. This compels companies to explore new ways to utilize the hidden potentials of humans and machines. Such potentials include people with disabilities, the diversity of people with migration background and the extensive knowledge base of elderly people.

Table 4-3. Trends on employment in Germany
(Source: Eurostat 2019, Destatis 2018b, Federal Employment Agency 2018).

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

As mentioned above, the competitiveness of Japanese and German manufacturing sectors could be impacted due to a decline in the skilled workforce as well as demographic and technological trends challenging the hitherto state-of-the-art production processes and workflows.

Both Germany and Japan are facing a shortage of skilled workforce as well as an aging workforce pool; this scenario has been leading to more diversified workforce structures in industry in terms of age, gender, and skills. At the same time, currently, advanced automation in the manufacturing sector is transforming job profiles and the way humans and machines interact at the workplace. Owing to the rapid pace of this development, discrepancies between skills demanded for planned tasks and actual capabilities of factory employees have emerged leading to a skill gap. In Germany, there is too much of a shortcoming in science, technology, engineering mathematics (STEM) and care qualifications, but this trend has been ongoing for some time now, starting long before Industrie 4.0 was introduced.

While job profiles and requirements may change, this – at least in the context of the German manufacturing sector – that does not automatically mean that vocational qualified workers are obsolete and people with necessary qualification are not to find. However, it's important that workers learn what is new to be learned. In addition, often there is only a slight change necessary in the vocational profiles.[77]

Relating to the importance of interactions between humans and smart systems, it also seems to be necessary to not only focus on how humans or machines can learn but also how they improve their skills. Therefore, the question is how smart, autonomous devices or systems and humans can learn from each other. In the context of HMI, there are basically two groups of learners (humans and machines) that, in turn, follow distinctive but interacting learning concepts. For the HMI, however, hybridization of the learning concepts is necessary in order to achieve mutual learning success between humans and machines. This mutual learning is potentially affected by different potential capacity of humans and machines in performing different tasks such as mechanical jobs and decision-making roles. Quality and performance variation in carrying out a task are regarded as key indicators, which identify and ultimately distinguish the capability of human and machine on performing the assigned task. Table 4-4 provides a comparison of quality and performance variation of the learner groups with respect to an assigned task.

Table 4-4. Comparing capability of human and machine (learner groups), based on quality and performance variation (Source: Ansari et al, 2018a, p. 119).

Capability		Human	Machine
Quality Variation in	Mechanical Job	• High inter-individual differences and diversities • It can be improved by training and job satisfaction	• Very low • It can be degraded over lifetime or due to inappropriate maintenance
	Decision-Making	• High inter-individual differences and diversities depending on problem-solving abilities, competences, experiences and qualification level • Personal, societal and institutional interests may influence on human decision-making • 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 affected by human, and complexity of the problem field • The 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) • High possibility of work fatigue and job dissatisfaction	• Very low (depending on the lifetime, associated degradation rate and service quality)

The already discussed differences in the capabilities of the (individual and technical) learners reflect enormous learning potentials both for human workers and smart machines or devices. The respective learning process may either be independent (distinctive training for each group) or dependent (co-occurrence of learning by executing a common task). At present, there is still a lack on exploring co-occurrence of human-machine learning. Hence, we have a strong tendency to differentiate between learning approaches.

77 See Pfeiffer et al. 2016.

Ansari et al. 2018a define the mutual learning as *"a bidirectional process involving reciprocal exchange, dependence, action or influence within human and machine collaboration, which results in creating new meaning or concept, enriching the existing ones or improving skills and abilities in association with each group of learners"*[78].

Case Study: "Learned non-use phenomenon" in manufacturing

In future, AI robot technology is supposed to be increasingly introduced into manufacturing systems in order to obtain high performance from the viewpoint of high quality and low cost. After all, what will be the extent of the influence of AI robot technology on humans in the long term? Taking the easy way of introducing in AI robot technology may have a negative effect on the proficiency of humans. This occurs because the humans might be accustomed to the situation that they do not need to do any skills in the manufacturing process. We need to consider the possibility of this emerging vicious cycle of AI robot introduction and a corresponding decline in the skills of human beings (left cycle on Figure 4-2).

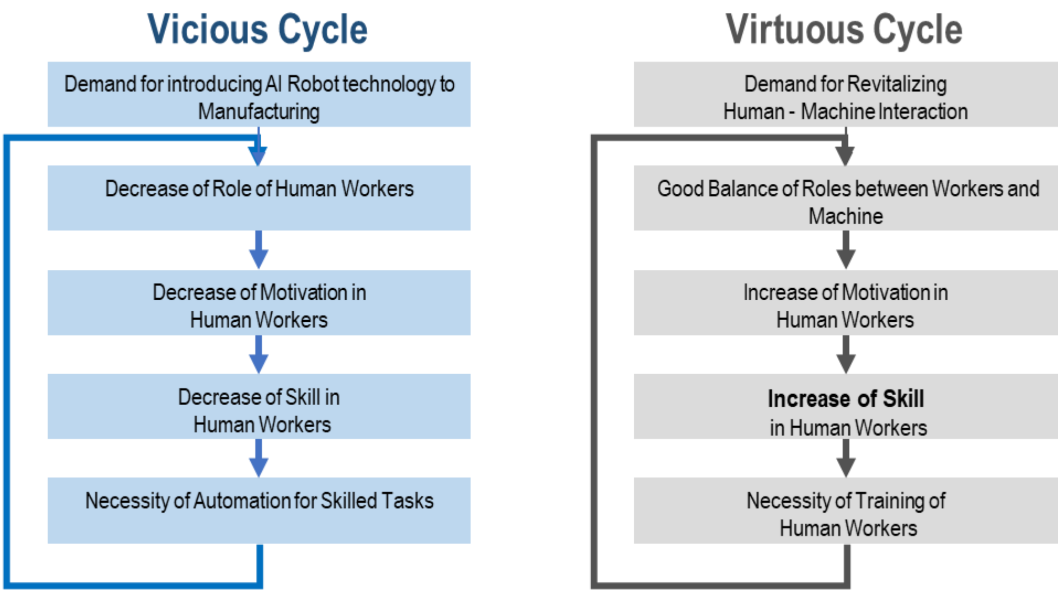

Figure 4-2. Vicious and virtuous cycle in humans and AI robot systems
(Source: The University of Tokyo).

In the field of brain science, substantial neurological injury usually leads to produce a vicious downward spiral that results in "learned nonuse" of the affected extremity.[79] Similar discussion has been conducted as for the relationship between automation and humans.[80].

As for the methodology to overcome learned non-use 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 arm for a period of consecutive weeks. In addition, use of the uninvolved limb can be restricted, so much so that the subject

[78] Ansari et al. 2018a, p. 119.

[79] See Taub et al. 2002.

[80] See for example Carr 2014.

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 the future manufacturing sites, two requirements need to be fulfilled: (a) The efficient achievement of tasks with the cooperation of humans and AI robots and (b) the enhancement of skills in human workers through applying training process. One possibility is to construct an excellent management system (might be AI-based) to implement a systematic harmonization of HMI that can arbitrate the above two problems (right cycle on Figure 4-2).

4.2. Managing the real-world and the cyber-world

Manufacturing companies are traditionally dominated by classical engineering roles from mechanical or electrical engineering, especially in R&D. Mechanical and electrical engineering have been at the core of innovation activities in manufacturing since the 19th century, co-evolving over the last 100 years and being at the core of the unprecedented development driving what we call industry today.

Nevertheless, over the past few decades, the importance of software as a driver for innovations in machinery or electric products has increased ever since. These software innovations have mainly occurred within embedded systems, physically confined to the single machine and still driven by the physics.

