



Strategic Target System to Select Digitalization Measures in Manufacturing Companies

Günther Schuh, Jan Hicking, Felix Jordan, Max-Ferdinand Stroh,
Stephan-Andrés Saß

► To cite this version:

Günther Schuh, Jan Hicking, Felix Jordan, Max-Ferdinand Stroh, Stephan-Andrés Saß. Strategic Target System to Select Digitalization Measures in Manufacturing Companies. 21th Working Conference on Virtual Enterprises (PRO-VE), Nov 2020, Valencia, Spain. pp.227-236, 10.1007/978-3-030-62412-5_19 . hal-03745799

HAL Id: hal-03745799

<https://inria.hal.science/hal-03745799>

Submitted on 4 Aug 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License



This document is the original author manuscript of a paper submitted to an IFIP conference proceedings or other IFIP publication by Springer Nature. As such, there may be some differences in the official published version of the paper. Such differences, if any, are usually due to reformatting during preparation for publication or minor corrections made by the author(s) during final proofreading of the publication manuscript.

Strategic Target System to Select Digitalization Measures in Manufacturing Companies

Günther Schuh¹, Jan Hicking¹, Felix Jordan², Max-Ferdinand Stroh¹,
Stephan-Andrés Saß¹

¹ Institute for Industrial Management, FIR at RWTH Aachen University, Campus Boulevard
55, 52074 Aachen, Germany,

² Elisa Deutschland GmbH, Campus-Boulevard 57, 52070, Aachen, Germany
{Guenther.Schuh, Jan.Hicking, Max-Ferdinand.Stroh, Stephan-Andres.Sass}@fir.rwth-aachen.de
Felix.Jordan@elisa.com

Abstract. Manufacturing companies face the challenge of selecting digitalization measures that fit their strategy. Measures that are initiated and not aligned with the company's strategy carry the risk of failing due to lack of relevance. This leads to an ineffective use of scarce human and financial resources. This paper presents a target system to help companies select relevant digitalization measures compliant with their strategy for IT-OT-integration projects. The target system was developed based on literature research and expert interviews, and later validated in two use cases. The target system considers the goals of production companies and combines them with digitalization measures. The measures are classified by different maturity levels required for their realization. Thus, the target system enables manufacturing companies to evaluate digitalization measures with regards to their strategic relevance and the required Industrie 4.0 maturity level for their realization. This ensures an effective use of resources.

Keywords: Industry 4.0, Digitalization, Strategy, IT-OT-Integration.

1 Introduction

Industry 4.0 requires producing companies to transform their technological landscape. One challenge is the integration of Information Technology (IT) and Operational Technology (OT) to achieve the business potentials of Industrie 4.0 [1, 2]. Since many OT-systems were developed to ensure an efficient production, they tend to lack interface standards for IT-systems. This results in technological silos and untapped data sources [3]. With limited digitalisation resources, especially in SMEs, companies need to have a clear understanding of the business case when entering IT-OT-integration projects: What are the expected efforts, and what is the business impact in return.

This paper introduces a target system that reveals the effect of Industrie 4.0 maturity levels on a production system's efficiency. It shall support companies to understand which maturity level has impact on the production system's efficiency. Thus, it sheds light onto the expected business impact of an IT-OT-integration project. The target system is one stream to support companies selecting their Industrie 4.0 projects. The second stream (not part of this paper) is a methodology to assess the technological maturity

of OT-systems. This methodology will help estimate the expected efforts to integrate OT-systems. Both streams combined will enable SMEs to quickly define and prioritize their Industrie 4.0 business cases.

This target system focusses on the IT-OT-Integration in a manufacturing environment. It is designed for being used by a company's (production-) management team.

The overall goal of the paper is reflected in the research question: "How must a target system for the selection of digitalization measures in the context of IT-OT integration in a manufacturing environment be designed?"

In the beginning of the paper the target system is derived based on a literature review. The Industrie 4.0 Maturity Index [4] is used to connect the goals with potential measures, the utility potentials. Afterwards, a general IT-OT-Integration methodology is presented, in which the target system can be used. In the end, the target system is applied to two use-cases and the results are discussed briefly.

