Criteria Catalog for Industrial IoT Platforms from the Perspective of the Machine Tool Industry

Philipp Werner[1], Dimitri Petrik[1,2]

[1] University of Stuttgart, Chair of Information Systems II, Stuttgart, Germany
{philipp.werner,dimitri.petrik}@bwi.uni-stuttgart.de
[2] University of Stuttgart, Graduate School of Excellence advanced Manufacturing Engineering (GSaME), Stuttgart, Germany

Abstract. Through providing digital services, machine tool manufacturing companies can address the customer demands for individual solutions and the increasing cost pressure. Applications are one way to provide these digital services, running on smart machine tools connected to software systems, known as industrial Internet of Things (iIoT) platforms. Despite the growing potential of iIoT platforms in the provision of industrial digital services and the increasing awareness of the platform approach among manufacturing companies, lack of requirements makes the platform challengeable for machine tool companies. Moreover, the domain specific industrial application of platforms has been limitedly researched, indicating a possible research gap. This paper presents a literature-based research on requirements for iIoT platforms, followed by the solution-oriented metrics, to fulfill each requirement. Together, the requirements and metrics form a structured criteria catalog for iIoT platforms, which can be used as a decision support tool for the machine tool industry.

Keywords: Platform Ecosystem, industrial IoT Platform, IoT Ecosystem, Criteria Catalog, Smart Machine Tool.

1 Introduction

1.1 Research Gap and industrial problem setting

Current machine tool manufacturing companies are challenged by the increasing product variety, offered by original equipment manufacturers (OEM) in different industries, and the related flexibility for their own products [1]. Customer demand for custom solutions, as well as the increasing role of the after-sales services in the competition, were also surveyed for the mechanical engineering industry by the German Mechanical Engineering Industry Association (VDMA) and McKinsey [2]. A machine tool manufacturer could address these challenges by offering digital or smart services within its service portfolio. Current empirical studies show a high interest within the machine tool industry to offer digital services to monitor machine data, in order to improve manufacturing processes [2-3]. Smart machine tools are estimated to increase machine productivity and life by about 5%, reduce maintenance costs by 10-

14th International Conference on Wirtschaftsinformatik,
February 24-27, 2019, Siegen, Germany

40% and reduce the energy consumption by 20% [4]. Such smart and connected machine tools are equipped with embedded computers and networks, monitoring and affecting physical processes to achieve the improvements mentioned above, through digital applications [5]. The possibility to increase the flexibility turns smart machine tools into platforms, being simultaneously a product (machine tool) and a platform (modular extension through applications) [6]. Smart machine tools are also closely related to the concept of cyber-physical systems (CPS), as they can be controlled remotely and communicate with surrounding systems and the physical world [7].

However, as various case studies show, various companies have failed to establish successful platforms in the past [8]. Current state of the market on iIoT platforms pictures its highly fragmented state, thus including more than 450 iIoT platforms available on the market [9]. In contrast to the current state of the market for iIoT platforms, platform-based markets are rather affected by the "winner-takes-all" competition logic of a platform-providing keystone company [10]. Due to the high fragmentation of the market, the right choice and utilization of an iIoT platform is a challenging task for machine tool companies and represents an entry-barrier for a provision of platform-based digital services in the after-sales. The practical problem from the perspective of the collaborative customer in the iIoT lies in the complexity during the platform selection process. On the other hand, the variety of iIoT platforms makes it difficult for the iIoT platform providers to gain significant market share, becoming a "platform leader" [11]. From the research perspective, previous scientific work on platforms focuses primarily on business-to-consumer (B2C) industries and the information technology (IT) cases [12-13], while the consideration of specific industrial requirements in the area of platforms still need further research. Additionally, the empirical studies also highlight the fact, that providing smart services through digital applications is a challenge for machine tool manufacturing companies, since 59% of those surveyed do not offer market ready solutions [2]. Considering these factors, there is an apparent need for research on these platforms for smart connected machine tools.

1.2 Research Questions and Structure

The main goal of this paper is to provide a criteria catalog for iIoT platforms as a decision support tool in the domain of smart connected machine tools, based on the definition of two research questions:

- RQ1: What are the relevant platform criteria for smart machine tools?
- RQ2: Which metrics fulfill the criteria identified in RQ1?

