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CURRENT AND FUTURE INDUSTRIAL CHALLENGES: DEMOGRAPHIC CHANGE AND MEASURES FOR ELDERLY WORKERS IN INDUSTRY 4.0

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Abstract: Future production is envisioned to be characterized by highly complex, varying and knowledge-intensive work processes, where the human more than ever will be in need for support and technological assistance. At the same time demographic change leads to a higher share of elderly workers with different abilities and needs. In this paper we present the results of a study we conducted with manufacturing companies in Austria. We discuss future work activities, the demographic challenge, age-related changes of human work ability, and the role age-appropriate work design and standardization as well as assisting systems can play to enable elderly workers for such a future industrial work setting.
Keywords: industrial engineering, demographic change, age-based work design, assistance systems

INTRODUCTION

The manufacturing industry remains a central driver for economic growth, societal wealth and improved standard of living. In the past, technology, particularly automation, has been the key driver for increasing manufacturing's productivity (cp.[1]). However due to globalization and the ongoing demographic change, as well as changing market demands, the manufacturing industry is now facing new challenges. Instead of just focusing on technological improvements, it now becomes necessary to focus on humans as central part of the production system, to increase the overall productivity and to compete in the globalized markets (cp. e.g. [2,3]). Due to flexibility and creativity as well as the ability to reason and to decide based on intuition, which can and will not be replaced by autonomous systems, the human will play a central role in the concept of the factory of the future (cp. e.g.[4]). Human presence in production is essential to compensate for technological limitations and to provide the most benefits for productivity, reliability, economy and flexibility (cp. [1,5]). For the human as the central part of such future production environments there are several changes and challenges to be considered which are discussed in the first part of this paper.

Beside the technological development towards "Industry 4.0" and cyber physical systems (CPS), the demographic change as a company external change is a central challenge for many manufacturing companies in Europe. Due to a complex combination of social and technological improvements like better prosperity, wealthy diet, better medical and social care, and human adapted work conditions the anticipated average (working) life increases (cp. e.g.[6,7,8]). This, at the same time, leads to a higher share of elderly workforce which might have special abilities, skills and needs concerning their work task, operating means and work environment. Therefore, in a time of increasing skill shortage in many industries[1], it becomes more than ever necessary to keep elderly and experienced workforce in employment assuring they have a high workability. The demographic challenge and changes of human workability with increasing age and possible measures and solutions are discussed in the second part of this paper.

Table 1 – Study sample overview by industry

No.	Industrial Sector	No.
No.1	Foodstuffs, drinks and tobacco industry	3
No.2	Textile and – leather industry	4
No.3	Electrical industry	6
No.4	Building material,- ceramic-, quarry and pit industry	7
No.5	Metal processing industry	9
No.6	Wood-,Paper and Printing industry	12
No.7	Mechanical engineering and vehicle manufacturing	13
No.8	Chemistry, pharmaceutical and plastics industry	13
Sum		67

To elaborate important existing and future changes, challenges, therefrom deriving problems and possible solutions with special focus on the demographic challenge a literature review and a survey with 67

[1] Cp. fk-monitoring.at/

manufacturing companies in Austria were conducted. In this study we focused on the technological, organizational and human-based changes of industrial work, the demographic challenge and the special needs of elderly workforce in industrial work settings as well as their aptitude for future manufacturing work. Table 1 and Figure 1 show an overview of the survey sample by industry sector.

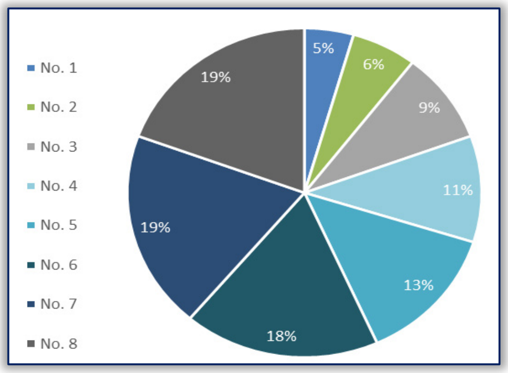

Figure 1 – Sample by industry

2. CHANGES TO THE MANUFACTURING INDUSTRY

External changes

Changing market demands and new technologies lead to several changes in industrial work systems. With the rising demand for customized and specialized products with ever shorter life-cycles automated mass production is no longer economically the best choice. Flexibility, speed and productivity of the production system are considered as the most important factors for competing in the increasingly volatile and globalized markets, as small batch sizes and manually assembled products regain relevance (cp.[4,10,11]). With the increasing number of product variants complexity in production increases as well. In order to deal with this complexity, new methods and technologies like assistance systems and information and communication technologies (ICT) become more important.

Technological changes

Currently we talk about the so called fourth industrial revolution after mechanization, electrification and automation there are now several "enabler technologies" which aim to revolutionize production industry (cp.[12,13]). These technologies should help factories in the future to cope with the changing market demand and increasing volatility.

Therefor the factories of the future are envisioned to be "intelligently" automated factories, in which machines, products, tools, workers and even customers are interconnected to cyber physical production systems (CPPS) (cp. e.g.[4] [16]). These connected sub-systems work together, exchanging information and data and striving for maximum value for each process-step along the value creation chain. Current top drivers of change are cloud technology, big data processing, the internet of things (embedded systems, sensors, etc.), sharing technology (crowd sourcing, crowd working etc.), intelligent automation of tasks (robotics, artificial intelligence, etc.) and advanced manufacturing ("industry 4.0", 3D printing, etc.) (cp. [12, 14]).

