Scalability of Assembly Line Automation Based on the Integrated Product Development Approach

Florian Hoffmann, Vanessa Wesskamp, Raphael Bleck and Jochen Deuse

Abstract

Product life cycles change, market developments and quantities are increasingly difficult to predict, as is the case in the production of charging stations. For these reasons, scalable assembly concepts with an adaptable degree of automation are becoming increasingly important. Currently, charging stations are still manufactured manually. With increasing quantities, however, manual production is no longer economical. New technologies such as lightweight robotics offer a great potential for making production more flexible in terms of quantity. At the same time, new challenges arise because these requirements must be taken into account from the very beginning of product development and process planning. Currently, there are no planning approaches and recommendations for action that take this into consideration. Therefore, the research project "Simultaneous product and process development of a charging station outlet module suitable for automation" (SUPPLy) develops an integrated, digital and simultaneous product and process development of a modular charging station suitable for automation. The aim of the project is to develop an assembly process which enables an economic production of charging stations in case of

F. Hoffmann (✉) · V. Wesskamp · R. Bleck · J. Deuse
Institute of Production Systems, TU Dortmund University, Leonhard-Euler-Straße 5, 44227 Dortmund, Germany
e-mail: florian.hoffmann@ips.tu-dortmund.de

J. Deuse
Advanced Manufacturing, School of Mechanical and Mechatronic Engineering, University of Technology Sydney, Sydney, Australia

T. Schüppstuhl et al. (eds.), *Annals of Scientific Society for Assembly, Handling and Industrial Robotics 2021*,
https://doi.org/10.1007/978-3-030-74032-0_23

fluctuating sales figures. The focus is not only on changes in the production process but also on a product design that is suitable for automation. The paper presents the ideas on a conceptual level.

Keywords
Integrated product development · Assembly · Scalability · Simultaneous engineering · Industry 4.0

1 Introduction

In order to maintain the competitiveness of the German automotive and supplier industry and to survive in global competition, Germany is to become the lead market for electric mobility [1]. To achieve this challenging goal, one million electric cars are to be in use on the roads by the end of 2022 [2]. The government's goal, and with it the establishment of electromobility as part of a sustainable transport system, will only be achieved if charging infrastructure solutions are available across the board that allow electric vehicles to be charged at any time and as needed. The development in this area is currently still in a premarket phase. Accordingly, demand for such products is still at a comparatively low level, meaning that extensive investments in plant and automation technology have not yet been economically viable for manufacturers. Due to low market demand and lack of economies of scale, the components and the manufacturing processes are very cost intensive, which in turn leads to high prices for the charging infrastructure. According to various forecasts, however, there will be a rapid and sustained increase in demand in the coming years. A nationwide charging infrastructure can only be set up if the corresponding charging stations can be built economically. So that a progressive industrialization of products and the corresponding production processes will become indispensable [2–4].

This paper presents a new approach for a scalable line automation. Chapter 2 gives an overview of existing planning approaches followed by a specification of scalability in charging station production, including the importance of human–robot-interaction (HRI) in Chap. 3. The developed concept is outlined in Chap. 4 including a theoretical application scenario. The paper concludes with an outlook.

2 Planning Approaches

Planning systems represent an important thematic basis for the development of scalable assembly concepts. They serve the analysis, planning, design and improvement of socio-technical work systems and can lead to more efficient processes through clever application. One of the conventional planning methods is the planning systematic according to REFA, a german association for work design, business organization and business development [5]. This contains general instructions for planning complex manufacturing and assembly systems. A central feature of the system developed by Rother and Harris [6] is the possible reduction of the degree of automation in order to enable increased flexibility and a continuous flow of employees. Dietz's [7] approach addresses the high and dynamically changing variant diversity in production systems over time and provides ideas for product structure dependent manufacturing system design. In contrary, the MABA-MABA (men are better at—machines are better at) planning approaches focus on skills-oriented process design between man and machine in the context of increasing automation [8].