Meanwhile the software industry has grown significantly over the last decades at an ever-increasing speed, while becoming 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. Together with an increasing complexity and addition of new layers of software this has established the field of software engineering which developed its own methods and tools as well as unique processes and organizational procedures.

The emergence of Industrie 4.0 now signifies the fact that both worlds get connected and merged. This leads to a whole new arena of innovation in this overlapping world which leverages the methods and procedures of the cyber-world on top of classical engineering how-to.

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

Software development itself is a "desktop-based" activity, confined to the virtual world of computers and servers. This in itself opens up careers to people who have hitherto been excluded from the workforce to a large degree, but who in the virtual world have no impediment any longer. We will give one example of this in the following chapter. Further, the development of software which is embedded in machinery requires not only software skills but also a deep understanding of those production technologies, in which the software is to be integrated. Therefore, qualified workers with insights and decades of experience into machinery, production technology and its hurdles, would bring a special expertise into software development if they have been additionally qualified.

To sum it up: the real-world and the cyber-world merge within Industrie 4.0 into a new domain of innovations where a new set of tools, methods and principles are the foundation to success, but have to be combined with existing processes, technological paths and worthful manufacturing qualifications and experiences. Manufacturing companies must actively make themselves acquainted with new challenges and adopt them, but activate and innovate their unique manufacturing expertise.

4.3. Sustainable innovations with diversities

Both Germany and Japan face a shortage of skilled labor and an aging labor force pool, leading to more diversified workforce structures in industry in terms of age, gender and skills. At the same time the advanced automation that is currently taking place in the manufacturing sector transforms job profiles and the way humans and machines interact at the workplace. Inclusive working environments will therefore become an even more significant competitive differentiator and a driver of business success, as they attract the most talented employees in a tight labor market. 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 with colleagues with different viewpoints generates a greater mix of ideas that spurs innovation.

Case Study in Germany: SAP "Autism"

[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 Europe's largest software company SAP 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 the software companies such as SAP – a key partner for the transformation to Industry 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 has been 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, which thus far has remained largely unaddressed by the labor market, adding to its overall competitiveness.

The Autism at Work Program was officially launched in 2013 and so far, as per Q2 2019, SAP has over 155+ employees with autism working in 26 different roles from 13 countries with a retention rate of 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 under-employed. People with autism are often attentive to routines and sameness and have difficulty 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, where 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, amongst 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. While 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, benefitting from saved social welfare costs and strengthened social cohesion. After all, the 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 tick. 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

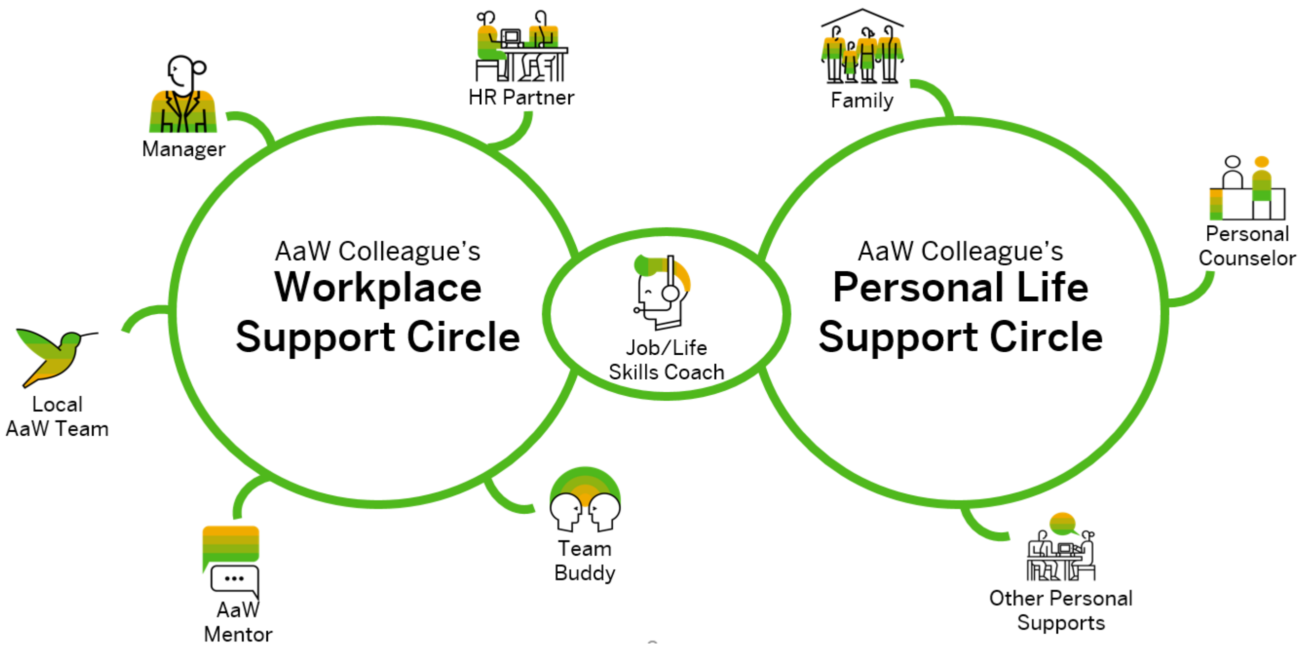

Figure 4-3. SAP's Autism at Work Program
(Source: SAP)

In order to help the program succeed, SAP has built a network of partners, including NGOs, research institutes and government agencies, supporting 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 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 of people with autism are used to being left out by conventional recruitment programs, the fact that their skills are sought after must be put on their radar.

The "harmonization" in the interaction between variety of human and machine is different from the complementation that simply compensates for the lack of functions, or the synchronization that is synchronized with either. Harmonization indicates a relationship that grows together by respecting and helping each other, leading to attractive results. In order to realize the above, it is first necessary to recognize individual characters and to respect and enhance each other.

That is, the world is becoming increasingly diverse in terms of HMI in the real world, and real-cyber world relationships. To ensure sustainable economic growth, we must realize a world in which human find fulfillment in their work while evolving hand-in-hand with machines. For the establishment of sustainable management system with above diversities, transition of HMI should be discussed as shown Figure 4-4.

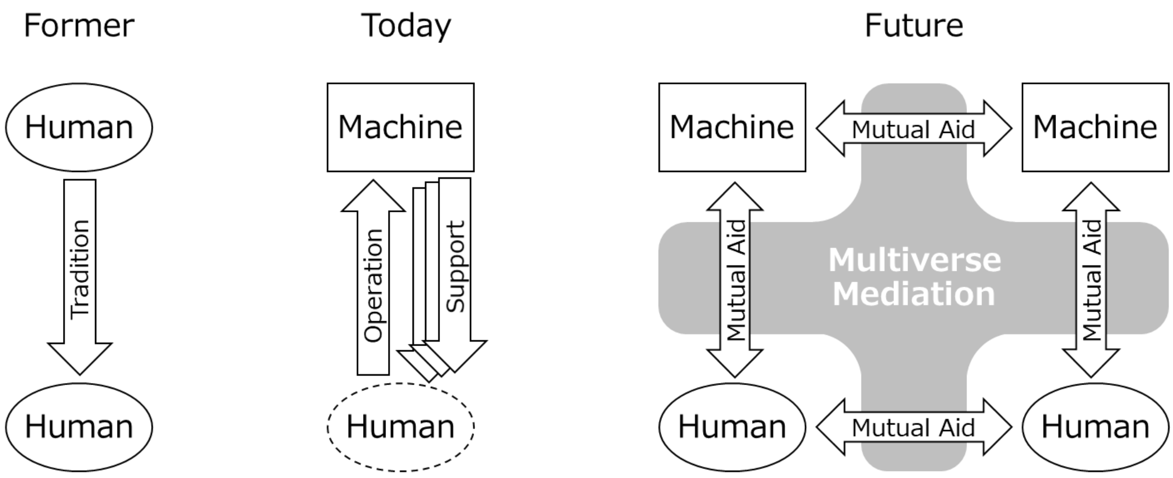

Figure 4-4. Transition of interaction models
(Source: Hitachi).