2 Background

IT-OT-Integration plays a significant role in the implementation of Industry 4.0 [1]. *Information Technology (IT)* is synonymous with the office floor systems, which capture, process, and provide data and information within the enterprise. IT includes ERP (Enterprise Resource Planning) and CRM (Customer Relationship Management) systems and supports the management's decision-making processes [5]. IT systems work with pre-processed data [6].

Operational Technology (OT) comprises of the shop floor systems, that support the physical value adding processes through supervising and controlling hard- and software [7]. Controlling and supervision occurs with OT-systems i.e. MES, SCADA, sensors and actors [5]. To better support and control the operational processes, OT-systems have to be capable of processing real-time data [6].

IT-OT-Integration describes the merging of operational technology with information technology, so that data can effortlessly be transferred between these systems [8].

The challenge of merging IT and OT systems in a manufacturing environment has scarcely been covered by literature. The literature was evaluated based on three selection criteria: 1) Are the challenges of IT-OT-integration addressed in particular, 2) Does the literature provide enough technical depth to derive guidance on how to tackle an integration project, 3) Does the literature consider the business potential of the IT-OT-integration activity?

None of the identified and analyzed literature met the requirements of addressing the issues of IT-OT-integration, while providing enough technical depths to serve as a guideline on how to tackle the integration. Finally, the identified literature lacks the business potential that accompanies the integration.

Only three of the examined papers are focusing on the issue of IT-OT-Integration [9–11]. While all three of them cover business benefits of integration, they maintain a high-level perspective, and do not consider the needs of a manufacturing company. And only [9] and [10] have at least some technical depth for the reader to assess the technical effort of the integration activity.

Literature that focuses on managing Manufacturing Execution Systems [12] tend to have a very deep technical depth but are lacking the differentiation between IT and OT landscapes and therefore cannot serve as guidelines through the IT-OT-integration.

In addition, literature that focusses the topic of Enterprise Architecture Management was assessed. None of the found pieces differentiated specifically between IT and OT systems, and while some provided some technical depth [13–16], only one stresses the business potentials of the integration [17]. As a result, none of them are suited for the paper's purpose. Furthermore, an analysis of reference architectures in the context of IT-OT convergence was done. Research produced poor results with regards to the technical depth [18, 19]. The reference architectures RAMI 4.0 and Industrial Internet of Things Reference Architecture (IIRA) lacked technical depth on managing IT-OT-landscapes and miss on OT-related business potentials regarding integration [18, 20].

To further individualize the needs of the SMEs, this paper uses utility potentials to closer analyze and identify, which measures must be implemented to achieve the desired sub-, intermediate, and overall objective. According to SCHUH AND KREUTZER utility is a highly individualized approach to measure the fulfilment of a need [21]. A potential is defined as the opportunity to develop or succeed [22]. In combination, this paper thus defines a utility potential to be the opportunity to successfully fulfil a business need. In the context of the developed target system the utility potential refers to the digitalization measure to be taken and its resulting utility.

3 Description of the Methodology

3.1 Derivation of the Target System

The methodology is supposed to enable producing SMEs to engage in IT-OT-integration projects that fit their company's (digitalisation) strategy. Furthermore, the authors assume that optimising the production system's efficiency is the paramount goal for the production manager. Hence, this generic target system discloses the impact of digitalisation maturity on the production system's efficiency. The target system combines two concepts: ERLACH'S work on production system efficiency and its influencing parts [23], and the Industrie 4.0 Maturity Index [24].

ERLACH discusses the effects of a production system's variability, quality, speed, and profitability on its efficiency. A production system consists of input resources that are processed into output in the production system. Accordingly, an increase in production system efficiency is achieved either by increasing the output with the same resource input or by reducing the resource input with the same output [25].