Furthermore, production systems as a whole are increasingly exposed to time dynamic influencing factors, so that the planning of changeable and adaptable systems is also of increased importance for the planned research project [9].

Production oriented approaches are particularly suitable for planning manufacturing and assembly systems with high volumes and low product variance. In many cases, these methods are geared towards more capital intensive systems in order to produce the required quantities as economically as possible by exploiting economies of scale. In order to enable the production of an economically viable product even in the case of fluctuations in demand, the pure consideration of production oriented approaches is insufficient. These approaches must be combined with measures to optimize product development in order to achieve a holistic method.

In this context Hengstebeck [10] provides an insight into the different areas that are affected by the planning of semi automated work systems (e.g. product development, production planning, maintenance). Deuse identifies a great potential in the realization of cyber-physical production systems (CPPS), in which human capabilities are enhanced through the intelligent use of information and communication technologies. For this purpose, new collaborative forms of work must be developed in which humans can optimise processes and act as active decision makers [11].

Simultaneous engineering enables a shorter time-to-market through a close integration of product development and production planning, which can lead to competitive advantages. In literature there are promising approaches that show possible process models. Erlenspiel [12] describes a method that focuses on development and construction and addresses simultaneous planning across phases. Similarly, Bullinger contributes to simultaneous engineering, focusing on efficiency and cost aspects [13]. Overall, it can be stated that none of the planning approaches presented above sufficiently meets the requirements for designing a scalable production system. The core objective of SUPPLy is to develop a scalable assembly system for the production of charging stations that ensures cost-effective operation at all times during production. For this purpose, it is necessary to continuously adapt the production capacity to the respective situation on the sales market [14]. The basis for this in a high wage country, such as Germany, is a flexible adaptation of the degree of automation with the help of HRI. Product design is being rethought to maximise flexibility and aligned with the needs of HRI technology. As outlined in the next chapter, several approaches have to be combined to meet the challenges of the market.

3 Quantity Dependent Charging Station Production

Although the German government has set concrete targets for the number of electric cars on the road for the next few years, it is very difficult to predict how sales will develop. Political measures, such as targets for fleet consumption, purchase premiums, or an adjustment of the motor vehicle tax to match emissions, lead to fluctuating demand in the market. [15]

Due to the prevailing market situation, specific requirements for the work system planning arise. Short planning cycles as well as a good and economic scalability are the core challenges in the planning process. Conventional sequential planning of assembly systems is not able to meet these market dynamics. In high wages countries a scalability using only personnel deployment is not economic. As explained above, an adaption of the degree of automation is a frequently used instrument. However specialised semi-automated or automated systems cannot react to short-term fluctuations. Taking increasingly shorter product lifecycles due to a fast technological progress into account, these systems are not economical either. Lightweight robots offer a new possibility for an adaptable degree of automation. Accordingly, the planning concept must combine HRI-compliant and modular product design with scalable assembly system development [16, 17].

Comparatively low investment costs and the possibility to use them with small adaption in different production systems as needed and the option to realise HRI, promises a high potential to increase flexibility. HRI offers many possibilities for automating manual assembly processes making optimal use of the strength and weaknesses of humans and robots [18]. By exploiting these synergies, the output volume can be increased by using a robot to partially automate previously manual tasks [10].

When planning and realizing a flexible automatable assembly system, greater attention must be paid to the expandability of the assembly system and the reusability of components. A modular system structure is recommended in order to minimize the resulting costs for rebuilding measures or for the restart [19]. The lightweight robots can be integrated with only minor changes to manual work systems and are able to produce especially small and medium quantities efficiently and economically [20, 21].

To realise this potential, the product must be suitable for the handling and assembly by robots as well as manual handling. The geometry of a product significantly influences the way it can be picked up by the robot end effector. Sharp edges or protruding parts make handling just as difficult as fragile plug-in connections. In many cases, bendable parts are not suitable for automated handling. In this context, design alternatives can already be considered during product development. With regard to the payload, lightweight robots capable of interaction are usually limited to single-digit kilogram ranges due to safety requirements. Due to these framework conditions, the production use of HRI is significantly determined by the product design [22, 23].

