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Machine Tools and Industrial Robots as Key Technologies to Enable Industry 4.0

The industrial environment has been changing rapidly over the past few years. Today, the Internet of Things (IoT) is finding its way into the global industry sectors. This ongoing industrial digitisation raises new challenges for the whole manufacturing industry. Smart factories are on the rise and promise higher efficiency and productivity. New technological developments in the field of hardware and software significantly extend today's possibilities. Cutting-edge digital manufacturing solutions, especially new smart machines and collaborative robots are being promoted as key enabling technologies in this fourth industrial revolution. However, in the era of Industry 4.0 the holistic integration is a matter of great importance. Taking a step towards Industry 4.0, it is crucial to give equal consideration to products, production processes and business activities.

Keywords: *automation, robots, industrial revolution, Industry 4.0, collaborative robots, smart factory*

A szerszámgépek és ipari robotok kulcsfontosságú elemei az Ipar 4.0-nak

Az ipari környezet jelentősen változott az elmúlt években. Napjainkban az IoT-ok (Internet of Things) egyre nagyobb részben jelennek meg a globális ipari szektorban. Az ipari digitalizáció egyre nagyobb kihívásokkal szembesíti az ipari vállalatokat. Az intelligens gyárak száma egyre nő, mert jobb hatékonyságot és termelékenységet ígérnek. Korszerű digitális gyártási megoldások és a kollaboratív robotok alkalmazása fontos szerepet játszanak a negyedik ipari forradalom megvalósításában. Azonban az Ipar 4.0 korszakában a holisztikus integrációnak egyre fontosabb szerep jut. A cikkben azt próbáljuk megmutatni, hogy milyen lényeges, hogy a terméket, termelői környezetet és az üzleti tevékenységeket egyszerre és egyenlő súllyal vegyük figyelembe, mert ez a lényeg az Ipar 4.0 felé vezető úton.

Kulcsszavak: *Ipar 4.0, együttműködő robotok, intelligens digitális gyár, negyedik ipari forradalom*

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1. Introduction

The aim of the paper is to introduce and explain the main technologies and principles that are required to design and operate production systems in the concept of industry 4.0. The paper collects the enabling technologies and details methods of collaborative robotics operations necessary for industry 4.0

The Internet is fundamentally changing the way in which organisations operate. This development is mainly facilitated through the advances of digital technologies. When in the early twenty-first century, the B2C (Business-to-Customer) sector was confronted with the challenges of the digital transformation, many established companies failed to catch up with new competitors entering the market. Disruptive business models and new disruptive technologies pressurized the once successful companies. Traditional processes had been replaced, supply chains had been dramatically changed, and the innovation cycles have become shorter.[3] Today, similar developments can be observed in the industrial sector, where digital technologies are on the rise. This is evoking a fourth industrial revolution and brings up new challenges for large companies and SMEs on both supply and demand sides.

It is highly important to underline that manufacturing industry is one of the most important industrial sectors in many of the world's leading economies.[4] Around the globe, popular political initiatives such as the German Industry 4.0 try to foster innovations in the field of digital machining solutions and have gained high interest.[5] This kind of automation is present in all other fields outside of industrial automation. Modern control engineering theoretical issues and control applications useful in solution of Industry 4.0 challenges are presented by R. Szabolcsi.[6] As examples of system automation, UAV emergency landing procedures,[7] or the example of the controller design for small UAV closed loop automatic flight control system leaning on the pole placement method,[8] are elaborated in other studies by Szabolcsi. However, there is still much to be done to match theory and practice. Looking at the depth of industrial digitalisation, a field of major importance is the so called enabling technologies.[9] To realise the vision of automatically controlled shop floors and fully connected enterprises, the carpeted and non-carpeted areas need to be centrally and intelligently managed. In this regard software and digital operational technologies in combination with smart machinery and equipment constitute the bais of every smart factory. This paper primarily focuses on the key enabling technologies for Industry 4.0. Although, there is a need to consider many different enablers, the focus will be placed on robots and digital machine tools as key enabling technologies for Industry 4.0. Regarding aircraft manufacturing, application of lean production principles and

[3] Acatech 2013, Umsetzungsempfehlungen für das zukunftsprojekt industrie 4.0. abschlussbericht des arbeitskreises industrie 4.0, April 8, 2013.