The *variability* of a production indicates the broadness of the production spectrum it can handle and whether it handles customer-specific products [23, 26]. Variability is defined as number of OK parts as output per number of (machine) setups [23]. Increasing the variability therefore has a positive impact on the production system efficiency [27]. The *quality* of a production can be derived from the scrap, the achievable tolerance level of the production processes and the adherence to delivery dates [23, 26]. It is defined that quality is measured by number of OK parts per number of total output. As

a result, a higher quality improves the efficiency of a production system [28]. The *speed* of a production is determined by the duration of the value-adding process steps, the associated secondary activities as well as the throughput time [23, 26]. Speed is defined as number of OK parts per time, and thus correlates positively with the production system efficiency [29]. The *profitability* of production refers to productivity, with employee productivity, machine utilisation and material utilisation being the main determination factors [23, 26]. Profitability can be determined as number of OK parts per costs. Hence, a higher profitability indicates an increased production system efficiency

ERLACH states that quality and profitability, as well as variability and speed, are conflicting, while variability and quality do not have a positive effect on each other but may affect one another in a negative way. Only speed and economy show a target compatibility, meaning that the optimization of the one leads to an improvement of the other [23]. These four factors are defined as the intermediate goals for the target system. The sub-objectives and their relations are arranged in the target system of overall and intermediate objectives as shown in Fig. 1.

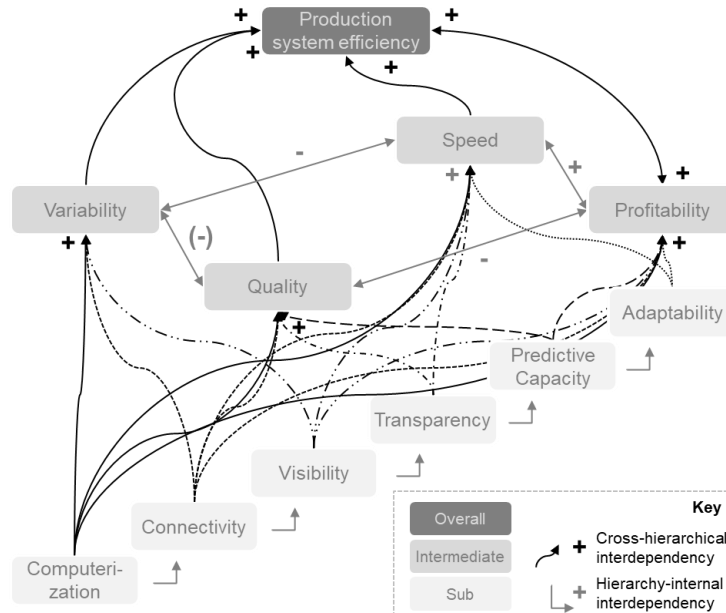


Fig. 1. Target system with overall, intermediate, and sub-objectives

The six maturity levels introduced by the Industrie 4.0 Maturity Index are introduced as sub-objectives: Computerization, Connectivity, Visibility, Transparency, Predictive Capacity, and Adaptability. *Computerization* is implemented when the relevant process steps in the area under consideration are supported or carried out through the (isolated) use of digital technologies [30]. The second level, *connectivity*, is achieved when the isolated digital technologies are integrated horizontally, i.e. have the necessary software interfaces and hardware ports through which they communicate with decentralized IT systems [30]. The *visibility* level means that the digital technologies are vertically connected as data sources, so that data and information about the business processes are

available and can be exchanged in real time [30]. The fourth level of maturity, *transparency*, will be achieved by contextualization of data and information. This enables root-cause analyses to support the decision-making [30]. The maturity level *predictive capacity* means that management can reliably project decisions and their effects into the future and thus simulate future scenarios to aid the decision-making process. In addition, the company can anticipate upcoming events and proactively demonstrate response actions to the management to make operations more robust [30]. *Adaptability* is the highest level of the Industry 4.0 Maturity Index and includes the ability to autonomously adapt to changes in the business environment, to make decisions through the IT systems in use and to initiate measures [30].

The paper introduces the maturity levels as sub-objectives. It is defined that there are no direct positive or negative correlations in between the maturity levels. Nevertheless, the preceding maturity levels need to be achieved before it is possible to reach the next maturity level.

Table 1 shows the positive correlations between intermediate and sub objectives with an “x”.

Table 1. Influence of the stages of maturity on the intermediate objectives

Maturity Level / Intermediate objective	Variability	Quality	Speed	Profitability	Source
Computerization	×	×	×	×	[31]
Connectivity	×	×	×	×	[32–34]
Visibility	×		×	×	[5, 35–38]
Transparency		×	×		[39]
Predictive Capacity		×		×	[40]
Adaptability			×	×	[32, 41]

A deeper understanding of this paper’s results can be gained with **Table 2**. It shows examples of measures pertaining to each maturity level in increasing order of maturity.