For this reason, when planning a scalable work system with a variable degree of automation, it is very important to involve the construction and design department from the outset in order to minimize scaling costs during production [24]. In this context, Nyhuis defines the five (product) characteristics universality, scalability, modularity, mobility and compatibility as so called transformation enablers. With the help of these characteristics, the requirements for a flexible assembly system and its components can be described [25].

External disturbances influence the assembly system during ongoing production operations and require constant adjustments [26]. In the present case of charging station assembly, significant fluctuations in demand must be taken into account for the reasons mentioned previously. For the first concept of a scalable charging station assembly line, scalability and modularity are particularly important in order to create an optimal basis for further flexibility-increasing measures. In the context of the project, modularity relates in particular to product development, which is at the beginning of the development process and has a direct influence on the subsequent scalability of production.

Production currently involves the assembly of numerous individual components, including their cabling. A promising approach in this context is the development of a **modular product design** that reduces assembly complexity and favours HRI. This in turn enables the necessary **scalability of production** depending on market needs. Due to the need to consider assembly possibilities and HRI suitability already in the product design, the SUPPLy project, as shown in Fig. 1 focuses on **simultaneous engineering** in relation to the integrated product development approach.

By linking modularity and scalability, an assembly concept is created that offers maximum adaptability depending on the quantity requirements while addressing the need for short planning cycles. For subsequent development steps, compatibility, universality and mobility must be taken into account with the aim of further increasing flexibility. By

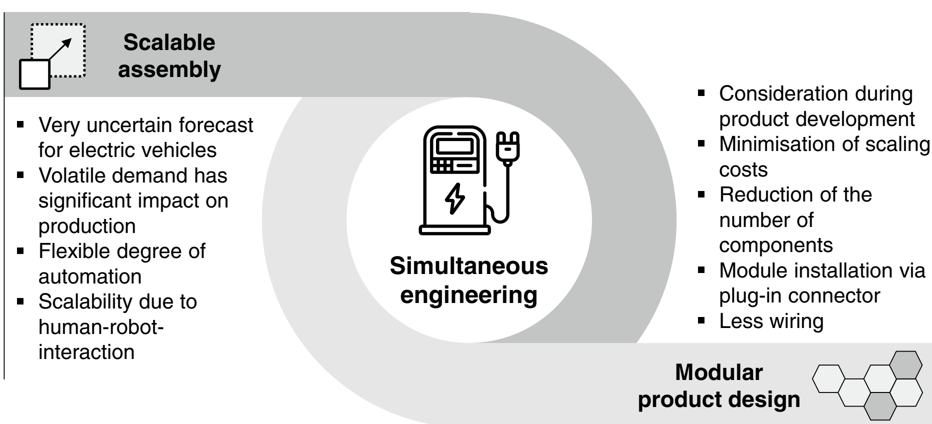

Fig. 1 Integrated product development approach in the SUPPLy project

taking these characteristics into account during product and process design, the future expandability and changeability of the overall system is guaranteed.

4 Application Concept

In the following, an application concept for the integrated product development ap-proach is described. As shown in Fig. 1, the simultaneous engineering concept is based on two approaches: The **modularisation of the product structure** and the **scalability of assembly line automation**. The two solution approaches are considered using the example of the manufacture of public AC (alternating current) charging stations. Many providers of charging stations are currently advertising with a modular design of their products. On closer inspection, however, it becomes clear that the modular approach is only from the customer's perspective. Similar to the vehicle configuration, the customer has the option to customize the station housing and can add or remove various technical components. However, a modular product structure from a design perspective is not yet applied.

A modern AC charging station for public spaces consists of a large number of individual parts, which are usually purchased separately. The assembly process for a charging station is currently very time-consuming and labour-intensive and is usually only carried out manually due to the extensive cabling effort. With an exemplary total assembly time of six hours, up to three hours must be allowed for the wiring of the components with subsequent functional testing. For this reason, the modularisation of the interior of a charging station is a promising approach. A large part of the components used is recurring standard parts, which are a fundamental part of every charging station regardless of the variant. Figure 2 shows standard components that can be combined in the course of a possible modularisation.