[4] *Erschließen der Potenziale der Anwendung von 'Industrie 4.0' im Mittelstand,* Studie im Auftrag des Bundesministeriums für Wirtschaft und Energie (BMWi), 2015.

[5] Mohd Aiman Kamarul Bahrin, Mohd Fauzi Othman, Nor Hayati Nor Azli and Muhamad Farihin Talib: 'Industry 4.0: A review on industrial automation and robotic.' *Jurnal Teknologi* 78, no 6–13 (2016).

[6] R. Szabolcsi, *Szabályozáselmélet* (Budapest: Óbudai Egyetem, 2019).

[7] R. Szabolcsi, 'Controlled Emergency Landing of the Unmanned Aerial Vehicles,' *Land Forces Academy Review* 84, no 4(2016), 364–371.

[8] R. Szabolcsi, 'Pole Placement Technique Applied in Unmanned Aerial Vehicles Automatic Flight Control System Design,' *Land Forces Academy Review* 89, no 1 (2018), 88–98.

[9] R. Szabolcsi, 'A New Emergency Landing Concept for Unmanned Aerial Vehicles,' *Review of the Air Force Academy* 32, no 2 (2016), 5–12.

procedures are proposed.[10] One of the latest initiatives in aerospace manufacturing is the idea of the introduction of 'Aerospace 4.0'. The concept of 'Aerospace 4.0' is an adaptation of those principles into Industry 4.0, but through the lens of the aviation and aerospace sector of industry. New technologies planned to be involved into 'Aerospace 4.0' are, but not limited to, Big Data, 3D printing techniques, mobile computing, use of augmented reality, soft computing (that is, machine learning), and Internet-of-Things (IoT).[11]

2. Sharpening the picture of industry 4.0

The digitisation has been influencing the world, the people and the way of doing business. One major development in recent years has been the 'Internet of Things' (IoT). In the IoT everything is connected to the internet, shares data and interacts with its environment.[12] Now, the digitisation is taking its course in the industrial sector. The Internet of Things is growing wider.

The digital transformation and the rise of smart machinery and new digital technologies influence the industrial production. Changing customer needs, shortening innovation cycles and applying cutting-edge technologies set new challenges in the global competition.[13] In the industrial sector this development is widely referred to as the fourth industrial revolution and promises enormous gains in efficiency and productivity for economies worldwide.[14]

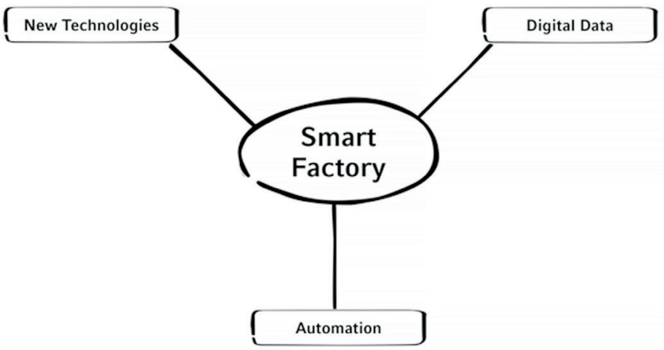

Figure 1
Smart Factory Technologies. Source: edited by the authors

In detail, the concept of Industry 4.0 describes the vision of fully connected and smart factories, which are vertically connected to the office floor and horizontally connected to dispersed value networks. Industry 4.0 aims to connect the digital and virtual world of

[10] Hsien-Ming Chang, Chikong Huang and Chau-Chen Torng, 'Lean Production Implement Model for Aerospace Manufacturing Suppliers.' *International Journal of Innovation, Management and Technology* 4, no 2 (2013).
[11] Dan Lewis, 'Aerospace 4.0 – why we need it,' Aerospace manufacturing, 10. 06. 2019.
[12] P. Mills, 'Smarter, Smaller, Safer Robots,' *Harvard Business Review* 11 (2015), 28–30.
[13] Günther Schuh, Till Potente, Cathrin Wesch-Potente, Anja Ruth Weber and Jan-Philipp Prote, 'Collaboration Mechanisms to Increase Productivity in the Context of Industrie 4.0,' *Procedia CIRP* 19 (2014), 51–56.
[14] 'Top Trends in the Gartner Hype Cycle for Emerging Technologies, 2017,' Gartner.