Former model (left on Figure 4-4) is a technology tradition model, basically applied to humans, in which a master teaches a disciple. In this model, scalability of technology tradition would be a potential challenge due to necessity of appropriate masters all the time.

Case Study in Japan: Technology traditions

In Japan, the technical tradition of traditional crafts such as lacquerware is still performed mainly by using the so-called apprenticeship system. Not only that, for example, but since the brazing work of the heat exchanger (which is the main component of the air conditioner) is accomplished by sealing thin copper tubes together, formalizing this technology is very difficult, and for skilled masters to train beginners efficiently has become a major issue.[81]

Today's model (middle on Figure 4-4) is a machine assistance model aiming at addressing the above mentioned potential challenge of the traditional technology transition model. Machines would provide relevant instructions and support automatically for compensating the potential gap in human skills for completing given tasks. However, excessive computer aids would lead to an increase of a learned-non-use phenomenon, and humans would in turn lose a skill they need to have.

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 it occurs that 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.[82] Although industrial robots are used in many cases for assembling

[81] See Hitachi Brand Channel 2018.

[82] See Nonaka 2019.

home appliances and spot welding of automobile bodies, sometimes it has occurred that the change of robotics program leads to a bottleneck in the event of a process change because it's difficult for an operator to understand the reasoning behind the program parameters set by the skilled operator or by the AI.[83]

So, the future management system for a systematic harmonization of HMI would have a multiverse mediation process among humans and machines (right on Figure 4-4). In this future model, the mediation would adjust interactions as mutual aids between human-human, human-machine, and machine-machine based on digitalized knowledge for inspiring sustainable growth of both humans and machines respectively.

This future model also observes interactions among human-human, human-machine, and machine-machine. Moreover, it accumulates that observed information as digitalized interactions between those entities. If a human is a skilled worker, the mediation process analyzes interactions for identifying key tips, produces adjustment for mutual aids to stimulating relevant actions.

Focusing on the interaction of (1) human-human and (2) human-machine based on this future model, the companies need to adopt the following strategies:

(1) Revisit their 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 human and machine in the same plant and, subsequently, harmonize task plans and adjust the programming of machines/robots so that they can assist their human counterparts optimally.

The strategies we propose have the potential to cause organizational disruption as they involve restructuring of internal processes and responsibilities. Some stakeholders may have an interest in maintaining the status-quo to secure their level of influence. Such dynamics may inhibit the implementation of diversity programs and new production processes based on tailored human-machine collaboration. In a first step, the mediation process and sharing of data should happen within a company. Then, in a second step, this procedure should be transferred to the whole society as long as no intellectual property is harmed. That is, for a sustainable society with well-being, knowledge acquired from interactions among human and machine should be formalized in public, transformed other interactions among human and machine as the mediation for continuous, efficient operations in the society.

According to these strategies solution scenarios are promoted in the following.

Case Study in Japan: Hitachi "Multiverse Barrier Free"

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

This case study describes Hitachi's activity of a systematic harmonization of HMI, called Multiverse Barrier-Free.[84] In Japan, the diversification of workers is progressing, mainly due to the declining birthrate and aging population. In addition, diversification is also progressing in machines,

83 See Hitachi Brand Channel 2019.

84 See Hitachi Brand Channel 2019.

which indicates that old machines introduced during the period of high economic growth and latest robots introduced in recent years are used together in the factory. Hitachi is promoting the development of a flexible production system utilizing human and robot cooperation[85] that optimizes work allocation between human and robot.

At conventional work sites, workers are taught by an expert, and perform according to the expert's model. However, as workers diversify, even if they receive uniform work and instructions, the gap with workers' existing ability increases the stress and workload of workers. As a result, they cannot work as instructed, and therefore, problems such as a decrease in productivity and loss of growth opportunities may occur.

In factories where diversification of machines progresses, there is a potential risk that human work is substituted by machines, 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 and prevents the growth opportunities, as mentioned in the case study: "learned non-use phenomenon" in manufacturing.

Given these problems, the concept of "Multiverse Barrier Free" has been proposed by Hitachi as a mechanism to promote sustainable growth rather than over-supporting each other in order to take advantage of the individual characteristics of diverse human and machine. In this concept, a mediation (which is mentioned in Figure 4-4) is created and performs for the purpose among interactions between human-human, human-machine, and machine-machine with following three steps shown in Figure 4-5.

- First step: Measuring

  The characters of human-machine interaction are digitalized and a private mediation is created for each interaction based on these characters. 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. With this policy Hitachi collaborates OKUMA to extract key tips of machine tool manufacturing for the manufacturing efficiency maximization.[86]

- Second step: Harmonizing

  In this step, the mediation generates appropriate policy of HMIs for the performance bottleneck compensation. For example, the mediation promotes an optimized organization plan of humans and machines to achieve a performance, an appropriate support menu from machines to humans, an appropriate operation policy from humans to machines with paying attention to machine's condition, etc. With this policy Hitachi has developed technology to optimize both production line configuration and product design.[87] Since product design specs require some production capabilities to workers, robots, etc., and since capabilities of workers and robots limit product design specifications such as weight, fineness, etc., a harmonization technology was established and examined in an automotive device manufacturing.

85 Hitachi R&D Group 2017.

86 See Nonaka 2019.

87 See Tsutsumi et al. 2018.

- Third step: Sustainable growth

  For the purpose of achieving growth of human and machine respectively, it is required to provide mutual aids for each human and each machine precisely. With this policy Hitachi is collaborating with Daikin for the sustainable growth of HMI for brazing.[88] In the collaboration a new process visualization function was added to existing brazing system for the brazing of copper tubes of heat exchangers in air conditioners, and an improving program of worker's brazing skill with the function was established.