Table 2: Exemplary extract of measures to achieve each Maturity Level

Maturity Level	Exemplary Measure	Source
Computerization	CNC controls throughout the factory	[4]
Connectivity	Machines are connected to MES	[4]
Visibility	Digital order, asset and material tracking	[42]
Transparency	Realization of a digital production shadow	[43]
Predictive Capacity	Manufacturing process optimization via machine learning	[44]
Adaptability	Adaptive reaction of manufacturing line to errors	[45]

Each exemplary measure represents part of the means to achieving the maturity level it is assigned to. Even though the maturity levels induce each other, they do not affect

each other positively or negatively. Combining these measures with consequential utilities describe utility potentials and are subordinate to the maturity levels in the target system and therefore to the intermediate and overall objectives.

3.2 Methodology for the Application of the Target System

The target system's application forms part of a bigger methodology for a goal-oriented IT-OT-Integration process. **Fig. 2** shows this process. It consists of two general streams, the assessment of IT and OT-Systems as well as the selection of utility potentials. In the end the two streams are combined to match the current IT-OT-Landscape with the selected utility potentials. However, both systems can be applied separately. The selection of utility potentials via the target system, which this paper focuses on, are marked in dashed lines, and are described in this section.

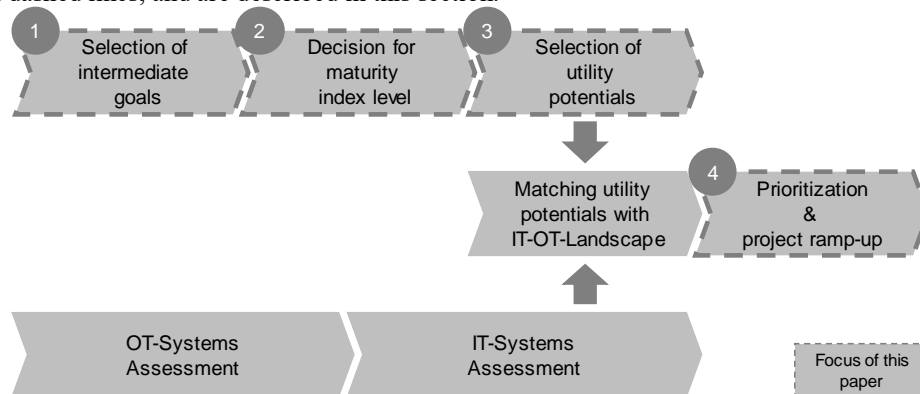


Fig. 2: Methodology for the application of the target system

The first step is the selection of intermediate goals. The overall goal for the target system is production system efficiency to achieve customer value, which is fixed. Generally, the intermediate goals should be selected based on the manufacturing and corporate strategy of the company. In a workshop, the potential benefits of the intermediate goals can be collected and mapped to the company's strategic goals.

Once the intermediate goals are selected, the current maturity level, as well as the aspired maturity level, must be selected.

Based on the selected maturity level the utility potentials are selected. This paper offers an exemplary selection of possible measures to realize the utility potentials. This list will be enhanced in future publications. However, the selected maturity level serves as base and inspiration for defining the concrete utility potentials that shall be taken.

Usually an assessment of a manufacturing facility reveals more than one potential measure or utility potential that can be addressed. Therefore, the last step of the proposed methodology is prioritization and project ramp up. In the beginning of this step the list of selected and identified measures is prioritized. The authors recommend a cost-benefit-analysis by assessing the potential costs in relation to the potential benefits of measures taken. The results can be visualized in a portfolio-matrix, to show cost estimate versus utility estimate.

Once the prioritization is finished, measures are selected and then transferred into individual projects, which can then be ramped up.

4 Discussion of the Target System for two Industry Use Cases

In this section, the authors present the practical application of the target-system for two industry use-cases. The target system was applied in expert workshops during the meeting of the user-committee of the underlying research project. The chosen targets of the participants have been randomly altered to ensure privacy.

Company 1 is a manufacturer of electronic components for a wide range of international customers. The batch sizes within their production differ from ten to 50,000 pieces.