computer technology with the world of industrial production. Every asset is connected to higher level systems and shares data in real-time. Often this is referred to as a Cyber-Physical System for digital factory solutions.[15] One point frequently referred to in terms of Industry 4.0 is the economical production of batch sizes starting from one.[16] Figure 1 depicts three main elements in the smart factory.

Automation, and in this regard, continuous smooth-running processes are the most critical part in Industry 4.0, as they are enabling machines to adapt to changes in real time. These continuous processes require a stronger convergence of IT, OT and machinery and equipment.[17] As a result, the only way of realising holistic Industry 4.0 solutions is to implement every machine, robot and worker into a company-wide digital infrastructure.[18] Higher level systems then perform actions and control the processes intelligently – the collected digital data can be used for predictive solutions and databased decision-making.[19] A 'digital twin' of the factory and all its assets allows simulation processes for adaptive control and management, and also on-line diagnostics, simulation and testing without interfering with the production. Central to the entire discipline of Industry 4.0 is the application of various technologies. Thus, the field of industrial digitisation requires a holistic and comprehensive digital realignment of the entire corporation. Factories are already working on the integration of different new technologies, but the interdisciplinary character brings additional issues. Manufacturers across various industries need to redefine their production processes and holistically integrate new technologies in order to enable smart manufacturing and digital factory solutions.

3. Key enabling technologies

Due to the different sectors and domain specific requirements, Industry 4.0 incorporates a great number of technologies. Despite this great variety, an indispensable component of Industry 4.0 is basic enabling technologies. The technologies can be categorised in new developments in the field of information and operational technology for future factories and the appropriate hardware needed to enable the new solutions. When it comes to IT and OT in terms of Industry 4.0, different areas are needed to be taken into account. The most important ones are as they listed below:

- IoT-infrastructure;
- digital data and processes;
- Manufacturing Execution systems (MES);
- Enterprise Resource Planning (ERP);
- Big Data and Analytics.

15 M. Luckenhaus, 'Machine vision in IoT: how machine vision technologies help to overcome new challenges related to connected and automated production,' *Quality* 55, no 5 (2016), 18–20.

16 Georg Weichhart, Arturo Molina, David Chen, Lawrence E. Whitman and François Vernadat, 'Challenges and Current Developments for Sensing, Smart and Sustainable Enterprise Systems,' *Computers in Industry* 79 (June 2016), 34–46.

17 L. Picket, 'Smart Manufacturing: A Digital Leap Forward,' *Quality* 55, no 6 (2016), 36–39.

18 Weichhart et al., 'Challenges'.

19 D. Zuehlke, 'Smart Factory – Towards a Factory-of-Things,' *Annual Reviews in Control* 34, no 1 (Apr. 2010), 129–138.

Overall, a basic IoT-infrastructure is necessary to enable digitization and benefit from the possibilities. Central to the entire discipline is the flow of data in the organisation to digitally map the business and production processes for extended control and optimisation possibilities. In this regard, MES and ERP systems are two building blocks for the realisation of continuous processes. Additionally, there is an increasing demand for new tools to connect the different organisational levels, especially business processes on the office floor and production processes on the shop floor.[20] As Shariatzadeh et al. stated, a 'common language' is required.[21] This imposes tough requirements on the interface compatibility of IT and OT. However, using dedicated software tools and digital technologies to support the production processes, factories become more resilient and smart. Implementing those interconnected software tools is an important step to enable Industry 4.0 and realise cost reductions and productivity increases.[22] In such fully connected factories, the collected data, in combination with the previously mentioned cloud technology and IT-tools, can be used for detailed analysis.[23]

Although software is becoming increasingly important, it is only half of the job. In Industry 4.0, there is a wide range of new solutions in the field of industrial hardware products. The holistic integration of both hardware and software in the factory is essential. As Zuehlke describes in his article: 'Everything, down to the smallest piece of equipment, must have a certain degree of built-in intelligence. In respect thereof, the holistic integration of all machines, workpieces, tools, other assets and human workers into a company-wide digital infrastructure is a crucial step towards smart manufacturing and digital factories.'[24] Looking at the shop floor integration, many important innovations that come from the fields of manufacturing and automation effectively transform a factory into a smart factory.[25] In the near future shop floors will be characterised by the application of highly automated machine tools and robots.[26] Therefore, those two technological fields can be described as the major transformational forces.