For workers this developments lead to an increasing work complexity, as for example the amount of information, which has to be considered in the production process steadily increases. Also it is assumed that future manufacturing processes will consist of many small standardized steps which can be combined in different ways to produce different product variants (cp. e.g. [4][4]). This in turn leads to higher work complexity and an increasing demand for information for the workforce, which can be met by organizational development measures, continuous professional worker training and the assistance of information and communication technology (ICT). The introduction of these ICT systems in manufacturing lines can thereby assist the workers and enable the humans to play a central role in this vision (cp.[15]). At the same time also the worker themselves need to develop a broader skillset in order to cope with the increasing complexity and needed interdisciplinary knowledge.

Subsequent change in work tasks, required worker skills and competencies

The introduction of industry 4.0 and CPPS implies significant changes of the production processes, and consequently to work-tasks in the manufacturing industry. This, again, impacts the skills and competencies required of industrial workers. The trend of automating easy and monotonous tasks like machine loading or unloading will continue. Workers will have to carry out more complex and indirect tasks like collaborating with machines at a higher share of their worktime (cp. [9]). The main task for workers will become observation and regulation of highly automated complex processes as well as the supervision and efficient application of machines. (cp. [4,16]). Therefore dealing with information and a big amount of data and interaction with machines will be the basic elements of future work tasks (cp. [5]).

With changing operating means and work tasks also the skills and competencies required of shop floor personnel will change (cp. e.g. [14]). As Industry 4.0 environments contain complex systems due to automation and interconnectivity between system elements, system competence - which includes the ability to recognize elements of the system, identification of system borders, understanding of functions and relationships within the system and the ability to predict the system behavior - will thus be a basic qualification for manufacturing work in Industry 4.0 (cp. [4]). Skillsets for future industrial work must contain complex problem solving skills, social skills, process skills and cognitive abilities whereas physical abilities are only seen as core requirement in a very low percentage of jobs (cp. [14,17][34]).

In short especially skills related to the IT-sector, information- and data- processing and organizational and process- understanding as well as interaction-skills with humans and machines are seen as crucial for workers in modern production systems. Furthermore the willingness and the ability for lifelong learning, multidisciplinary thinking and acting belong to the most important competences (cp. [5,18]). Essentially, this means that industrial workers are expected to become knowledge workers, in a sense that significant portions of their jobs will require activities that involve cognitive abilities like applying (complex) knowledge, searching for knowledge, creating new knowledge or sharing/transmitting new knowledge (cp. [19][19]).

3. CHALLENGES FOR MANUFACTURING INDUSTRIES

This changes lead to new challenges for manufacturing companies. Based on the survey results the seven most important future challenges in Austrian companies are listed in Figure 2.

» Increasing demands on production system´s flexibility

As a result of changes in market demands such as the increasing demand for individualized and specialized products with ever shorter and more dynamic product life cycles, flexible, dynamic and agile production systems will be needed in the future where variant-rich production of small batch-seizes is economically viable (cp. e.g. [2,12,17,20,21]). 91% of the involved companies rate this issue as number one future challenge.

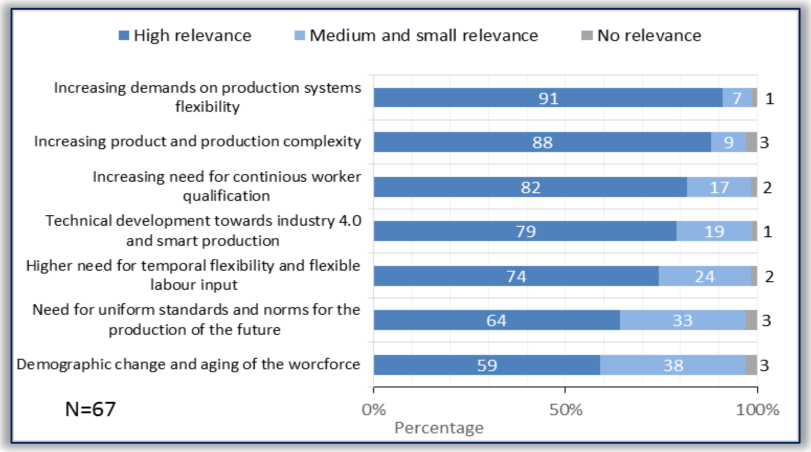

Figure 2 – Changes in industrial work (own research)

» Increasing production or product complexity

The technological development leads to new possibilities to meet the flexibility challenge. However the use of “intelligent” production technologies to produce smart products (e.g through embedded systems and components) in turn increases the complexity of products, the production system, the production processes and the work processes. At the same time, the increasing number of variants and decreasing lot sizes also lead to increasing complexity in these areas (cp. e.g. [2,12,20]). 88% of the participants see the increasing complexity as a very important challenge.

» Increased requirements on worker qualification throughout their careers

Due to the increasing automation and digitalization of production, new challenges are created for companies and their employees, for example in the area of worker qualification. If simple activities such as machine loading are automated, the employees must be qualified for other and more complex activities. However, as complexity of production and products increases, an increase of work task complexity can be expected as well. Therefore, the future workforce must have other skills and higher qualifications and constantly adapt them to the quickly changing working conditions (cp. e.g. [4]).

Increasing demands in worker qualification and training are seen as very important challenge by 82% .