Company 2 is a prototyping and product development provider. Next to series manufacturing of products for their customers, they are building prototypes from mechanical to mechatronic products. The batch sizes range from one to several hundred products.

Table 3 shows an excerpt from the results of the application of the target system in both companies. Both companies selected a single intermediate goal. During the workshop it became obvious, that the selection of the intermediate goal is challenging and should be done with care. In this case, company 1 focusses on *quality* improvement and company 2 on *speed*.

Table 3: Example results of target system application

Company / selected items	Company 1 (Electronics)	Company 2 (Prototyping)
1. Intermediate goal	Quality	Speed
2. Maturity Level	Transparency	Connectivity
3. Prioritized measures	Realization of a digital shadow	Implementation of ERP-System
	Automated calculation of production KPIs	Connection of existing machines to MES

Afterwards, the companies identified their Industrie 4.0 maturity level based on the information provided for the Industrie 4.0 Maturity Index. Both companies identified lower maturity levels for themselves, which represents the current state of the industry [30]. The maturity level reflects the current state of Industry 4.0 in a company. To advance in their level, industry 4.0 measures need to be applied. Based on the selected maturity level the companies developed potential measures to reach their goals. In the presented use-cases, company 1 mainly focused on the realization of a digital shadow to improve the overall quality in production. Company 2 selected the implementation of an ERP-System as the main goal for improving its production speed.

Generally, the feedback regarding the developed target system was exceedingly positive. This first evaluation confirmed the findings in literature from which the target system was derived. The application was very intuitive and good to explain.

Further improvement can be made on the list of potential measures provided. This will be enhanced within the research-project. Some participants of the workshop also mentioned that some companies' challenges could not be covered directly by the target system. This is because the target system serves as a bridge between the strategical and the practical perspective, focusing on IT-OT-Integration. Therefore, it serves as a means of improvement rather than for troubleshooting. All participants agreed that the system was helpful in aligning current digitalization measures taken in a manufacturing environment with the company's strategy.

Future research will focus on assessing the current IT-OT-Integration level in a manufacturing environment to select measures based on the planned development of a company. This will further improve the application and coverage of the target system.

5 Conclusion

This paper focuses on the development of a target system for selecting digitalization measures in a manufacturing companies. Based on that, a target system linking company goals with Industrie 4.0 maturity levels and utility potentials is presented. Next to that, the paper presents a methodology for the application of the target system. Finally, the methodology is applied to two industry use-cases and evaluated based on the results.

The first applications of the target system show, that it can be used successfully for structuring the digitalization process within a manufacturing company. Once the IT-OT-Assessment stream is added to the methodology it will reach its full potential as the selection of utility potentials can be matched with the current IT-OT-Landscape and vice versa. Both utility potentials as well as the assessment of the IT-OT-Landscape need further development, which will be covered in future publications.

6 Acknowledgements

The IGF project 20768 BG of the Research Association FIR e. V. at the RWTH Aachen University is funded via the AiF within the framework of the programme for the funding of cooperative industrial research (IGF) by the Federal Ministry of Economics and Energy (BMWi) on the basis of a resolution of the German Bundestag.

7 References

1. Schlick, C. (ed.): Megatrend Digitalisierung - Potenziale der Arbeits- und Betriebsorganisation. GITO, Berlin (2016)
2. Weber, H., Viehmann, J.: Unternehmens-IT für die Digitalisierung 4.0. Springer Fachmedien Wiesbaden, Wiesbaden (2017)
3. Agarwal, N., Brem, A.: Strategic business transformation through technology convergence. Implications from General Electric's industrial internet initiative. *IJTM* 67, 196–214 (2015)
4. Schuh, G., Anderl, R., Gausemeier, J., Hompel, M. ten, Wahlster, W.: Industrie 4.0 Maturity Index. Managing the Digital Transformation of Companies. Munich (2017)