As part of the development of a modular product structure, an early concept for an outlet module is being developed that combines various basic components and can therefore be installed into any product variant. When developing this integral design, it is important to consider the subsequent usability in hybrid work systems according to the

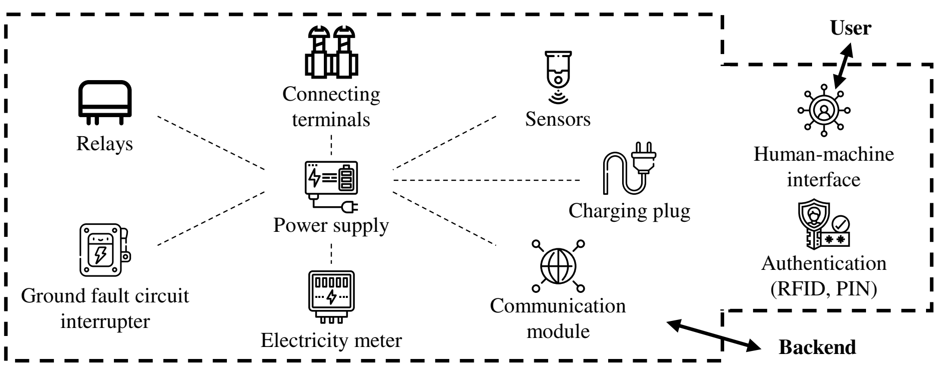

Fig. 2 Possible modularisation of standard components of a charging station

framework conditions for the use of HRI explained in Chap. 3. The aim is to reduce assembly time in order to increase quantities and to be able to adjust the degree of automation depending on market demand.

One of the main challenges is to reduce the amount of cabling by using different technologies. It is conceivable to design a motherboard that enables assembly by means of plug connections, as is the case with desktop computers, for example. In this way, optional interfaces could be created that enable the installation of customised modules (e. g. a user interface) without affecting the installation of the standard components.

By reducing or possibly even eliminating the manual cabling effort, the assembly time can be additionally reduced, which in turn favours high quantity requirements. In order to take into account, the payload of the robot, the module size can be adapted accordingly depending on the function combination, so that different handling and assembly processes can be automated. The integration of several standard electrical components, might make an in-house production economically feasible for certain parts. This would create the possibility of integrating the respective components firmly into the module instead of continuing to use the parts individually. In this way, additional influence can be exerted on the nature of the geometry and the surface, for example, to reduce the number of necessary gripper changes and eliminate associated set-up losses.

Due to the lack of product development, only basic framework conditions can currently be defined for the consideration horizon of the planning approach. It can be assumed that a large part of the wiring effort can be reduced by redesigning the individual electrotechnical components into functional modules, but that this is not completely eliminated. In order to enable very high piece count scenarios with simultaneous economic efficiency, flow production is used as the basic set-up principle already during the creation of a first planning draft. Figure 3 shows an exemplary layout for a corresponding assembly line.

Due to the prevailing framework conditions in charging station production, production must be designed for a high degree of flexibility in terms of unit numbers right from the start of planning. The assembly line has four workstations where the modular socket module is assembled manually. The work planning should take into account a possible parallelisation of the assembly so that, if necessary, the cycle time of the workstations can

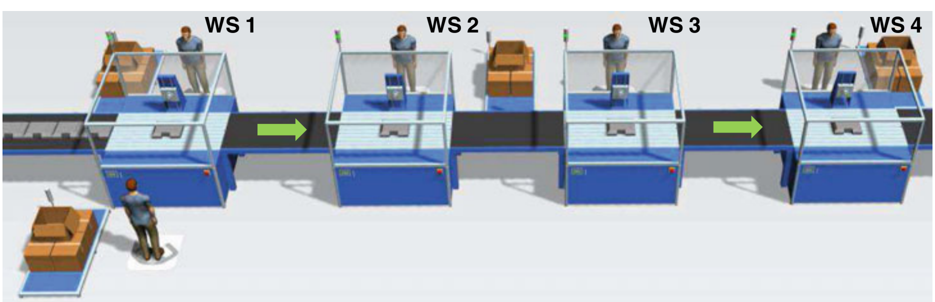

Fig. 3 Layout of an assembly line with manual operations

be reduced due to a necessary adjustment of the line cycle by means of additional employees (e. g. workstation 1) and thus the output quantity increased.