» Technical development towards industry 4.0 and smart production

The term "industry 4.0" refers to the digitization of production and the linking of the digital and physical world to cyber-physical systems (CPS). In the factory of the future, connected machines are expected to be able to intelligently and independently create "smart" products and to adapt flexibly to the dynamic conditions. (cp. e.g. [12,21]). The introduction of meaningful, innovative technologies in their production processes is a key challenge for 79% of the interviewed companies.

» Need for temporal flexibility, flexible labor input and adapted working time models

In addition, future work will require greater temporal and geographical workforce flexibility. In order to be able to flexibly meet the requirements of the volatile markets and job market fluctuations, new and more flexible working and working-time models will be needed. (cp. e.g. [2,18,20])

In 74% the need for more temporal flexibility was rated as very highly or highly important challenge.

» Need for uniform standards and norms for future production

The networking of machines and people required for industry 4.0, as well as the networking of entire business sectors and companies, which is described by the concepts of horizontal and vertical integration, requires a uniform set of norms and standards. In addition, the issue of data security is a particular challenge connected to this (cp. e.g. [17].

The need for new standards and working norms are a very important challenge for 64% of the sample.

» Demographic change and ageing workforce

Another key challenge is the increasing average age of workforce due to the demographic change. Elderly people are often seen as less powerful and less resilient group at shop floor workplaces. However, as the group of elderly workers will become the largest group of available workforce, it is particularly important to recognize, exploit and successfully integrate their potential. 59% rated the demographic challenge as highly important for their company. In addition longevity and aging society is one of the top drivers of change in a survey representing 13 million employees in 15 major developed and emerging economies [14].

The demographic challenge

Besides average population aging other problems and issues connected to the demographic change were identified in the manufacturing industry as shown in Figure 3. The most important effects of the demographic change are an increasing need for meaningful and helpful supporting technologies and assistance systems to meet the higher requirements of elderly workers, age-appropriate human resource management (including workplace design, workforce-leadership, age-appropriate personnel development, human-oriented workload and the adaptation of work to user needs), an increasing shortage in skilled workforce and a need for company internal training and worker qualifications. At the same time it is assumed that the demographic change and the higher amount of elderly workforce can lead to problems with the occupational efficiency, the ability to innovate and the loss of operational knowledge if no countermeasures are taken. On the other hand less than a quarter (22%) expect new market possibilities deriving from the demographic change (see Figure 3).

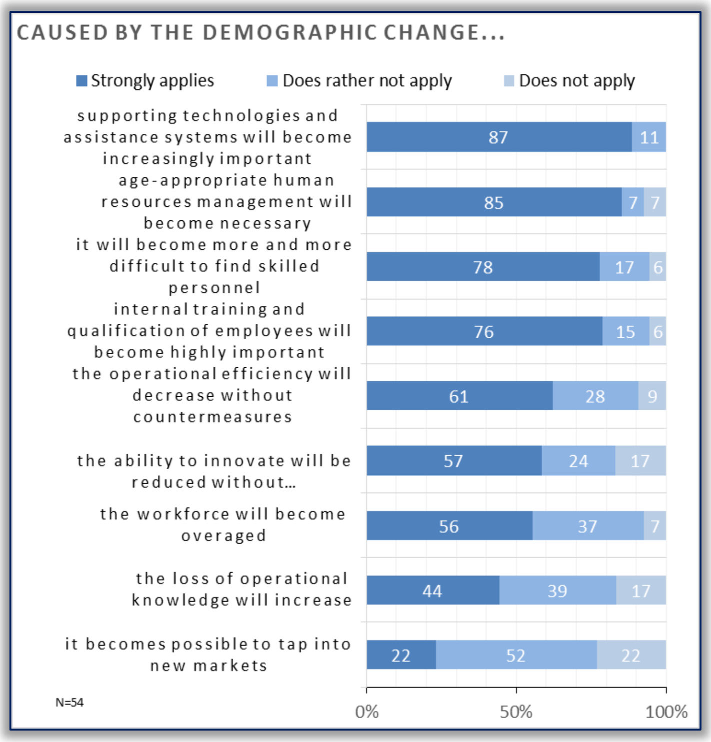

Figure 3 – The demographic challenge (own research)

The age challenge: Elderly people in current industrial work environments

Most obvious effect of the demographic change is the increasing number of elderly people in society and in industrial work settings. Many physical, sensory and cognitive skills change during the aging process which leads to a mismatch in the workforce's workability and the demands at manufacturing work places. As a result a very low percentage (8.9 % in our survey) of the manufacturing workforce is older than 55 years and only 1,8% is older than 60 years which might become a major problem if the share of workforce aged 55 years and older will increase as predicted by more than 15%.

Important general age-related changes are summarized in Figure 4[2]. Particularly decreasing physical capabilities (e.g. muscular strength or fine motoric skills) decreasing sensory abilities (e.g. sense of hearing or vision) changing cognitive and mental functions (e.g. mental flexibility, speed of information processing, declining function of short term memory) and declining amount of information which can be processed at the same time, as well as smaller willingness to learn new things and adapt to changes or to work with new operating means and technologies negatively influence the industrial workability. On the other hand, caused by increasing life and job experience and changing problem solving strategies, many skills like leadership skills,

[2] Own representation based on [22,23,24,25,26,27,28,29,30,31,32,33,34]

self-organization skills, the ability to judge in new or complex situations, problem solving skills, social and teamwork-skills, etc. increase with age (cp. [22,23,24,25,26,27,28,29,30,31,32,33,34]).

In short many abilities tend to decrease when getting older and therefore older workforce has special requirements on workplace and work task design to perform to their potential. When age-related changes in skills and competencies are not considered in designing workplaces and work tasks, elderly people might not be able to work in a highly productive way. However industry will have to find a way in applying older workers in future and to make use of their specific advantages like their profound experience.