5. Noronha, A., Moriarty, R., O'Connell, K. and Villa, N.: Attaining IoT Value: How To Move from Connecting Things to Capturing Insights. Gain an Edge by Taking Analytics to the Edge
6. Kuusk, A.G., Gao, J.: Consolidating People, Process and Technology to Bridge the Great Wall of Operational and Information Technologies. In: Tse, P.W., Mathew, J., Wong, K., Lam, R., Ko, C.N. (eds.) Engineering asset management 2013. Proceedings of the 8th world congress, pp. 1715–1726. Springer, Cham (2014)
7. Chemudupati, A., Kaulen, S., Mertens, M., Mohan, S.M., Reynaud, P., Robin, F., Zimmermann, S.: The convergence of IT and Operational Technology (2012)
8. Phani Kumar Garimella: IT-OT Integration Challenges in Utilities. October 25th - 27th, 2018, Kathmandu, Nepal : an IEEE Nepal Sub Section Conference. IEEE, Piscataway, NJ (2018)
9. Kuusk, A., Gao, J.: Factors for successfully integrating operational and information technologies. In: 2015 Portland International Conference on Management of Engineering and Technology (PICMET), pp. 1513–1523. IEEE (2015 - 2015)
10. Verdouw, C.N., Robbemd, R. and Kruize, J.W.: Integration of Production Control and Enterprise Management Systems in Horticulture (2015)
11. Lara, P., Sánchez, M., Villalobos, J.: Bridging the IT and OT Worlds Using an Extensible Modeling Language. In: Comyn-Wattiau, I. (ed.) Conceptual modeling. 35th International Conference, ER 2016, Gifu, Japan, November 14-17, 2016 : proceedings, 9974, pp. 122–129. Springer, [Cham] (2016)
12. Kletti, J.: MES - Manufacturing Execution System. Springer Berlin Heidelberg, Berlin, Heidelberg (2015)
13. Kremer, H.: Informationsmanagement. Springer Gabler, Wiesbaden (2015)
14. Lehner, F., Scholz, M., Wildner, S.: Wirtschaftsinformatik. Eine Einführung. Hanser, Carl, München (2008)
15. Zimmermann, A., Schmidt, R., Sandkuhl, K., Jugel, D., Möhring, M., Wißotzki, M.: Enterprise architecture management for the Internet of things. Bonn (2015)
16. Tiemeyer, E., Bergmann, R.: Handbuch IT-Management. Konzepte, Methoden, Lösungen und Arbeitshilfen für die Praxis. Hanser, München, München (2015)
17. Matthes, D.: Enterprise Architecture Frameworks Kompendium. Springer Berlin Heidelberg, Berlin, Heidelberg (2011)
18. IIC - Industrial Internet Consortium: The Industrial Internet of Things Volume G1: Reference Architecture (2019)
19. Bassi, A., Bauer, M., Fiedler, M., Kramp, T., van Kranenburg, R., Lange, S., Meissner, S.: Enabling Things to Talk. Springer Berlin Heidelberg, Berlin, Heidelberg (2013)
20. Status Report: Reference Architecture Model Industrie 4.0 (RAMI4.0) (2015)
21. Schuh, G., Kreutzer, R.: Methodology to Assess the Utility Potentials of Cyber-Physical Systems' Field Data. A Literature Review and Rough Solution Concept (2017)
22. Cambridge University Press: POTENTIAL | meaning in the Cambridge English Dictionary, <https://dictionary.cambridge.org/dictionary/english/potential>
23. Erlach, K.: Wertstromdesign. Der Weg zur schlanken Fabrik. Springer, Berlin, New York (2010)
24. G. Schuh, R. Anderl, R. Dumitrescu, A. Krüger, M. ten Hompel: Using the Industrie 4.0 Maturity Index in Industry – current challenges, case studies and trends (acatech COOPERATION)
25. Gottmann, J.: Produktionscontrolling. Springer Fachmedien Wiesbaden, Wiesbaden (2016)
26. Pfeffer, M.: Bewertung von Wertströmen. Kosten-Nutzen-Betrachtung von Optimierungsszenarien. Springer Gabler, Wiesbaden (2014)
27. Deuse, J., Lenze, D., Klenner, F., Friedrich, T.: Manufacturing Data Analytics zur Identifikation dynamischer Engpässe in Produktionssystemen mit hoher wertschöpfender