This is conceivable, for example, through an individual assembly sequence, which must be taken into account in the product design. In the event that economic production is no longer possible due to manual assembly activities, the next stage can be applied by using HRI. Figure 4 shows an example of a possible line adaptation.

Workstation three and four are converted into HRI workstations with the aim of further reducing the cycle time of the line. A skill-oriented division of labour between humans and robots must be taken into account. Necessary cabling, for example, will continue to be carried out by humans. Appropriate analyses can be used to determine the HRI potential of individual workstations [27].

For this purpose, an HRI preassembly could be integrated, as shown in Fig. 4 for the fourth workstation, in which the work content is divided accordingly. The tasks could be divided in such a way that one employee carries out the necessary wiring at the pre-assembly workplace. The wired module is then brought into the assembly line by a robot and mounted there in collaboration with another employee. Depending on the degree of decoupling from a necessary assembly sequence, any line layouts are conceivable. Appropriate line layouts are to be worked out depending on the quantity requirements and the work contents are to be distributed to the respective workstations. In addition to the sensible division of labour between humans and robots, the assembly sequence also plays an important role.

The concept presented in Chap. 4, which follows the approach of an integrated product development in order to maximise the production flexibility, represents the first stage of a reference planning process for charging station production. The planned procedure must be substantiated by initial product development approaches and market requirements. In this context, the use of simulation software would be useful to analyse and economically evaluate different scenarios. In addition to market development, other factors must be taken into account that influence the choice of a production system technology. These

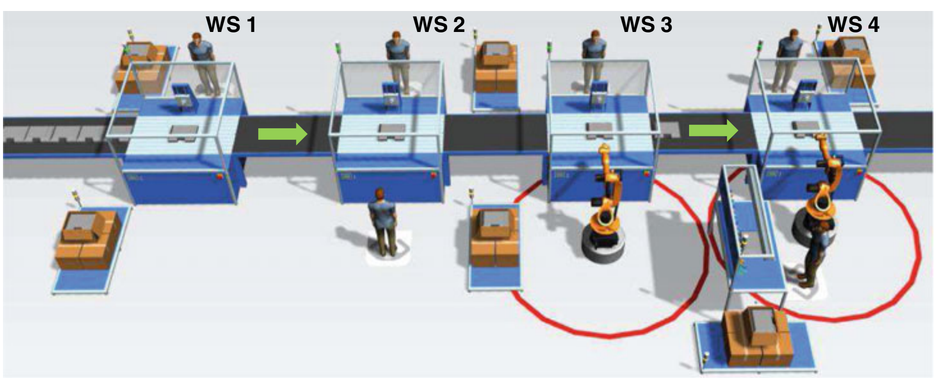

Fig. 4 Layout of an assembly line with scalable degree of automation

include, for example, the duration of the product life cycle, political deregulation or general technological progress [28]. Since electromobility is a comparatively young technology, it can be expected that various technical innovations will be developed, especially at the beginning. Due to the many external influences and uncertainties, it can also be assumed that a very high degree of flexibility in the number of units is required to enable an economic production of charging stations in the high-wage country Germany. The following planning stages must therefore further favour and promote the flexibility of production.