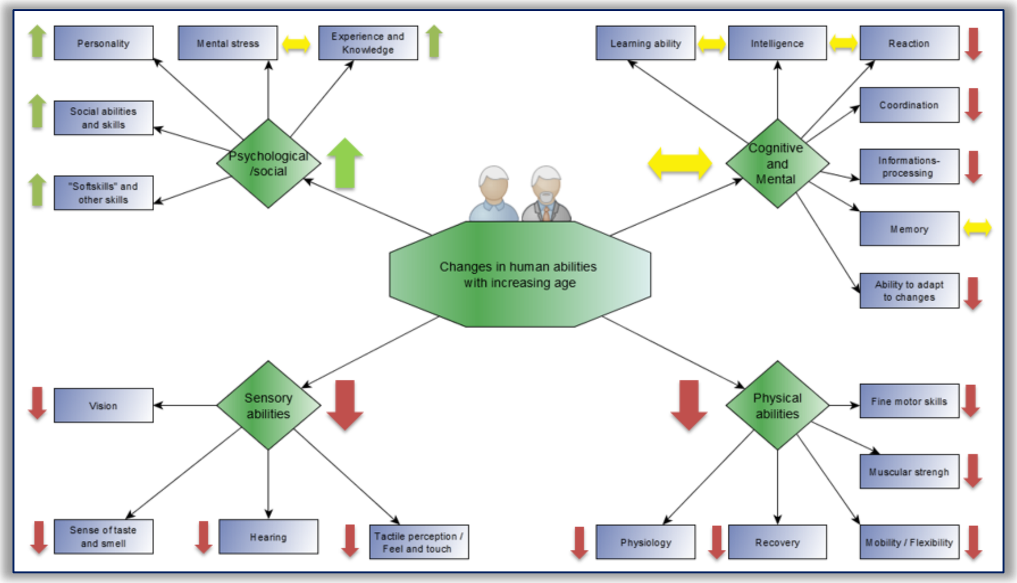

Figure 4 – Age related changes of human workability relevant skills (own representation based on[1])

Elderly workers in industry 4.0 work environments

We have already discussed above, that as system complexity rises, and physical work is increasingly automated, new work tasks in Industry 4.0 are knowledge intensive and related to applying complex knowledge, searching for relevant knowledge, creating new knowledge and sharing/transmitting knowledge. Additionally, as the markets demand so and production technology is able to deliver smaller batch sizes and customized products, interaction between stakeholders within and across organizations, or even between private customers and producing organizations can be expected to increase. As discussed above elderly workers have no disadvantage in such work tasks, on contrary based on their experience and often increased organizational and social skills they might even perform better compared to their younger colleagues.

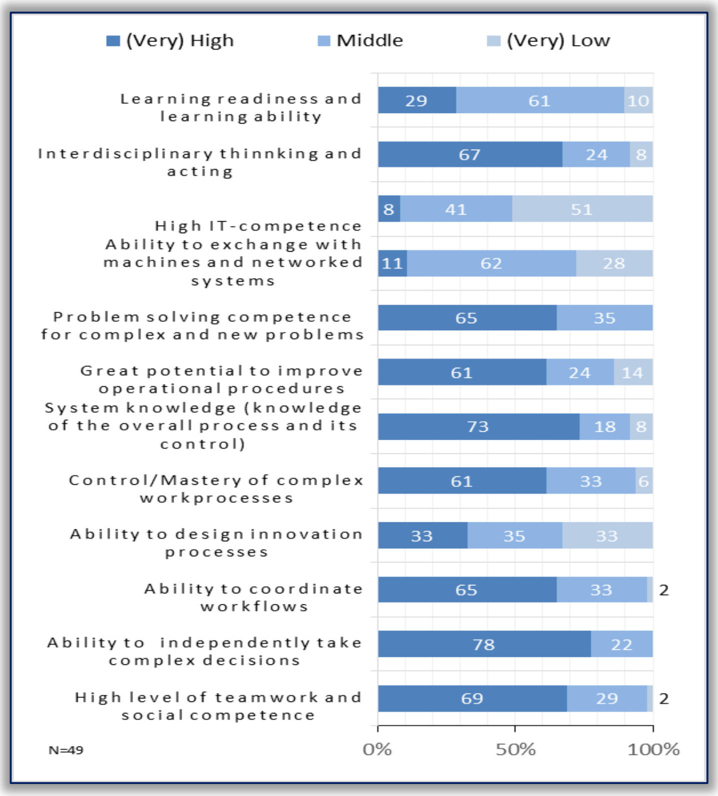

Figure 5 – Skill level at elderly workers (own research, questions based on [18])

In 2014 a German study elaborated special skills and abilities needed for the implementation of Industry 4.0 [18]. Based on their results willingness for lifelong learning (86%), interdisciplinary thinking and acting (77%), IT competences (76%), the ability to permanently exchange with machines and networked systems (75%) and problem solving and optimization skills (75%) are seen as most important skills. After that system knowledge (72%), control of increasingly complex work processes (71%), the ability to work with indirect contacts (65%), structural participation in and the design of innovation processes (61%), increased coordination of workflows (60%) and independent decision making (53%) as well as increased social skills (43%) are seen as necessary skills (cp.[18]). On the other hand high physical abilities like strength or fine motoric skills are not seen as a core skills for future work (cp.[14]). As especially physical abilities and capabilities decline and cognitive respectively social abilities stay constant or increase, elderly workers have the same - or better - preconditions to work within this future industrial work settings.