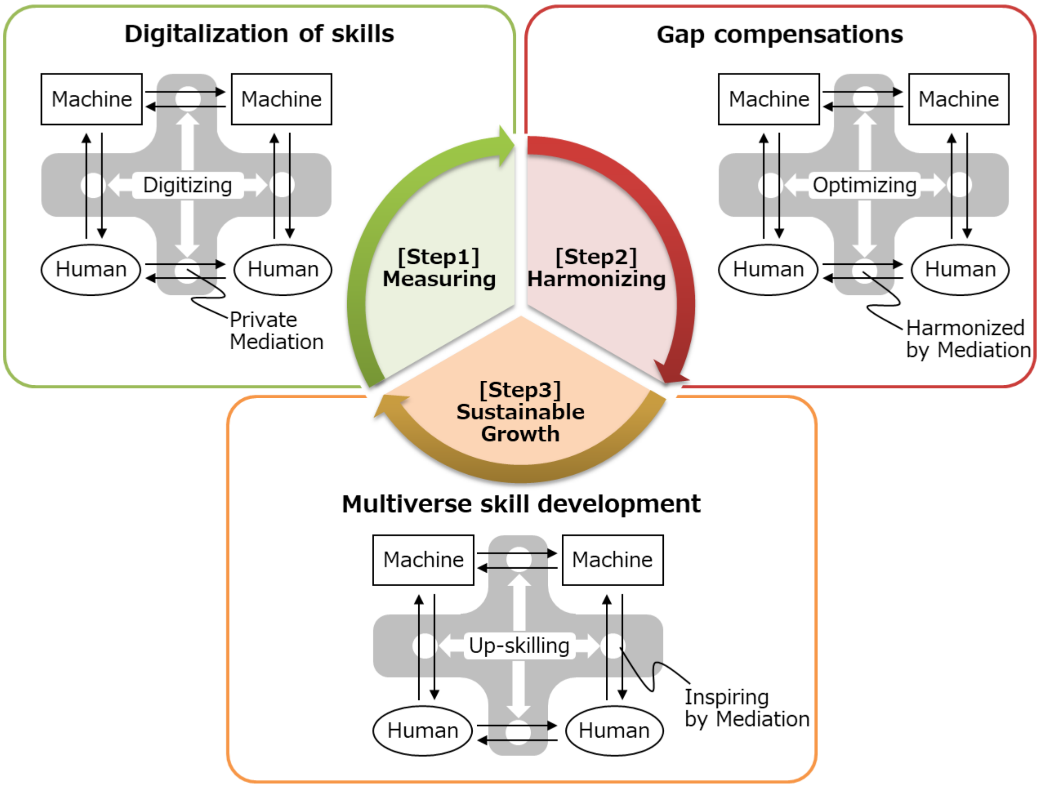

Figure 4-5. Key three steps of Hitachi's Multiverse Barrier Free (Source: Hitachi).

That is, the essential value of Hitachi's Multiverse Barrier Free is;

1. Help human and machine develop their creativity continuously
2. Replace operations which becomes obsolescent and versatile with automatic control as much as possible to free humans from having to perform tedious tasks
3. This continuous expression of creativity contributes to maintain the maintenance and development of machine in the sustainable society, too.

Hitachi has launched this Multiverse Barrier Free concept at the Hitachi Social Innovation Forum 2018.[89]and has released concept videos on YouTube.[90] Hitachi contributes to the creation of a society where diverse humans and machines grow together.

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[88] See Hitachi Brand Channel 2018.

[89] For more information regarding the Hitachi Social Innovation Forum, see http://hsiftokyo.hitachi/en/.

[90] See Hitachi Brand Channel 2019.

5. Challenges to the new paradigm of human-machine collaboration

The impact of the digital revolution, such as IoT and AI, on industry and society is already evident. With the projected growth in population and increase in prosperity, an increase in overall global market volume for products and services will offer tangible opportunities. Such demand even develops towards increasingly customized products. On the other hand, manufacturing labor decreases globally.

Addressing the societal trends mentioned before, industry in general is changing its ways and becoming increasingly diverse and complex, as we have become aware today. The new paradigm of industrial manufacturing can rapidly adjust the physical and cyber system (CPS) to changes in customer requirements. Responsiveness to the customer is most visible in the case of using the human-machine collaboration which is appealingly more productive presented opportunities to gain a new competitive advantage for the enterprise. However, how will humans and machines interact with each other, and what role will our thoughts play?

In this chapter, we focus on the augmented human and self-learning machines collaboration work in future manufacturing which is referred to as human-machine collaborated smart manufacturing. Potential solutions are described to play out the new ways of interaction and moreover the integration between human and self-learning machines so as to facilitate both in operation and management to be flexible and adaptable, which can also lead to creating a more satisfying work style as a result.

5.1. Current situation

On the work site, many efforts have been taken in trying to make machines function in a more intelligent way and self-learning with features such as sensing technologies and AI. For machines on a worksite, technology barriers exist with respect to routine cognition of frequently changing work tasks and their functionality restriction. Traditional machines require more technical effort to realize the routine cognitive, where advanced machines or robots are more efficient in adapting routine cognitive in manufacturing process. For workers, technology barriers exist on both routine and non-routine cognitive and the interaction along with the behaviors change at the machine. Management barriers exist on problem-solving and innovative skills according to the fast change manufacturing process for workers on worksite as well. As shown in Figure 5-1, on the one hand, basic skilled workers are not able to do as many tasks as professional skilled ones, and on the other, the support provided by machines depends on the different levels of intelligent function that a machine is implementing.

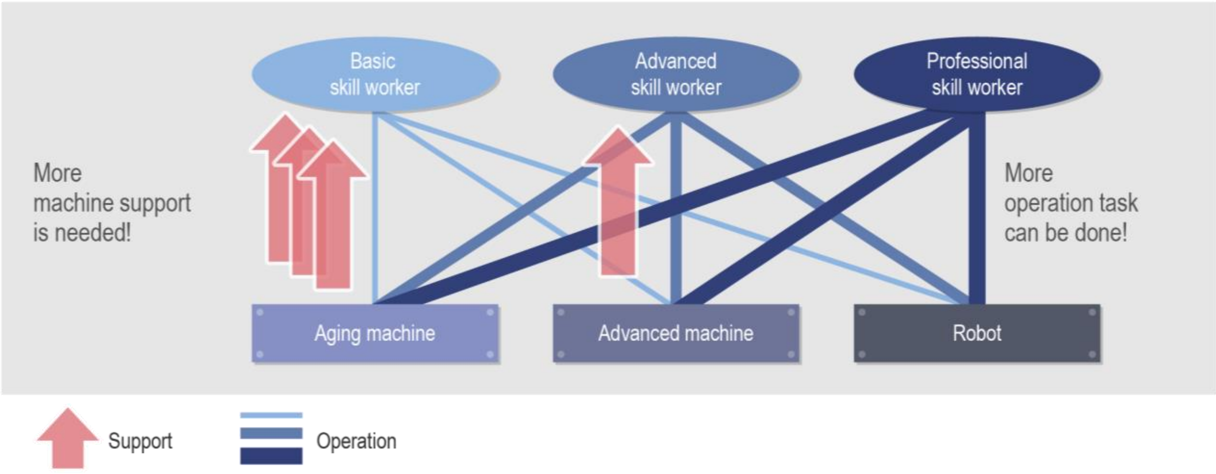

Figure 5-1. Current situation in manufacturing
(Source: Mitsubishi Electric Corporation).

Furthermore, taking companies as a whole into account, various situations present a wide range of difficulties for management on a worksite. Thanks to the efficient, increasing usage of manufacturing information, this will help make the right decision at the right time in the future workplaces. It is clear that gauging and communicating the readiness of every individual worksite is becoming more important all the time.

5.2. Future development

Taking the current speed in the integration of CPS, machines are oriented on the basis of having availability through the connectivity for all instances participating in the manufacturing process.

Such dividends should not be only reflected in the machines by taking advantage of CPS, but the role of human is also expected to expand, leading to an optimization of the manufacturing process in both the workplace and management.

Given the above situations, to properly address the barriers, the following two aspects of strategic approaches can be emphasized:

- Increasing the intensity of cognitive technology and thus working to a greater extent toward human-machine collaboration, by enabling features such as collecting human intelligence on shop-floor along with knowledge-sharing management, merging the human intelligence with CPS and additionally the learning in process management, collaborative robotics and activity recognition for highly skilled workers, including the overall interface design.
- Increasing the intensity of supervising skills, thus raising the returns reflected in human capital by making a systematic assessment of enterprise management possible.

5.3. New paradigm of human-machine collaboration

The new paradigm of human-machine collaboration in manufacturing, as shown in Figure 5-2, can make a big leap in terms of a company's competitive abilities. This figure can be interpreted as a generalization of Figure 4-5.