5 Conclusion and Outlook

At present, assembly systems planning processes do not adequately address the prob-lem of volatile sales. The current situation on the electromobility market contributes to the relevance of the research approach. The integration of interacting human–robot systems is a promising approach for making production more flexible in terms of quantity. However, the requirements for a flexible degree of automation must be already taken into account during product development. For these reasons, the project goal was the integrated, digital and simultaneous product and process development for modular, automation capable charging stations. The current working status of these two approaches is still at concept level. After reviewing and evaluating the relevant literature, uniform goals and the further procedure were defined as part of a joint kick-off event. The project partners Institute for Factory Automation and Production Systems (FAPS) and Compleo Charging Solutions are currently working on the technical aspects of product development, which will be used to define the framework for a scalable production process. On this basis, the production planning is carried out. The research project SUPPLy started in January 2020 and has a funding period of 36 months. In addition to the new development of a modular outlet module, the objectives include the conceptual design and commissioning of an assembly line developed especially for this purpose.

Acknowledgements The research and development project SUPPLy is funded under Grant No. 01MV19001B within the scope of the German "Elektro-Mobil" technology program run by the Federal Ministry for Economic Affairs and Energy and is managed by the German Aerospace Center in Cologne. We would like to thank our project partners Compleo Charging Solutions GmbH and FAPS for their valuable contributions.

References

1. German Federal Government: National Development Plan for Electric Mobility. https://www.bmu.de/en/download/the-federal-governments-national-development-plan-for-electric-mobility/ (2009). Accessed 11 Dec 2020
2. German National Platform for Electric Mobility (NPE): Progress Report 2018 - Market ramp-up phase. http://nationale-plattform-elektromobilitaet.de/en/the-npe/publications/ (2018). Accessed 11 Dec 2020
3. Federal Ministry of Transport and Digital Infrastructure (BMVI): The future of mobility is electric. https://www.bmvi.de/SharedDocs/EN/Dossier/Electric-Mobility-Sector/electric-mobility-sector.html (2019). Accessed 11 Dec 2020
4. Federal Ministry of Economic Affairs and Energy (BMWI): Electric mobility in Germany. https://www.bmwi.de/Redaktion/EN/Dossier/electric-mobility.html (2020). Accessed 11 Dec 2020
5. REFA: Grundlagen der Arbeitsgestaltung. Hanser, München (1993)
6. Rother, M., Harris, R.: Creating continuous flow. The Lean Enterprise Institute, Brookline, USA (2001)
7. Dietz, C., Richter, R., Deuse, J.: Variantenmanagement im Simultaneous Engineering. Ein Vorgehen zum Abgleich von Produktstruktur und Fertigungssystem. Zeitschrift für wirtschaftlichen Fabrikbetrieb (ZWF) **108**, 325–329 (2013)
8. Dekker, S.W.A., Woods, D.D.: MABA-MABA or Abracadabra? Progress on Human-Automation Co-ordination. Cogn. Technol. Work **4**, 240–244 (2002)
9. Baudzus, B., Krebs, M., Deuse, J.: Design of manual assembly systems focusing on required changeability. In: Dimitrov, D., Schutte, C. (eds.) Proceedings of International Conference on Competitive Manufacturing (COMA), Stellenbosch, South Africa, 30.01.-01.02.2013, pp. 269–275 (2013)
10. Hengstebeck, A., Weisner, K., Deuse, J., Roßmann, J., Kuhlenkötter, B.: Betriebliche Auswirkungen industrieller Servicerobotik am Beispiel der Kleinteilemontage. In: Wischmann, S. (ed.) Zukunft der Arbeit - Eine praxisnahe Betrachtung. Springer, Berlin (2017)
11. Deuse, J., Weisner, K., Hengstebeck, A., Busch, F.: Gestaltung von Produktionssystemen im Kontext von Industrie 4.0. In: Botthof, A., Hartmann, E.A. (eds.) Zukunft der Arbeit in Industrie 4.0, pp. 99–109. Springer, Berlin, Heidelberg (2015)
12. Ehrlenspiel, K.: Integrierte Produktentwicklung. Carl Hanser Verlag GmbH & Co. KG, München (2009)
13. Bullinger, H.-J. (ed.): Systematische Montageplanung. Hanser, München, Wien (1986)
14. Dove, R.: Agile Production: Design Principles for Highly Adaptable Systems. In: Maynard, H. B., Zandin, K.B. (eds.) Maynard's industrial engineering handbook. McGraw-Hill standard handbooks, 5th edn. McGraw-Hill, New York, USA (2001)
15. Federal Ministry of Economic Affairs and Energy (BMWI): Regulatory environment and incentives for using electric vehicles and developing a charging infrastructure. https://www.bmwi.de/Redaktion/EN/Artikel/Industry/regulatory-environment-and-incentives-for-using-electric-vehicles.html (2020). Accessed 11 Dec 2020