Figure 5 summarize our survey results which rate the skill levels of the above mentioned skills at elderly industrial workforce. It shows that many important skills are rated as very high for elderly workers. Especially independent decision making in complex situations (78%), system knowledge and process understanding (73%), social and teamwork skills (69%), interdisciplinary thinking and acting (67%), problem solving and coordination skills (65%) are seen as strengths of this group (Figure 5). At the same time problems and need for assistance can be derived at the lower rated categories like IT competences, interacting and exchanging with new technologies, participation in innovation and lifelong learning (Figure 5).

As elderly possess many abilities that are needed for industry 4.0 - maybe even on a higher level than younger ones - it is of great importance to provide them with suitable working environments where they can perform at their capacity. To achieve such working environments several measures and solutions should be considered.

4. MEASURES AND POSSIBLE SOLUTIONS FOR AGE APPROPRIATE WORKING

Age Based work design

To tailor work environments to specific need of elderly workers is the aim of age-based workplace design which combines ergonomic findings with age related needs. As mentioned above elderly workers have different skills and abilities caused by several changes they experience in the aging process. Many of these changes do not influence their workability negatively. On the contrary their increased experience and competencies in complex and indirect tasks as for example interdisciplinary thinking, problem solving and process understanding makes them to a worthy resource for future work. To enable them to perform to their potential they need a work environment which addresses their different needs and preconditions. Important critical factors which have to be considered are (cp.[24,30,32,33,35,36,37,38]):

» Organization of work:

Within the organization of work it has to be considered that monotone work tasks that require a steady concentration and very complex, abstract and totally new work tasks should be prevented from being given to elderly workers. Furthermore high workloads with time- and/or performance-pressure as well as a highly takt-bounded and other-directed pace of work, selective and sub-divided attention as well as interruptions and disturbances should be prevented much more for older workforce.

» Work environment:

Especially the decreasing visual capacity and the vulnerability to environmental conditions like illuminance or climate have to be considered more in detail. This means that labels and warnings have to be written in a proper contrast and size. Furthermore the increased sensibility to noise and vibrations as well as to the exposition to hazardous gases and substances should be considered.

» Technology and operating means:

Different declining abilities of elderly workforce can partly be compensated by technology. For example a declining sense of vision can be compensated by adaptable symbols, contrasts and a color scheme. Therefor supporting technologies, assistance systems and human machine interfaces should be designed easy, intuitive, and adaptable to user needs to compensate for lower IT affinity and skills elderly workers might have. Regarding operating means high requirements regarding the reaction- and movement-capabilities as well as fine motor skills and none-ergonomic design of operating means should be avoided. Furthermore increased requirements regarding the manual precision of operating machines or tools are critical and should be assisted by technology.

» Human factors:

Heavy loads to be carried, pulled or pushed as well as continued physical aerobic work with high necessary forces and sudden load-peaks should be completely avoided. Also constrained postures, longer static muscle-work and one-sided strain are much more critical to older workers. Moreover individual operating ranges and different body-forms are more important to be considered in work-place design for older workforce as their ability to adapt to non-optimal work and body postures decreases heavily.

» Working- and break-time

Because of the changed bio-rhythm and the with age increasing inability to adapt to changing working times especially shift and night work has to be avoided. Proper breaks to guarantee recovery are of great importance. Also the possibility of flexible work- and break-times should receive greater attention.

Age related and age-based standardization

A widely used help in designing work for workforce with different needs is international and national standardization. Standards can serve as a pool of scientific and practical information und give advice in how to design different workplaces and work environments. The majority of 63% of the sample is using international and national standards in their working system (see Figure 6).

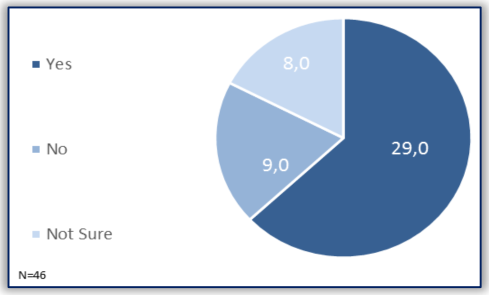

Figure 6 – Use of standards in working system design

There are several areas where standardization and age-appropriate work design hit each other. Standards that are important in both areas deal with disciplines of general and machinery safety, ergonomic standardization, accessible design of work environment, work places and operating means and finally of the field of standardization for people with special needs.

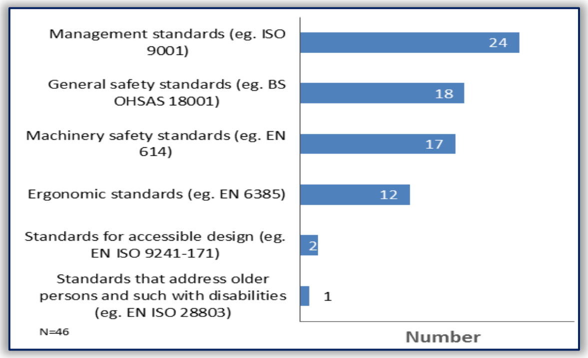

Figure 7 – Used standards by Group

Whereas management and general safety standards as well as the machinery safety ones are used by many companies in the sample, lesser use ergonomic standards and only a few use standards that deal with persons with special needs (see Figure 7).