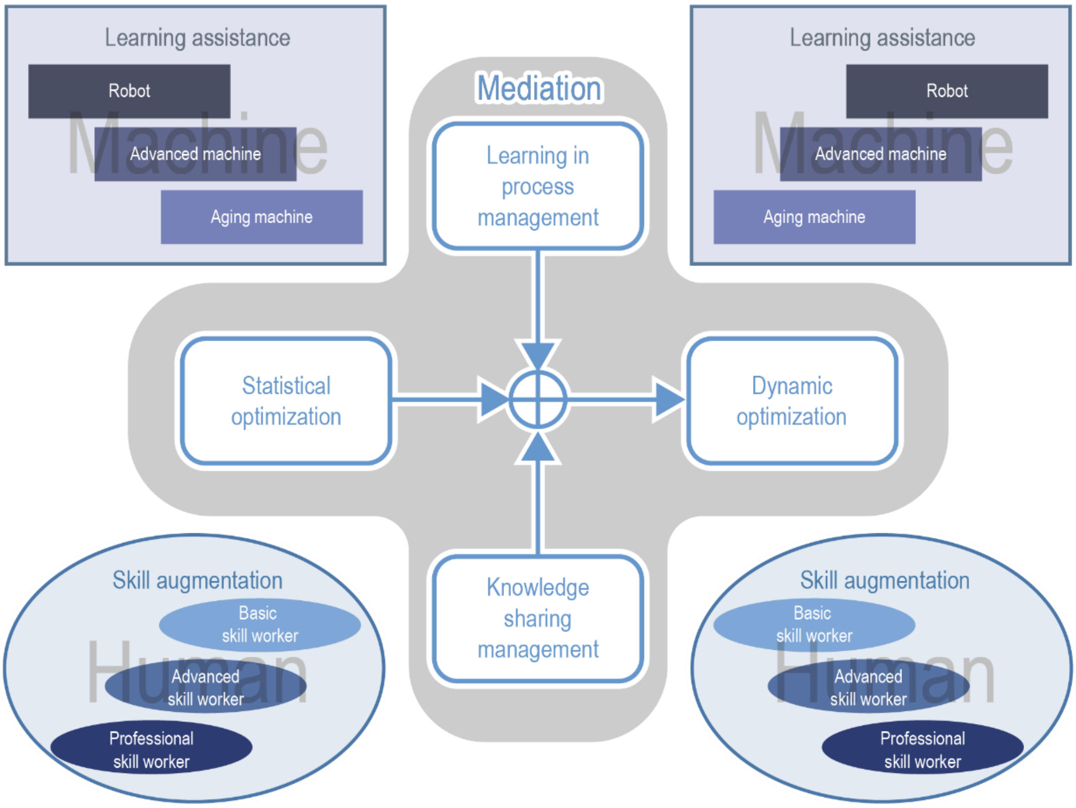

Figure 5-2. New paradigm of human-machine collaboration
(Source: Mitsubishi Electric Corporation).

In the workplace, workers involved in the technical systems must adopt statistical optimization as well as dynamical optimization increasingly with the self-learning machines in an appealing way. The reason behind this is the fact that collaboration is required, especially with the support of digital technologies. It is also obvious that demand is likely to shift to the intensive margin of total capability that reaching out the enterprise management with such a new paradigm of human-machine collaboration as a whole. Companies can expand their implementation of flexibility as well as adaptability to the emerging sustainability that matches its strategic business competitive environment.

The following case studies introduce different aspects of the key elements for the new paradigm of human-machine collaboration implication.

Case Study in Japan: Mitsubishi Electric "Collective Intelligence"

Collective intelligence, which is based on lessons-learned and ideas gathered by participants in a company, organization or society contributes not only Kaizen, successive improvement of products and productions, but also innovations, as shown in lateral thinking[91] and TRIZ[92].

However, the reduction in the productive population leads to the deceleration of Kaizen and innovation due to less amount of knowledge, lessons-learned, and ideas collected from the worksites. In the future, workers in the workplace will have to come to terms with increasingly complex manufacturing processes; their adaptability of skills and efficiency of operation are more important when it comes to manufacturing.

In addition, the less productive populations prevent companies from providing for long-term skills development in their workplaces. This also concerns, first and foremost, striving to establish a culture that will be more accommodating in the different approaches implemented in workplace itself. However, considering the drastic and dramatic changes occurring throughout current business environments, it is a key to success to have employees' latest feedback about 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 5-3) is a goal worth striving for, whose purpose is ensuring that the lessons-learned and collected ideas in the workplace can continue to be implemented and explored through a platform that reflects the increasing diversity of manufacturing and accelerating the processes in actual manufacturing environment. Such a collective intelligence platform can also assist utilizing data and leveraging skills and knowledge efficiently to contribute to the collaboration and the training of human on worksite to enable them to focus on more creative and value-adding tasks.

[91] See de Bono 1967.

[92] TRIZ is a Russian acronym for the "Theory of Inventive Problem Solving". See Altshuller/Shapiro 1956.

Figure 5-3. Collective intelligence platform
(Source: Mitsubishi Electric Corporation).

As shown in Figure 5-4, the collective intelligence platform gathers data not only from machine systems, but also from the human by communication platform that state the lesson-learned idea, suggestion and recommendations with the increasing knowledge-intensive data & knowledge base. Exploiting the diversity of manufacturing, AI aids collective intelligence platform to evaluate the correlation of data, the similarity of methods, and the effect to prototyping ideas. The information gained from AI analysis is highlighted as skills and knowledge and stored as use cases to the data & knowledge base. These skills and knowledge will be shared by humans who are involved as members via communication platform for on-demand education, idea evaluation, simulations. As a result, members' developed ideas will be accelerated. Furthermore, categorizing skills and knowledges regarding the key performance indicators in the collective intelligence platform, can provide guidance apparently and accommodate the actual transformation cycles of skills and knowledge with the goal to exploit higher smart manufacturing maturity as successfully as possible.[93]

[93] See Shi et al. 2019.