4. Machines, robots and human workers working hand in hand

The industrial digitisation represents a major shift in how manufacturers operate. This fourth industrial revolution fundamentally transformed, and will continue to transform, the industrial sector. Integrated in a digital infrastructure, future factories will be able to produce in high quality at low costs and on demand. This directly affects the competitive landscape of the whole industry. In respect thereof, the holistic integration of all machines, workpieces, tools, other assets and human workers into a company-wide digital infrastructure is a crucial

[20] Matthias M. Herterich, Falk Uebernickel and Walter Brenner, 'The Impact of Cyber-physical Systems on Industrial Services in Manufacturing,' *Procedia CIRP* 30 (2015), 323–328.

[21] Navid Shariatzadeh, Thomas Lundholm, Lars Lindberg and Gunilla Sivard, 'Integration of Digital Factory with Smart Factory Based on Internet of Things,' *Procedia CIRP* 50 (2016), 512–517.

[22] Petri Helo, Mikko Suorsa, Yuqiuge Hao and Pornthep Anussornnitisarn,'Toward a cloud-based manufacturing execution system for distributed manufacturing,' *Computers in Industry* 65, no 4 (May 2014), 646–656.

[23] O. Sauer, 'Information Technology for the Factory of the Future – State of the Art and Need for Action.' *Procedia CIRP* 25 (2014), 293–296.

[24] Zuehlke, 'Smart Factory,' 21.

[25] H. Weiss, '"Predictive Maintenance": Vorhersagemodelle krempeln die Wartung um,' ingenieur.de, 2012.

[26] L. Thames and D. Schaefer, 'Software-defined Cloud Manufacturing for Industry 4.0,' *Procedia CIRP* 52 (2016), 12–17.

step towards smart manufacturing and digital factories for every industrial company. Robot applications emerge from knowledge of the loads affecting its technical status.[27] Segmentation and classification of loads of the UGV of general use were discussed, and the investigation of importance of the UGV maintenance was presented by Szabolcsi and Menyhárt.[28] The UGV is a vehicle activated by electrical energy.[29] The accessibility of the UGV mostly depends on electrical energy available aboard. In SVM and Fuzzy logic were introduced to evaluate technical status of the batteries applied by the UGV.[30]

4.1. Smart machinery and equipment

The ongoing changes influence the shop floor management, and the success of the industrial digitisation is highly affected by the widespread integration of smart machining solutions. Due to the advent of smart manufacturing technologies in particular, connected machinery and equipment are in the position to produce with higher efficiency.[31] Smart machine tools are equipped with sensors and embedded systems and connected to the higher-level systems to collect process data in real time.[32] A variable number of sensors measures the machining data (for example spindle speed, temperature, accelerations, forces, vibrations, sound). The data of the machines enables predictive service solutions and increase the machine run time through continuous condition monitoring.[33] Targeting existing machines, retro-fit solutions allow manufacturers to integrate those into the smart manufacturing environment in a comfortable way at low cost.[34]

Dealing with the interface between human workers and machines, a central issue in Industry 4.0 is the interaction between human workers and the software and hardware systems. New human machine interfaces (HMI) are needed.[35] Machines provide in-built assistance software and control panels. These solutions aim to simplify the machining process and reduce complexity for the workers. Employees in the smart factory will use a wide set of mobile devices. Weichhart et al. indicated that 'the increasing use of smartphones, tablets, mobile devices and sensor networks demonstrates the connectivity between people and people, people and machines, machines and machines'.[36] For example, industrial tablet computers can be used for different applications and allow advanced, location-independent process management and monitoring of the assets. Sauer et al. point out that