Further existing industrial standards from this six areas were screened, using an approach including the above described critical factors connected to age-based work design, in order to determine to what extend the special needs of elderly workforce is covered or not. From over 31.000 standards that are valid in Austria 100 standards were selected that cover the field of industrial workplaces and contain aspects that could be critical in accordance to these factors. After the extensive review of the selected standards about 77% of these standards were classified as standards with high or at least medium need for action in terms of elderly workforce. Therefore only 23% considered the specific characteristics of older workforce in a sufficient way (see Figure 8).

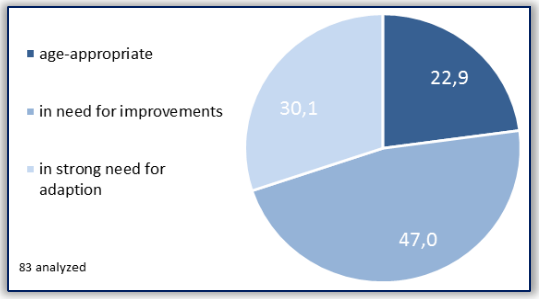

Figure 8 – Age-appropriate standards

Assisting Technologies for elderly workers

As complexity and general work requirements get higher and higher, the workforce is in need for support and assistance to deal with the increasing demands. Technology can support humans physical work, collaboration and cooperation (interaction with other humans, social entities and technologies), and cognitive work. It will become necessary to find a distribution of work between technologies (computers) and humans, such that each does what each is best at. So, a partnership between computers and humans in industrial environments could contribute not only to making industrial production processes more efficient and flexible, but also making industrial work environments more attractive work environments for humans and especially elderly workers by extending and complementing their abilities.

» Support for physical work

Support for physical work in industrial settings is often addressed in automation and robotics literature and can take for example the following forms:

- Reinforce the physical abilities like strength or fine-motoric skills and lower the physical work related strain. This can be done by using exoskeletons, positioning devices, robots or automation of monotonous tasks (cp. [39])
- The adaption of tools and work places to different body sizes and movement areas and impaired ability to move parts of the body.
- Avoiding health risks by lower physical under- or overload through monitoring of body data like pulse rate or the dose of hazardous substances.
- Increasing occupational safety by improving work ergonomics and avoiding risks in human-machine-interaction for example though recognizing the human action-intension

≡ Adapt signals and warning signs to workers' physical characteristics, in particular to hearing or visual, or other sensory impairment.

» Support for collaboration and cooperation

People need to communicate, to organize work (scheduling, planning, distribution of tasks, monitoring of tasks and results of work, etc.), and to ensure a common ground (e.g. standard work processes, best practices, joint vocabulary, etc.). Such work can be understood as articulation work, work that is necessary in order to make operative work efficient in collaborative settings (cp. [40]). A large field of research, called CSCW (computer supported cooperative work) deals with the support that ICT can give to just these kinds of tasks (communication, work organization, common ground) and the special needs related to elderly workforce.

» Support for cognitive work

As industrial work becomes more knowledge intensive, support for cognitive work becomes highly relevant in manufacturing industry. Similar to support for physical work, technology can complement what humans can do. For instance, there are a variety of tasks that humans can do, but computers may be better at, such as looking for a specific, pre-defined pattern in a large database. There are other tasks, like finding a new workaround to a given problem that humans are better at.

Concrete examples for functionalities that extend or support humans in cognitive work are:

≡ Visualizing alternative decisions that take into account human information processing in order to reduce biases in decision-making.
≡ Lower required short-term memory effort by visualizing detailed on-demand information.
≡ Suggesting breaks to work, in order to ensure concentration. Such suggestions could take into account age, but could also be based on monitoring physiological signals such as pupil size.
≡ Lower the amount of errors made on the shop floor by real-time observation of the process and skill- and ability based work instructions.
≡ Supporting continuous professional training and learning.

5. CONCLUSIONS

As mentioned beforehand there is an increasing demand to focus on worker needs in industrial work settings caused by the demographic challenge and the technological development towards CPPS can be used to meet this demands. CPPS have a strong socio-technical character. Therefore it is necessary to use an approach which considers the three parts of such system: the human (H), the technology (T) and the organization (O) (cp. [41]). Figure 10 shows such a production system where humans and technologies work interconnected in new organizational patterns. These systems will have to meet quickly changing demands in the increasingly volatile markets and they will have to deal with external problems in their natural and social environment for example the demographic change and the average aging of population. As elaborated in the paper there are several issues which have to be considered and several levers which can be used to meet the requirements at the different crossings of the three factors (H-T, T-O, and H-O, see Figure 9 and Figure 10)