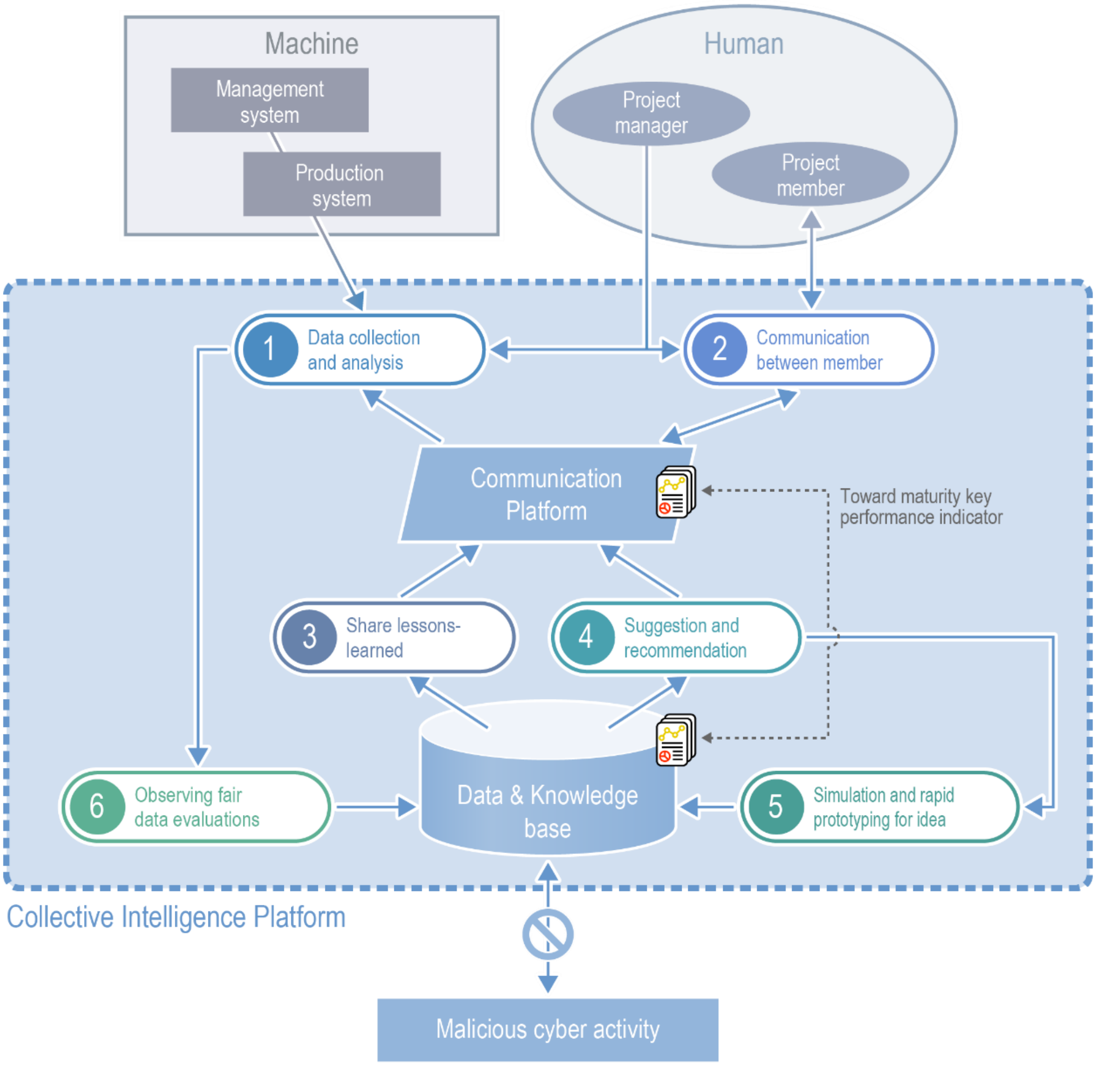

Figure 5-4. Meaning of using collective intelligence platform (Source: Mitsubishi Electric Corporation).

Enabling the diversity of manufacturing with collective intelligence exploits breakthroughs in the company, such as cell style production system for electromagnetic switch assembly,[94] is successful. In this example, one worker collaborates with robots takes charge of a broader range of the manufacturing processes to accomplish the assembly, where robots compensate for the weaknesses of the worker and the worker's value lies in process judgment. The knowledge gained from one cell can be put to practice faster through collective intelligence management board can evaluate the return on investment in time plan and make more manufacturing happen.

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

[94] See Mitsubishi Electric's concept of the e-F@ctory. URL: https://us.mitsubishielectric.com/fa/en/solutions/efactory.

Case study in Japan: The University of Tokyo "Digital Triplet"

An important approach to promote the human-cantered manufacturing is to encourage on-site engineers and technicians in developing new ways of executing engineering activities on their own initiatives, in addition to routine works specified by manuals and supervisors. This is the traditional way of Kaizen in Japanese manufacturers. While this means that CPPS (Cyber-Physical Production Systems) should be equipped with this functionality, we view that this has not been realized. Digital Triplet discussed in this subsection is the concept to add this functionality to CPPS.

Although continuous improvement (Kaizen) for pursuing lean production done by manufacturing engineers and shop floor technicians is an important key for high-quality manufacturing, activities of continuous improvement are not digitalized to be "smart" in CPPS[95], since many engineers and technicians cannot follow the digital transformation. With the growing digitalization of manufacturing system, the question is what kind of next-generation system we need for supporting engineers in creating maximum values in manufacturing, rather than just "automating" engineers' activities.

This section deals with the situations, as seen in typical Japanese manufacturing companies, where manufacturing system engineers are always stationed at the shop floor and continuously improve the manufacturing systems with workers. They conduct engineering activities including operation of manufacturing systems, problem solving when some troubles occur, continuous improvement (Kaizen) for pursuing lean production, and new development of manufacturing system.

In order to solve this problem, we are proposing "Digital Triplet".[96] Digital Triplet aims to support engineers to solve troubles and to create various values throughout a product life cycle. While Digital Triplet is a kind of Cyber-Physical Production System,[97] Digital Triplet adds the functionality to encourage engineers in developing new ways of executing engineering activities on their own initiatives to CPPS.

[95] See Monostori et al. 2016, Geisberger/Broy 2014.

[96] See Umeda et al. 2019.

[97] See Monostori et al. 2016, Geisberger/Broy 2014.

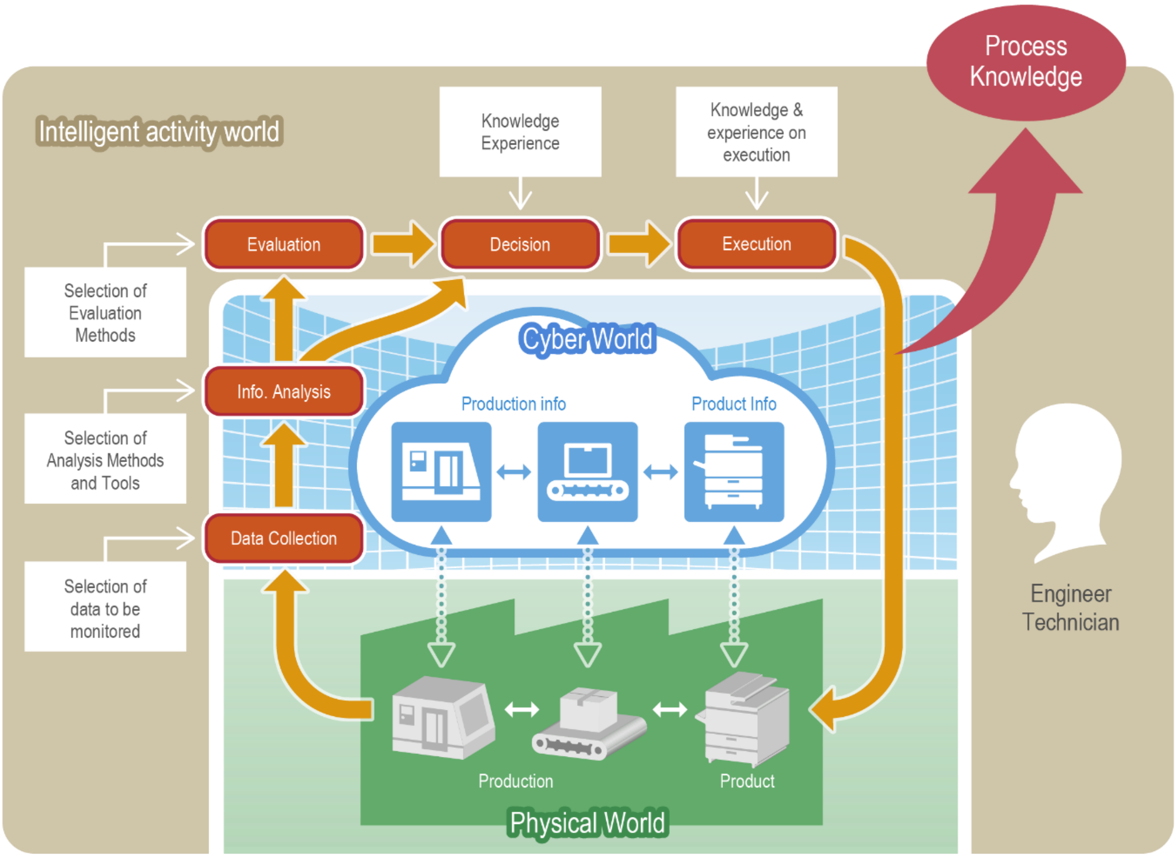

Figure 5-5. An engineering cycle on Digital Triplet
(Source: Mitsubishi Electric Corporation).