16. Krüger, J., Lien, T.K., Verl, A.: Cooperation of human and machines in assembly lines. CIRP Ann. **58**, 628–646 (2009)
17. Kock, S., Vittor, T., Matthias, B., Jerregard, H., Kallman, M., Lundberg, I., Mellander, R., Hedelind, M.: Robot concept for scalable, flexible assembly automation. In: IEEE International Symposium on Assembly and Manufacturing (ISAM), pp. 1–5, Tampere, Finland (2011)
18. Haddadin, S., Suppa, M., Fuchs, S., Bodenmüller, T., Albu-Schäffer, A., Hirzinger, G.: Towards the robotic co-worker. In: Siciliano, B., Khatib, O., Groen, F., Pradalier, C., Siegwart, R., Hirzinger, G. (eds.) Robotics Research, vol. 70, pp. 261–282. Springer, Berlin, Heidelberg (2011)
19. Mehrabi, M.G., Ulsoy, A.G., Koren, Y.: Reconfigurable manufacturing systems: Key to future manufacturing. J. Intell. Manuf. **11**, 403–419 (2000)
20. Wu, P.S., Tam, H.Y., Venuvinod, P.K.: Hybrid assembly: A strategy for expanding the role of "advanced" assembly technology. Comput. Electr. Eng. **22**, 109–122 (1996)
21. Hägele, M., Schaaf, W., Helms, E.: Robot Assistants at Manual Workplaces. Effective Co-operation and Safety Aspects, Stockholm, Sweden, 199–204 (2002)
22. Selevsek, N., Köhler, C.: Angepasste Planungssystematik für MRK-Systeme. ZWF **113**, 55–58 (2018)
23. Boothroyd, G.: Assembly automation and product design, 2nd edn. Manufacturing engineering and materials processing, vol. 66. Taylor & Francis, Boca Raton, USA (2005)
24. Lanza, G., Stähr, T., Sapin, S.: Planung einer Montagelinie mit skalierbarem Automatisierungsgrad. Zeitschrift für wirtschaftlichen Fabrikbetrieb (ZWF) **111**, 614–617 (2016)
25. Nyhuis, P., Heinen, T., Brieke, M.: Adequate and economic factory transformability and the effects on logistical performance. Int. J. Flex. Manuf. Syst. **19**, 286–307 (2007)
26. Wiendahl, H.-P., Hernández, R.: The transformable factory—strategies, methods and examples. In: Dashchenko, A.I. (ed.) Reconfigurable Manufacturing Systems and Transformable Factories, pp. 383–393. Springer, Berlin, Heidelberg (2006)
27. Ermer, A.-K., Seckelmann, T., Barthelmey, A., Lemmerz, K., Glogowski, P., Kuhlenkötter, B., Deuse, J.: A Quick-Check to Evaluate Assembly Systems' HRI Potential. In: Schüppstuhl, T., Tracht, K., Roßmann, J. (eds.) Tagungsband des 4. Kongresses Montage Handhabung Industrieroboter (MHI). 4. Fachkolloquium der Wissenschaftlichen Gesellschaft für Montage, Handhabung und Industrierobotik, Dortmund, 26. - 27.02.2019, 128 - 137. Springer Vieweg, Berlin (2019)
28. Cisek, R., Habicht, C., Neise, P.: Gestaltung wandlungsfähiger Produktionssysteme. Zeitschrift für wirtschaftlichen Fabrikbetrieb (ZWF) **97**, 441–445 (2002)