[27] R. Szabolcsi and J. Menyhárt, 'Loads Affecting UGV's Technical Status,' *Review of the Air Force Academy* 30, no 3 (2015), 15–20.
[28] R. Szabolcsi and J. Menyhárt, 'The Importance of Maintenance During UGV Use,' *Land Forces Academy Review* 80, no 4 (2015), 486–492.
[29] Thames and Schaefer, 'Software-defined', 12–17.
[30] J. Menyhárt and R. Szabolcsi, 'Support Vector Machine and Fuzzy Logic,' *Acta Polytechnica Hungarica* 13, no 5 (2016), 205–220.
[31] Weiss, '"Predictive Maintenance"'.
[32] Picket, 'Smart Manufacturing', 36–39.
[33] 'Standardization'. International Federation of Robotics, 2017.
[34] G. Gorbach and C. Polsonetti, 'Realizing value from the Industrial Internet of Things,' *InTech* 62, no 4 (2015), 12–18.
[35] Jay Lee, Hung-An Kao and Shanhu Yang, 'Service Innovation and Smart Analytics for Industry 4.0 and Big Data Environment,' *Procedia CIRP* 16 (2014), 3–8.
[36] Weichhart et al., 'Challenges'.

an information-overload must be prevented, which requires a role based distribution of information – users, for example machine workers receive exactly the information they need at a certain time to complete their tasks.

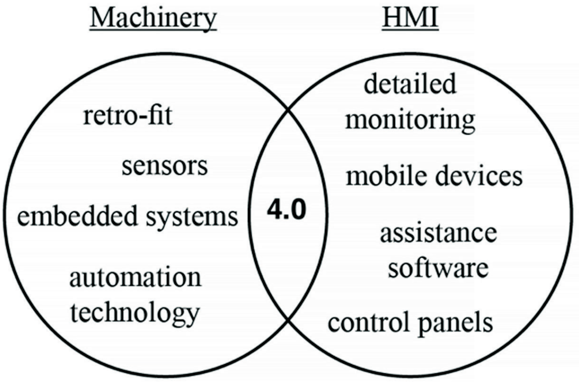

Figure 2
Machinery and HMI in Industry 4.0. Source: edited by the authors

Smart machinery and equipment is important to produce more efficiently and with higher reliability. The new technologies on the shop floor level of companies are enabling the digital transformation of factories.

4.2. Smart collaborative robots

An integral part of a smart factory is such an automation that ensures high process reliability and manages increased complexity in the era of mass customisation. The market for industrial robots has been growing rapidly over the past few years. The statistics below show the growing interest in robot technology and the estimated market growth in the next years.

Together with the higher level and embedded systems, next-level automation technology is the key to adaptive production processes in the smart factory. In the history of factory automation, robots have always played a vital role. The IFR defines a robot as 'an automatically controlled, reprogrammable multipurpose manipulator programmable in three or more axes which may be either fixed in place or mobile for use in industrial applications'.[37] The new, smart and collaborative robots are characterised by visual systems and sensors to be aware of the environment and guarantee the safety of workers.[38]

However, the maturity of the collaborative robots is at a fast developing, but early stage. Looking at the recent Hype Cycle of emerging technologies, the collaborative robots are moving to the peak of inflated expectations. The time until the technology can be used in terms of productivity is estimated to five to ten years.

[37] J. Lawton, *Collaborative Robots and the Future of Work*, Boston, MA, 2015.

[38] J. A. Corrales, G. J. García Gómez, F. Torres and V. Perdereau, 'Cooperative Tasks between Humans and Robots in Industrial Environments,' *International Journal of Advanced Robotic Systems* 9, no 3 (2012), 94.