As can be seen in Figure 5-5, an engineering activity consists of data collection, information analysis, decision by the engineer, and execution of a plan in the physical world. We call this cycle "engineering cycle". When an engineer executes a cycle, this creates some values from the data. These round rectangles in Figure 5-5 are represented in the traditional CPPS. But important things for supporting the manufacturing system engineers to construct the engineering cycles are rectangles in this figure such as selection of data to be collected selection of analysis methods and tools. They are not described in the traditional CPPS but the 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[98] is a good reference of this framework; the main difference of human-centered CPPS and Digital Triplet resides within the subject who develops engineering cycles; while CPPS developer in human-cantered CPSS, manufacturing system engineers in the field in Digital Triplet.

We are going to describe these engineering cycles as reusable process knowledge. In other words, we would like to formalize, collect and archive the process knowledge of manufacturing system engineers, support human activities by reusing and deploying the knowledge, and employing the knowledge to education and generalizing the knowledge. By utilizing this process knowledge, we can improve engineering cycles, including the HMI method. This is a new form of knowledge transfer from

[98] See Ansari et al. 2018b, 2018c.

experts to novice engineers and training of novices in that, namely, an expert engineer develops an engineering cycle for a specific problem (e.g., to increase productivity of a manufacturing system) by himself/herself. Digital Triplet records this engineering cycle as a process of data collection, usage of several AI tools, simulators, and other software, and execution of some actions, with annotations of the engineer. By tracking this process record, a novice engineer can study expert's thinking approach and how to solve this problem.

Digital Triplet is an extension of CPPS, focusing on the integration of continuous improvement (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 training of novices in the era of 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 values 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 material. 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 be injured, 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 the 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 the protection of human, security embraces data protection and thus aims at protecting robots from cyber-attacks. 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. 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 detailed knowledge of encryption technologies. In addition, the impact on existing software implementations 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 for performing maintenance takes away valuable time from production activities. In addition, automation teams might be replacing parts that are still fully functional because of the specific load profile within the production process. This may cause significant costs that could have been avoidable in the event that users of the machine had known better.

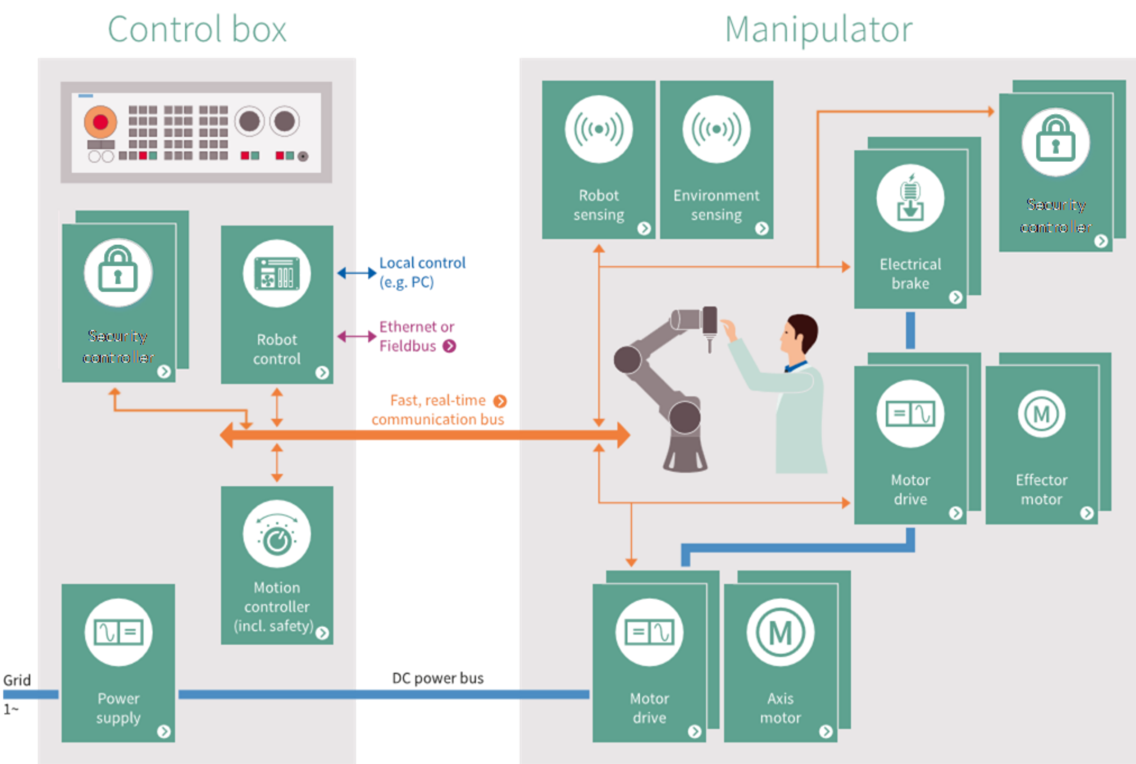

Figure 5-6. Structure of a CoBot including sensing and security components (Source: Infineon).

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 – these are two examples of signs that a motor, gearbox or bearing is in need of repair or maintenance. For instance, if power consumption goes up slightly but steadily, perhaps there is some increased mechanical resistance. This can result from close-to-fail bearings causing the electrical system to draw more current than usual. The semiconductor industry has used the unique properties of silicon to create cheap and tiny sensors to measure a wide variety of signals. With this wealth of low-cost but high-quality sensing capability, there is little reason not to 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, an Artificial Intelligence 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 a 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 based on the time of flight principle that might function as "eyes". MEMS microphones might give "ears" to machines and pressure sensors providing a kind of "feeling" to them. This reliable "understanding" of the environment improves the safety of human co-workers.

Case study in Germany: Learning Factory

Learning factories typically are factories that are designed and implemented to educate and to train workers for creating the new skills that are necessary to create an advanced production environment.[99] Production technologies rapidly adopt the concepts of information and communication technologies as well as new production paradigms such as additive manufacturing or collaborative robotics. In the future, the frequency of changes in production will increase. Competence building in a production environment is required increasingly, that, in turn, has also implications to 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 human´s role in advanced value chains. As information and communication technologies impact production technologies more and more it becomes increasingly important to train workers 4.0 for keeping track 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 being updated and further competences are created. Such places need to be established either physically or as in cyber space or as a combination of both as a cyber-physical education and training environment. Learning factories represent a cyber-physical education and training environment, dedicated to support lifelong learning.

[99] See Abele et al. 2018.

One practical example of a learning factory is the “ETA factory”. It has been 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, this 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 5-7).[100]

Figure 5-7. Cyber-physical education and training environment
(Source: ETA-factory, Darmstadt).

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 an implemented into practice. For example, the “Map Industrie 4.0”, that is provided by the “Plattform Industrie 4.0”, lists already realized use cases, test beds, and support services in the context of Industrie 4.0. It demonstrates that various initiatives, activities and implementations of learning factories that have been initiated by companies (e.g. SAP, Festo) or scientific and public institutions (e.g. wbk [Institute of Production Science] of the Karlsruhe Institute of Technology [KIT], Fraunhofer IGCV).[101]

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

100 See further https://eta-fabrik.de/bildung/lernfabrik/.

101 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.