The second section of this paper describes major concepts and research streams, related to iIoT platforms. The first research question is addressed in the third section. Firstly, the research design of the conducted literature analysis is described, followed by the extraction of the relevant criteria. The section after that focuses on the relevant metrics of each identified criterion. These metrics provide a more detailed description of each criterion and allow a systematical application of the criteria for instance during a selection process of an iIoT platform from the perspective of a mechanical engineering company. Together, the criteria and the assigned metrics are building a structured criteria catalog with relevant criteria for an application of the platform approach for smart machine tools. The criteria catalog builds the artefact of this paper. The scientific approach to achieve the first artefact is a structured literature analysis.

The overall scientific contribution of this paper is an extension of platform research for the industrial application. The focus on smart machine tools is justified due to the high importance of the industrial IoT in this industry and could be adjusted to other manufacturing industries.

2 Theoretical background and related concepts

This contribution relies on three major concepts related to the iIoT platforms, which are explained in this section: CPS, iIoT and technological platforms.

As mentioned in the introduction, the provision of customized solutions requires machine tool companies to extract data from machine tools and use this data to control them. This is achieved due to sensors, actuators, embedded computational power and connection of a machine tool to external data-processing platforms, thus creating loops between the physical assets (machine tools) and their digital counterparts [7, 14]. The analyzed machine data can be used for autonomous parameter change of the machine by the actuators. This goes beyond the traditional automation technology of machine tools. Hence, such machine tools are defined as smart and fit the definition of CPS.

The integration of CPS in machine tools is also related to the concept of iIoT. IoT is a paradigm of the integration of internet and communication technologies (ICT) and real-time data analytics in physical assets. The application of IoT on industrial assets in the manufacturing builds the concept of iIoT [15]. Even though, IoT can be applied in various industries [16], this paper is domain specific and is based on the application of IoT in the machine tool industry. Smart machine tools, in the context of iIoT (beyond the simple automation) are able to track various sensor data, monitoring the machine itself, the manufacturing process and the quality of the manufactured product [17] and this data can be used for digital services. However, the historical evaluation of sensor-based data and the provision of the analyzed data as a service to external companies requires additional software systems [18], known as iIoT platforms.

The data analysis and related visualization are hosted as platform-based applications, which can be developed by third-party companies. Therefore, iIoT platforms are related to the technology platforms concept, defined by Cusumano and Gawer [11] and platform-based innovation by the ecosystem [13]. This concept builds the third related theoretical concept of this contribution. According to this definition, technological platforms provide a dominant technology, including industry standards and transforming them into a complete customer solution. The provider of a technological platform is considered as a keystone company [19]. Due to the control over the platform, the platform-providing keystone company is enabled to form alliances and partnerships with third-party companies, which are considered as competing complementors, consequently building a platform-based ecosystem [13]. The participation of third-party companies is supported by the modular design of technological platforms, which in the case of iIoT is represented by platform-based applications. Those modular applications extend the value of the platform through network effects [20]: if for instance an application for cost reducing condition monitoring of a machine tool is presented in the application store of an iIoT platform, more machine tool companies would consider using the platform. Similarly, more developers would complement to the iIoT platform, if a platform-based ecosystems contains enough application customers. In order to enable such a complementary third-party development of complementary modules, the interfaces of the platform have to be open. The platform provider is in the position to determine how to share the interface specifications with the third-party companies. Empirical examples of iIoT platforms, as Mindpshere (Siemens) or Thingworx (PTC) correspond to the both classifications of open technological platforms, providing specification and tools for the integration of application by complementary third-party companies [21-22]. In addition, the application stores of both iIoT platforms show exemplary applications, provided by third-party companies [21-22]. Therefore, iIoT platforms fit into the theoretical concept of open technological platforms.

3 Creating the Platform Criteria Catalog for Machine Tools

3.1 Research Methodology

The aim of the literature review is the identification of the current state of research towards the derivation of relevant criteria for platforms for machine tools based on the found literature. The structured literature research approach is sophisticated, reproducible, systematic, transparent and scientific [23-24].

The methodological approach used in this work follows the scientific work of Webster and Watson [25]. In addition, the approach is based on the work of Rashman et al., Soni and Kodali [26-27] and Winter and Knemeyer [28]. The review period for the literature review is between January 2002 and December 2017, thus covering 15 years. The reason for choosing the year 2002 as the start point is that Gawer and Cusumano distinguish different platform types in their work and subdivide platforms into internal platforms, supply chain platforms and industry platforms in that year [11]. As stated above the platforms are examined in an industrial application context. For this reason, the focus of the platform analysis is the current state of practice in regard to the classification of the platforms according [11]. Therefore, the start date can be set to 2002, since it is ensured that the term industry platform does not exist before 2002. The reason for choosing December 2017 as the end date is that the latest scientific publications should be considered in order to develop the broadest possible set of criteria and this was the current date during the review period.