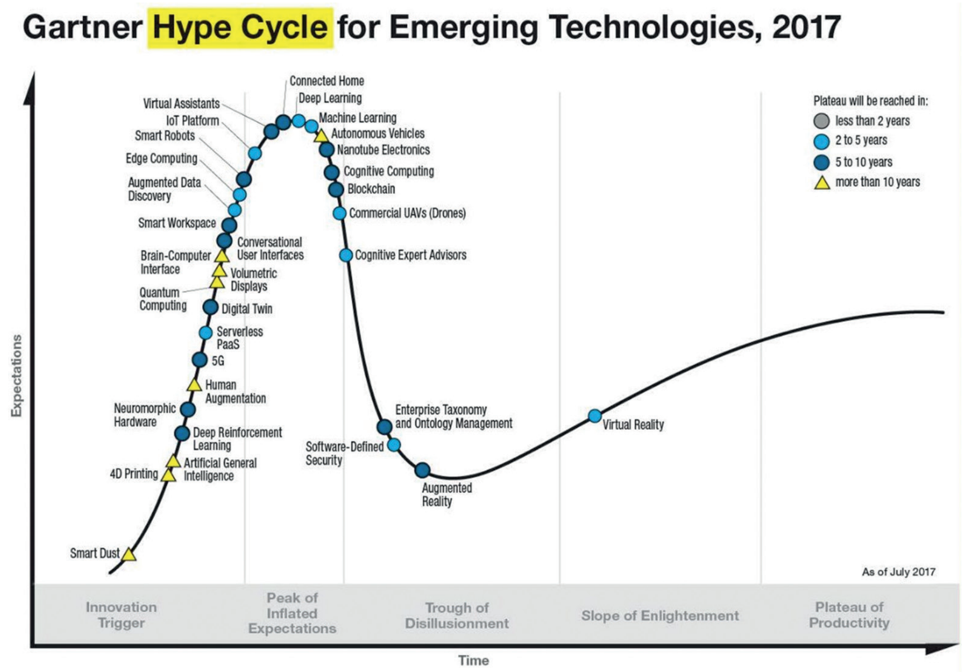

Figure 3
Hype Cycle Emerging Technologies. Source: I. Veza, M. Mladineo and N. Gjeldum, 'Managing Innovative Production Network of Smart Factories,' *IFAC-PapersOnline* 48, no 3 (2015), 555–560.

Until this plateau of productivity is reached, there will be some kind of uncertainty about the risks and chances. Nonetheless, after the hype there will be the 'Slope of Enlightenment' where the real potential of the technology becomes clear and the first practical implementations have been successful.[39]

Figure 4 shows a robot at a manual workplace that assist the worker. For example assembly tasks can be done with support of collaborative robots. Furthermore, the robot is instructed to perform an assembly operation, that is, it is not programmed in the classical way.[40]

Furthermore, robots will support the workers in many more scenarios. In a smart factory, robots are able to collaborate with their human colleagues and automate processes. In this regard, collaborating with robot manipulators on the shop floor means that robots perform monotonous tasks and reduce the workload of employees. Industrial robots will become smarter, lighter and more compact. On a shop floor, where robots interact with their environment (machine tools, workers, transportation equipment), this enormously boosts competitiveness. As Mills states, 'adaptive robots increasingly gain the capacity to be trained by people and to be programmed on the fly to do whatever needs doing, their efficiency and

[39] Veza, Mladineo and Gjeldum, 'Managing.'.

[40] T. Stock and G. Seliger, 'Opportunities of Sustainable Manufacturing in Industry 4.0,' *Procedia CIRP* 40 (2016), 536–541.

flexibility will skyrocket'.[41] The evolution of the robot technology and the increase in flexibility highly influences the potential use cases. Especially due to their various application purposes, smart robots, which collaborate with human and automated machining processes, are a key technology to enable Industry 4.0. If there are flexible robots that can be moved easily from machine to machine and perform their tasks, this affects the whole factory organisation. Collaborative robots can assist workers, for example, by holding the heavy part while the worker performs the necessary tasks (for example assembling an additional part) on it.