Case study in a collaboration of Germany and Japan: DFKI and Hitachi "Worker activity recognition, evaluation, and transfer"

The aging society and declining birth rate are one of the biggest social issues in mature societies such as Europe and Japan. Especially for manufacturing companies, the retirement of the experienced workers, who have been supporting strong industry, is a serious problem. Therefore, there is an immense need for a 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 the factories for instance quality control, reducing risk of accidents, maintaining workers' health, and knowledge transfer from experts to novices and/or to/from machines.

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 are different 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, the activity of "check manual" may refer to a situation where a worker is reading papers in factory A, but in factory B it may be the situation where a worker keeps looking at a display (to read 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 the target activity has the same name of "check manual". In other words, with conventional methods it is required to create a customized model for every individual customer.

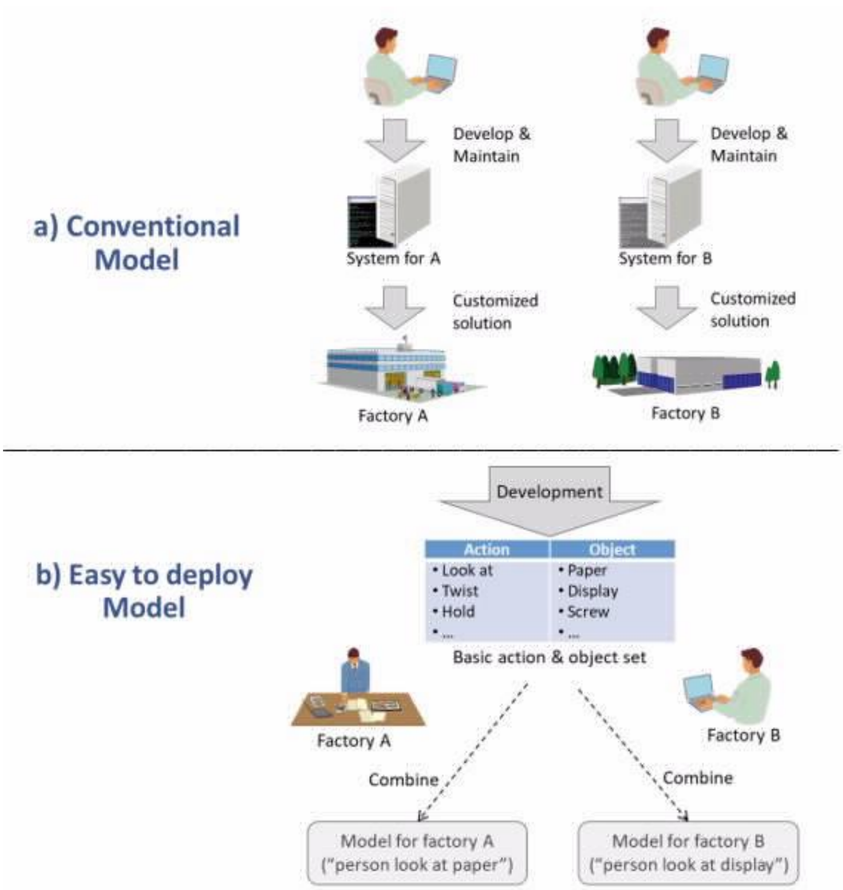

Figure 5-8. Conventional model vs easy to deploy activity recognition model (Source: DFKI).

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

The goal of this research is the development of an easy-to-deploy human-activity recognition model, [102] which can be applied to different factories as standard solution with limited or no customization needs, therefore deployable with low cost. In addition, explaining machine’s decisions to human is a vital component of this approach.

The key idea is to recognize complex activities based on the combinations of simpler components,[103] like the actions and objects involved in the activities and explain the recognition to human in both visual[104] and textual form[105].

We used two wearable sensors; one is a smart glass or eye-tracker with camera providing the egocentric vision of the worker, and the other is motion-tracking sensor (armband sensor or full-body sensor) on the body. These sensors are utilized to recognize gazed objects and basic actions respectively.[106] Although many conventional systems use fixed cameras as sensors, wearable sensors are more appropriate especially in a complex industrial environment because fixed cameras often suffer from the difficulty of occlusion and view angle.

We assume that even though the representation of the activities may be different from factory to factory, what’s different is just how to combine actions and objects (hereinafter these are collectively called “basis”). In other words, we assume that the recognition modules for the basis, namely action and object, can be commonly used in different factories.

Figure 5-9 provides an overview of the proposed model.[107] This framework enables recognizing a new activity without time-consuming retraining process 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 basic action and object. Recognitions decisions of both actions as well as gaze guided object detection are supported both with visual[108] and textual explanations[109]. These explanations play vital role to build a trust on machines where human and machine are in working in close proximity.

[102] See Al-Naser et al. 2018.

[103] See Al-Naser et al. 2018.

[104] See Palacio et al. 2018, Siddiqui et al. 2018.

[105] See Ohashi et al. 2017.

[106] See Al-Naser et al. 2018, Ohashi et al. 2017, 2018.

[107] See Al-Naser et al. 2018, Ohashi et al. 2017, 2018.

[108] See Palacio et al. 2018.

[109] See Ohashi et al. 2017.

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

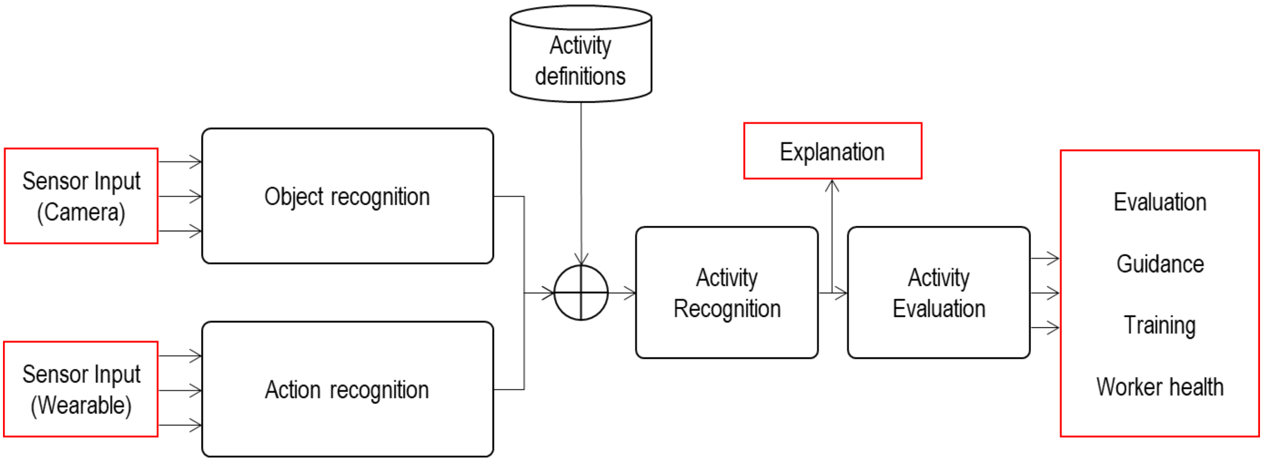

Figure 5-9. Overview of the framework
(Source: DFKI).

This system introduces a deep neural network (DNN) based explainable action recognition method that utilizes wearable sensors and a gaze-guided object recognition method[110] to recognize activities. The experimental results showed comparable performance to the conventional methods with an accuracy of over 90%.

By developing 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.

110 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.

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