Three different databases are used to conduct the structured literature research: Business Source Premier (EBSCOhost), IEEE Xplore and Science Direct. Google Scholar is also included in the research to get a broader overview of existing relevant articles and include relevant papers, which are not covered by the three databases. Business Source Premier includes a large number of business, finance and management journals and is therefore selected. To cover the technical area in relation to CPS and the industrial context, Science Direct, which includes articles on technical and engineering subjects, is also included in the research. IEEE Xplore provides articles on the world's most cited publications in electrical engineering, computer science and electronics and completes the research. The databases are searched using the following terms: "Industry Platform", "IoT Platform", "Service Ecosystem", "Service Platform" and "Software Ecosystem"; linked by the Boolean operator AND with the following terms: "Cyber Physical System", "Industrial Internet of Things", "Industry 4.0", "Machine Tools" and "Smart Manufacturing". Only English-language articles are considered.

3.2 Results from the Literature

The review process returns 147 articles after the removal of duplicates. For this purpose, the title, the abstract and the conclusion are read first from each of the 147 articles. Looking at the titles, abstracts, and conclusions, many of the articles found do not address RQ1. Therefore, 125 articles are excluded, leaving a sample of 22 articles. The backward search on the related work lists of the identified 22 articles, followed by the forward search using Google Scholar, identifies six additional articles. The sample therefore contains 28 articles, which are completely analyzed. After reading through the articles completely, another seven articles can be excluded because their contribution cannot be used for RQ1. In the end, 21 articles provide possible relevant examination criteria for intelligent machine tool platforms. However, the search includes articles which do not explicitly refer to embedded systems in the machine tool industry, but provide general criteria, which can be relevant for open platforms for intelligent machine tools. The following matrix, as proposed by Webster and Watson, depicts the found criteria and the relevant articles.

The examined articles describe criteria for intelligent machine tools highlighting various perspectives on this field. These perspectives can be classified as CPS in manufacturing, Software-Product-Service-Systems, industrial IoT Platforms, service platforms for machine tools or they offer a generic view on platforms or software ecosystems. After the detailed analysis of the described concepts in the literature, 13 identified requirements are grouped in six criteria for the machine tool platform approach, which are depicted in the following table:

Table 1. Platform criteria list for intelligent machine tools

ID	*Criterion*	*Sources*
1	Security of the platform	[29-33], [36], [39-40], [43-49]
2	Modularity of the platform	[30], [32-37], [41-42], [45], [47-49]
3	Degree of openness (Platform and Interfaces)	[29-30], [32-35], [37-38], [42-44]
4	Functionalities on the platform	[29-30], [32-33], [36], [39-40], [45], [47]
5	Range of the platform	[30], [32], [36]
6	Autonomy of all stakeholders	[35], [37]

- **Security of the platform:** Data security, information security, system security and quality assurance measures could be summed up to a key criterion "Security of the platform". It seems to be currently the most commonly cited criterion in the literature (15 of the 21 articles). Some articles describe the aspects of safety and protection of sensitive production data as the most urgent challenge for platforms [40, 48] and some consider the data processing security of CPS as an important challenge [45]. Quality assurance as a criterion, which was also cited in six articles, additionally contributes to the safety of the platform. If the open platform brings various companies (for example a machine tool company and a third-party software company) quality assurance plays an important role. If a platform could internally assist the machine tool manufacturer in achieving quality measures on third party applications, it could increase the trust of the machine tool manufacturer in the externally developed software modules. System safety means the security of the machine to its environment and ensures no persons or work pieces are harmed by incorrectly programmed software. A failure could result in serious material or personal damage [29, 44]. However, as the literature mostly states the data security and the information security, the system security will be summed up under the generic term "Security of the platform".