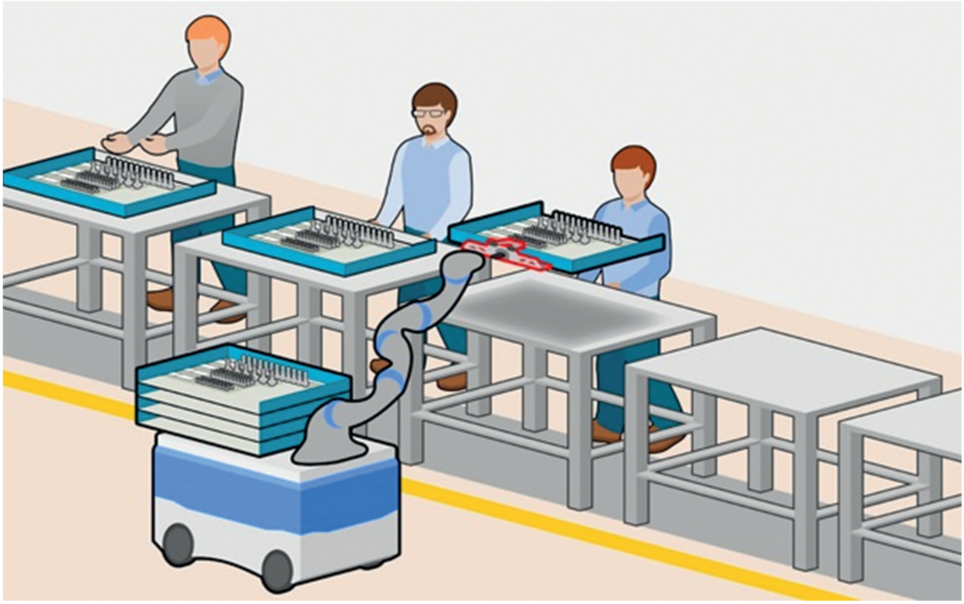

Figure 4
Collaborative robot assisting manual workers. Source: 'Robots: Humans' Dependable Helpers,' Fraunhofer-Institut für Fabrikbetrieb und Automatisierung IFF.

4.3. Smart Factory organisation

New machine tools, innovative robot and machining technology or smart mobile devices play a vital role in Industry 4.0. In such a smart environment, the products and raw materials are uniquely identifiable, can be localised at all times and know their own history, current status and alternative routes to achieve their target state. This will leverage transparency and also increase productivity in the manufacturing sector. This transparency is seen as one of the key advantages of industrial digitisation. It enables a completely new way of companies working together. In terms of the supply chain management, the higher connectivity also allows a demand-oriented production.

41 R. Neubert, 'Powering the Industrial Internet of Things,' *Plant Engineering* 70, no 2 (2016), 32–34.

Transport equipment will be interchanging data with the machines to realise the coordination of supply and products. Additionally, the next-level industrial robots and machine tools create new efficiencies. Moreover, it enables a whole new way of producing goods – individually, fast and on-demand. The interconnection and continuous data exchange can be used for decentralised decision making and smart shop floor organisation, as the assets share information about their condition and the products manage their own production. Scenarios like an autonomous production plant may become possible in future factories. Nonetheless, humans will always play a significant role in the future. In the mid-term, robots and smart machines and Industry 4.0 solutions are not aiming to replace workers. Manufacturers mainly benefit from the ability to manage the production in real time, which is important to react to changes in the environment quickly and is particularly useful in the manufacturing environments of today, with an increasing number of customised products. Indeed, robots can perform tasks like part- and tool-handling, cleaning and maintaining autonomously – therefore, these tasks in manufacturing will certainly be automated. Eventually, a future is possible where tasks of human workers will be limited to the monitoring of the automated equipment. However, a factory is more likely where robots and humans will work hand-in-hand together.[42]

5. Conclusions

In conclusion, the Internet of Things is no longer relevant just to private users. Instead, it represents an effective way to take production to a new level of effectiveness. Even though it is a relatively new concept, many outstanding opportunities had been identified by different institutions worldwide. Furthermore, the first practical implementations show the potential in the individual mass production of goods. The increasing degree of automation brings the chance to produce individual products on demand, in high quality and at low cost. Nonetheless, the chance to adapt to environmental changes and produce with outstanding efficiency and productivity can only be put into practice when all the hardware and equipment is interlinked and connected. What are especially important enablers to meet the vision of mass customisation are smart machines in combination with robots that fully automate the processes. As a result, manufacturers are forced to develop comprehensive strategies in order to undertake these chances. In the future, we plan to exploit the research further in the field of collaborative robotics.

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[42] Ibid.

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