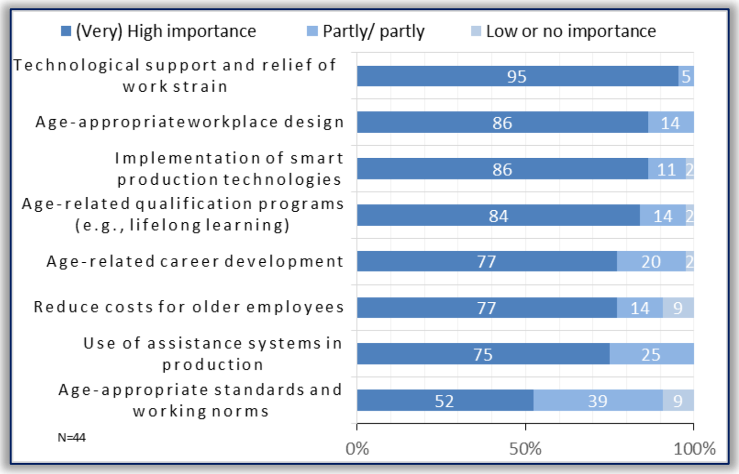

Figure 9 – Most important measures for elderly workers

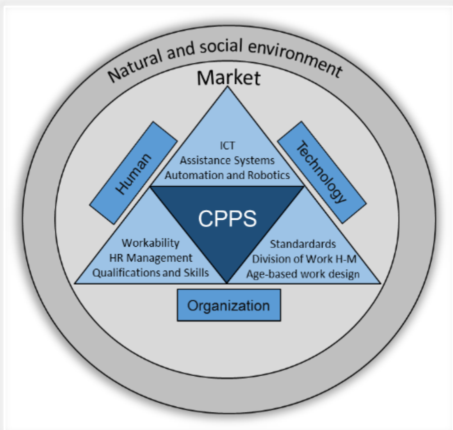

Figure 10 – Levers for the demographic challenge (adapted from [4,41])

At the H-T connection innovative supporting technologies are seen as very important measure to facilitate work by 95% of the sample. Assistance systems, ICT and physical support through robotics and automation can enable the human and especially elderly workers to perform to their potential and compensate for physical or cognitive impairments. At the T-O interface age based industrial standardization, age based working methods, work- and workplace design (86%) and skill-based work division between humans with different abilities or humans and machines can be means to adapt work to human conditions. Finally at the H-O link caring about the worker´s workability (e.g. occupational health and safety systems), providing a suitable occupational education system to equip the workforce with the right qualifications and skills and an age-appropriate human resource management are important factors to keep workers efficiently in employment.

In a time of average ageing populations and increasing skilled workforce shortage the use of the high potential elderly workforce provides is essentially necessary for a sustainable human resource management. The experience of elderly workers combined with general human advantages like flexibility and creativity assisted by the right technologies working in age-appropriate work environments on organization will therefor become a central factor in the production systems of the future.

Note

This paper is based on the paper presented at 9th International Conference "Management of Technology – Step to Sustainable Production" – MOTSP 2017, organized by Faculty of Mechanical Engineering and Naval Architecture of the University of Zagreb, CROATIA and University North, Varaždin, CROATIA, in Dubrovnik, CROATIA, 5 – 7 April 2017.

References

[1] Anil, M., Arunkumar P: Advanced technologies and humans in manufacturing workplaces: an interdependent relationship, International Journal of Industrial Ergonomics, 33(2004)4, 295-313.
[2] Bauernhansl, T. et al.: Industrie 4.0 in Produktion, Automatisierung und Logistik. Anwendung, Technologien, Migration. 1. Aufl., SPRINGER, Wiesbaden, 2014.
[3] Botthof, A.: Zukunft der Arbeit im Kontext von Autonomik und Industrie 4.0. In: Botthof A. u. Hartmann E.A., Zukunft der Arbeit in Industrie 4.0. Springer Vieweg. Berlin, 2015, 4-6.
[4] Deuse, J. et al.: Gestaltung von Produktionssystemen im Kontext von Industrie 4.0. In: Botthoff A., Harmann, E. A.: Zukunft der Arbeit in Industrie 4.0. Springer Vieweg, Berlin, 2015.
[5] Gehrke, L. et al.: A Discussion of Qualifications and Skills in the Factory of the Future: A German and American Perspective, Conference Paper, 2015.
[6] Riley, J: Rising life expectancy: a global history, Cambridge University Press, Cambridge 2001.
[7] WHO: World Health Statistics 2016: Monitoring health for the SDGs, www.who.int/gho/publications/ world_health_statistics/2016/EN_WHS2016_AnnexB.pdf?ua=1, 2016-10-17.
[8] WHO: Austria: WHO statistical profile online, www.who.int/gho/countries/aut. pdf?ua=1, 2016-11-17
[9] Siemens AG: Competencies for the future of manufacturing, Siemens Industry Journal, (2013)2, 11-25.
[10] Bächler, L. et al.: Über die Entwicklung eines prozedul-interaktiven Assistenzsystems für leistungsgeminderte und –gewandelte Mitarbeiter in der manuellen Montage, In: Rathmayer, S., Pongratz P. (Eds.), Proceedings of DeLFI Workshops 2015 (DeLFI 2015), München, Germany, 1st September 2015.
[11] Steinhilper, R. et. al.: Komplexität messbar machen; Eine Methodik zur Quantifizierung von Komplexitätstreibern und -wirkungen am Beispiel der Refabrikation, ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, 107(2012), 360-365.
[12] Bischoff, J. et al.; Studie – Erschließung der Potenziale der Anwendung von Industrie 4.0 im Mittelstan,. Agiplan GmbH, Fraunhofer IML, ZENIT GmbH, 2015.
[13] Schumacher, A. et. al: Von Smart Technologies zur Smart Factory, WINGBusiness, (2016)2, 14-18.
[14] World Economic Forum: The future of jobs, Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution, www3.weforum.org/docs/WEF_Future_of_ Jobs.pdf_, 2016-12-16.
[15] Kagermann, H. et. al.: Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0 – Abschlussbericht des Arbeitskreises Industrie 4.0, Forschungsunion im Stifterverband für die Deutsche Wissenschaft, Berlin, 2013.
[16] Frey, C. B., Osborne, M. A: The future of employment: How susceptible are jobs to computerisation?, 2013, www.oxfordmartin.ox.ac.uk/downloads/academic/The_Future_ of_Employment .pdf, 2016-8-7
[17] Spath, D. (Ed.), Ganschar, O., Gerlach, S., Hämmerle, M., Krause, T., Schlund, S.: Studie: Produktionsarbeit der Zukunft – Industrie 4.0. 2013.
[18] Schlund, S. et. al. Studie - Industrie 4.0 Eine Revolution der Arbeitsgestaltung, Ingenics AG, Fraunhofer IAO, 2014.
[19] Kelloway, E. K., Barling, J.: Knowledge work as organizational behavior. International Journal of Management Reviews, 2(2000), 287–304.
[20] Ludwig, T. et al.: Arbeiten im Mittelstand 4.0 – KMU im Spannungsfeld des digitalen Wandels, 2016.
[21] Simon, W.: Blick in die Zukunft: Industrie 4.0. Industrial Engineering, 2(2013), 38-40
Biermann, H., Weißmantel, H.: Regelkatalog SENSI-Geräte: bedienerfreundlich und barrierefrei durch das richtige Design, Inst. für Elektromechanische Konstruktionen, Darmstadt, 1997, www.emk.tu-darmstadt.de/~weissmantel/sensi/sensi.html, 2015-07-20.
[22] Blumberger, W. et al.: Arbeit – Alter – Anerkennung, IBE-Research Report, Volumen 2, Linz, 2004.
[23] Ilmarinen, J., Tempel, J.: Working ability 2010 – What can we do so that you stay healthy?, Hamburg, 2002.
[24] Ilmarinen, J.: Towards a Longer Work life! Ageing and the Quality of Work life in the European Union, Finnish Institute of Occupational Health, Ministry of Social Affairs and Health and Juhani Ilmarinen, 2006.