- **Modularity of the Platform:** Modularity also increases the scalability of a platform, which is why both terms are summed up as in the criterion a "Modularity of the Platform". Modularity seems to be an important subject of research, as it is mentioned in 13 articles. The scalability of the platform does not currently seem to attract much attention, being stated in just one article. In order to develop a uniform knowledge base for an intelligent machine tool, various companies collaborate on the open platform across numerous corporate boundaries [30, 32, 36]. The modularity of an open platform for intelligent machine tool is necessary to use the different capabilities of the involved actors as third-party software developers or sensor manufacturers and to reduce the complexity for the machine tool manufacturer. It is also discussed that platforms enable synergies between all those involved companies and can lead to more innovations [34]. Though modularity leads to a reduction of the technological complexity of the intelligent machine tool, it simultaneously increases the management and governance complexity of the platform, which can also be a major challenge for a machine tool company, as it requires additional management efforts. Finally, the intelligent machine tool has to be manageable despite its modularity and the resulting platform complexity [34]. An intelligent machine tool produces great amounts of data that has to be stored, processed and analyzed, which could present a major challenge for a manufacturer. Consequently, the platform should handle this challenge and deliver scalable resources [36]. Moreover, it becomes important for the manufacturing company to decide which modules should be developed on his own and which should be outsourced to third party companies.
- **Degree of Openness (Platform and Interfaces):** This criterion sums up openness and the integration of the platform. During the life cycle of a platform, the degree of openness can change. It could make sense to keep the platform more closed in the beginning, until it gathers a certain amount of early adopting users and developers and open it afterwards. For a mature platform with a large group of developers and users it is preferable to increase the openness, as it generates more overall value for

all involved stakeholders, through increased innovation [44]. A high degree of openness with uniform standards helps to improve the efficiency of the integration of the intelligent machine tool as a platform in the systems operated by the customer [29, 32] (for instance manufacturing execution systems or other information systems). Moreover, it helps to access all the capabilities, know-how and data with a platform-based ecosystem with a smaller investment [36-38]. In order to attract a large number of complementing third-party companies, it is recommended to provide good documentation and interfaces for the complementors [30]. A lower degree of openness requires a higher beginning invest, though it can result in a competitive advantage through the full control of development modules of a platform [38] and preventing the unsuitable complementors to access the platform [30]. Additionally, empirical analyses show the dominant usage of closed platforms by manufacturing companies, preferring to restrict the degree of openness of the platform and to collaborate only with specific partners [35, 42].

- **Functionalities on the Platform:** Functionalities unite the user interface (UI), the functionality, support and services and the test environment and test access. According to the UI as a criterion the platform services and the machine tool interface should be understandable and easy to use for the user [30]. It is also recommended to provide the machine data analysis in the browser, making it accessible with mobile devices, in order to improve the UI [39, 45]. Functionality represents the variety of analysis options and applications for the customer. The support and services target two groups. On the one hand, the customer of smart connected machine tools could require support regarding the maintenance of the intelligence of smart connected machine tools [32]. On the other hand, the complementing third-party companies could require support of a platform provider during the development. A test environment is important for the customer of a smart machine to test, whether the platform sufficiently supports the required functionality, consequently reducing the risk of bad investment and sunken costs. The complementing third-party software company could also test their prototypes and reduce their risks and training costs [29-30].
- **Range of the Platform:** The range increases the awareness level of the platform among the customers and complementing third-party companies, which indicated to what extent the platform can prevail in the future as a standard. Uniform interfaces and industry standards are required to achieve high range of a platform, thus increasing the platform complexity for the platform provider [30, 36]. These uniform standards can only be enforced if the platform has a certain reach and market share. Support in terms of quality assurance by the keystone also increases the range [30].
- **Autonomy of all Stakeholders:** All participating stakeholders are autonomous to the platform and can independently decide, whether and how they participate in the platform ecosystem. This boosts the innovative strength within the platform, due to the resulting competition [37]. If not prevented, autonomous stakeholders will either complement or even compete with their complementary innovation with the platform provider. However, high degree of autonomy of the stakeholders, increases the competition and results in higher degree of platform-based innovation [37]. Furthermore, the positively perceived autonomy of the stakeholders, can be used by

the keystone and by the complementing stakeholders to attract new stakeholders in the platform-based ecosystem, because this indicates lower dependency risks for the stakeholders [35].