- Variabilität. In: Schlick, C. (ed.) Megatrend Digitalisierung - Potenziale der Arbeits- und Betriebsorganisation, pp. 11–26. GITO, Berlin (2016)
28. Schröder, A.-K., Nebl, T.: Qualität - Einflussfaktor auf die Produktivität. In: Specht, D. (ed.) Weiterentwicklung der Produktion. Tagungsband der Herbsttagung 2008 der Wissenschaftlichen Kommission Produktionswirtschaft im VHB, pp. 117–141. Gabler, Wiesbaden (2009)
29. Adam, D.: Produktionspolitik. Gabler Verlag, Wiesbaden (1976)
30. G. Schuh, R. Anderl, R. Dumitrescu, A. Krüger, M. ten Hompel: Industrie 4.0 Maturity Index. Managing the Digital Transformation of Companies – UPDATE 2020 – (acatech STUDY)
31. Vajna, S., Weber, C., Zeman, K., Hehenberger, P., Gerhard, D., Wartzack, S. (eds.): CAX für Ingenieure. Eine praxisbezogene Einführung. Springer Vieweg, Berlin, Germany (2018)
32. Bürger, T., Tragl, K.: SPS-Automatisierung mit den Technologien der IT-Welt verbinden. In: Vogel-Heuser, B., Bauernhansl, T., Hompel, M. ten (eds.) Handbuch Industrie 4.0 Bd. 1. Produktion, pp. 207–217. Springer Vieweg, Berlin (2017)
33. Vajna, S., Weber, C., Schlingensiepen, J., Schlottmann, D.: CAD/CAM für Ingenieure. Hardware, Software, Strategien. Vieweg+Teubner Verlag, Wiesbaden (1994)
34. Mertens, P., Bodendorf, F., König, W., Schumann, M., Hess, T., Buxmann, P.: Grundzüge der Wirtschaftsinformatik. Springer Berlin Heidelberg, Berlin, Heidelberg (2017)
35. Kleinemeier, M.: Von der Automatisierungspyramide zu Unternehmenssteuerungs-Netzwerken. In: Vogel-Heuser, B., Bauernhansl, T., Hompel, M. ten (eds.) Handbuch Industrie 4.0 Bd. 1. Produktion, pp. 219–226. Springer Vieweg, Berlin (2017)
36. Geissbauer, R., Vedso, J. and Schrauf, S.: Industry 4.0: Building the digital enterprise. What we mean by Industry 4.0 / Survey key findings / Blueprint for digital success
37. Wellenreuther, G., Zastrow, D.: Automatisieren mit SPS. Vieweg+Teubner (2009)
38. The IT/OT integration imperative for utility distribution businesses (2016)
39. Manyika, J., Chui, M., Brown, B., Bughin, J., Dobbs, R., Roxburgh, C., Byers, A.: Big Data: The Next Frontier for Innovation, Competition, and Productivity (2011)
40. VDI Verein Deutscher Ingenieure e. V.: Ganzheitliche Produktionssysteme – Grundlagen, Einführung und Bewertung. Beuth Verlag, Berlin 03.100.50 (2012)
41. Reinhart, G., Kolberg, D., Marseu, E., Gorecky, D., Koch, J., Plehn, C., Zühlke, D.: Strategien zur Transformation der Produktionsumgebung. In: Reinhart, G. (ed.) Handbuch Industrie 4.0. Geschäftsmodelle, Prozesse, Technik, pp. 213–256. Hanser, München (2017)
42. Goto, S., O. Yoshie, and S. Fujimura.: Industrial IoT Business Workshop on Smart Connected Application Development for Operational Technology (OT) System Integrator. IEEE IEEM2017 : 10-13 Dec, Singapore. IEEE, Piscataway, NJ (2017)
43. Pelino, M., Hewitt, A.: The Forrester Wave™: IoT Software Platforms, Q4 2016. The 11 Providers That Matter Most And How They Stack Up (2016)
44. Global Lighthouse Network.: Insights from the Forefront of the Fourth Industrial Revolution (2019)
45. Geleş, E., Kern, M., Schneider, B., Ullrich, A., Vladova, G., Gronau, N., Lipinski, R. von, Buße, D., Oertwig, N.: Metamorphose zur intelligenten und vernetzten Fabrik. In: Weinert, N., Plank, M., Ullrich, A. (eds.) Metamorphose zur intelligenten und vernetzten Fabrik. Ergebnisse des Verbundforschungsprojekts MetamoFAB, pp. 39–120. Springer Vieweg, Berlin (2017)