[25] Kleindienst M. et.al.: Demographic change and its implications for ergonomic standardization, Book of proceedings of Ergonomics 2016, Zadar, June 2016.
[26] Kruse, A. et.al.: Gerontologie-eine interdisziplinäre Wissenschaft, Bayrischer Monatsspiegel Verlagsgesellschaft mbH, Munich, 1987.
[27] Prasch, M.: Integration leistungsgewandelter Mitarbeiter in die variantenreiche Serienmontage, Herbert Utz Publishing Company GmbH, Munich, 2010.
[28] Rensing, L. Rippe, V.: Altern- zelluläre und molekulare Grundlagen, körperliche Veränderungen und Erkrankungen, Therapieansätze, Springer, Berlin, Heidelberg, 2012.
[29] Richter, G. et. al.: Demografischer Wandel im Arbeitsleben, Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (Eds.), Dortmund, 2012, www.baua.de/de/Publikationen/Fachbeiträge/ Artikel30.html, 2015-28-07.
[30] Riedel, S. et al: Einflüsse altersabhängiger Veränderungen von Bedienpersonen auf die sichere Nutzung von Handmaschinen, Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (Eds.): Research Project F 2118, Dortmund, Berlin, Dresden, 2012, www.baua.de/de/Publikationen/ Fachbeitraege/F2118.pdf, 2015-07-20.
[31] Schlick, C. et. al.: Arbeitswissenschaft, Springer, Berlin, Heidelberg, 2010.
[32] Weger, G.: Alter(n)svielfalt im Betrieb. In Alter(n)svielfalt im Betrieb-Strategien und Maßnahmen für eine nachhaltige Unternehmenspolitik in kleinen und mittleren Unternehmen, Arbeitsbereich Gender and Diversity in Organizations, Wirtschaftsuniversität Wien (Eds), 1. Edition, 2006, 22-29.
[33] Winkle,r R.: Ältere Menschen als Ressource für Wirtschaft und Gesellschaft von morgen In: Clemens, W., Höpflinger, F., Winkler, R. (Eds.): Arbeit in späteren Lebensphasen-Sackgassen, Perspektiven, Visionen, Haupt Publishing Company, Bern 2005, 84-104.
[34] Bullinger, H. et. al.: Alter und Erwerbsarbeit der Zukunft, Springer, Berlin Heidelberg, 1993.
[35] Sandrock, S.: Alternsgerechte Arbeitsgestaltung – ein Baustein zum Erhalt der Leistungsfähigkeit. Betriebspraxis & Arbeitsforschung, (2014)221, 42-45.
[36] Brandenbutg, U., Domschke, P.: Die Zukunft sieht alt aus: Herausforderungen des demografischen Wandels für das Personalmanagement,Gabler Verlag, Wiesbaden, 2007.
[37] Grabbe, J., Götz, R.: Arbeits- und Beschäftigungsfähigkeit- Grundlage von Innovations- und Wettbewerbsfähigkeit. In Klaffke M.: Generationen-Management: Konzepte, Instrumente, Good-Practice-Ansätze, Springer Fachmedien, Wiesbaden, 2014.
[38] Daub, U. et. al.: Assistive technologies for workers in the automotive industry, 15. Internationales Stuttgarter Symposium, Springer Fachmedien, Wiesbaden, 2015, 899-908.
[39] Schmidt, K., Bannon, L.: Taking CSCW Seriously – Supporting Articulation Work, Computer Supported Coop Work, 1992.
[40] Ulich, E.: Mensch, Technik, Organisation: ein europäisches Produktionskonzept, In Strohm, O., Ulich, E. (Eds.): Unternehmen arbeitspsychologisch bewerten, Schriftenreihe Mensch, Technik, Organisation, Band 10, vdf Hochschulverlag, Zürich, 1997, 5-17.

ISSN 1584 - 2665 (printed version); ISSN 2601 - 2332 (online); ISSN-L 1584 - 2665