3.3 Matching Requirements and Metrics to Create a Criteria Catalog

The platform provider should fulfill all the identified criteria. Hence, this section provides metrics for each criterion. This paper uses the term metrics to describe solutions, currently offered by the platform providers, in order to fulfill the requirements for a platform in the area of smart machine tools. The criteria with their metrics form the criteria catalog, thus answering the RQ2 and representing the artefact of this contribution. The identification of the metrics is based on two relevant articles [8, 50], which were congruently identified through the literature research. Both articles build the foundation for the application of solution-oriented metrics on the identified criteria for two reasons. Firstly, both articles use a similar approach, separating requirements and solutions from each other. This approach matches with a core principle in the quality function deployment (QFD). QFD separates neutral requirements from the product-specific solutions. The application of the core principle of QFD is justified by the higher efficiency of this of this method during the product development in terms of customer satisfaction [51], which seems suitable considering the high fragmentation state of the market for iIoT platforms. Furthermore, the application of QFD on software design in the past [51]. Secondly, both articles list comparable platform criteria to those identified in this paper. The following table presents the criteria catalog with the metrics, which are suited to fulfill each criterion.

Table 2. Criteria catalog including metrics

ID	*Criterion*	*Metrics*
1	Security of the platform	Backup & Recovery Data encryption Threat prevention Traceability Management of access roles and rights Single-Sign-On Existing evaluation possibilities Existing certifications
2	Modularity of the platform	Scoping the ratio between own and external development Modular machine tool design (hardware) Specification of design principles
3	Degree of openness (platform and interfaces)	APIs for expanding the connected smart machine tool Functional description of the APIs Integration possibility of non-platform machine tools Technical description of the APIs Support of various formats for data exchange Presence of standards

		Accessibility of the platform
4	Functionalities on the platform	Uniform user interface
		Social media connection
		Systems for functional testing possibilities
		Test access to the platform or a demo version
		Trainings and Certifications
		Support and transaction processing by the platform
		Availability of a help desk for complementors
		Cooperation in development
5	Range of the platform	Number of end users
		Number of complementors and partners
6	Autonomy of all stakeholders	Autonomy of complementors

4 Conclusions and Further Research Outlook

The overall benefit of this paper is a structured criteria catalog, suitable for researchers and practitioners to benchmark the highly dynamic market for iIoT platforms, identify relevant concrete criteria of a platform a improve the platform selection process for a company, connecting its assets as the smart machine tools with the platform. Moreover, the criteria could also address the platform providing companies. The business model development of a platform providing company for instance could use the results to uncover similarities between the iIoT platforms and to change them, in order to differentiate the platform from the competition.

The results of this paper are surely limited, concerning the subjectivity in the choice of search terms. Additional search terms could reveal additional relevant criteria, which were not identified. In addition, the structured literature search is limited by the exclusion of German articles from engineering conferences, which also have strong research interest in the integration of a platform approach for smart connected machine tools. The literature analysis also does not consider some viewing levels on platforms, as platform governance or interactions of the platform ecosystem with its environment [50, 51], which could also influence the criteria or extend the catalog. However, the elaborated criteria catalog could influence the platform governance, as it has a strong intersection with the degree of the openness and the architecture of a platform [10]. The limited search period providers additional constraints, as it does not consider the high dynamics in the market of iIoT platforms, excluding newest possible metrics or features, implemented and introduced during 2018. Therefore, criteria and corresponding solution-oriented metrics introduced after the end of the search period are not included in the catalog. Moreover, the application of the catalog still needs an empirical validation, which is not addressed in this paper. Against these limitations, a follow-up multiple-case study on market-ready iIoT platforms would provide potential topics for future research. Consequently, the application of the criteria catalogue and the evaluation of the application will be the next steps. These steps would provide additional managerial implications for the iIoT platform-providing companies and offer potential for further development of the catalog.

The results also provide a foundation for an empirical evaluation of the researched criteria. Manufacturing companies could be suitable candidates for an empirical study in the future with the goal to extend and to prioritize the researched criteria.

References

1. Westkämper, E., Löffler, C.: Strategien der Produktion. Technologien, Konzepte und Wege in die Praxis. Springer, Heidelberg (2016)
2. Roland Berger: Predictive Maintenance. Service der Zukunft – und wo er wirklich steht. Roland Berger (2017)
3. Staufen: Deutscher Industrie 4.0 Index 2017. Staufen Digital Neonex GmbH und Staugen AG (2017)
4. James, M., Chui, M., Bisson, P., Woetzel, J., Dobbs, R., Bughin, J., Aharon, D.: The Internet of Things: Mapping the value beyond the hype, McKinsey Global Institute (2015)
5. Porter, M. E., Heppelmann, J. E.: How smart, connected products are transforming competition. Harvard Business Review 92, 64–88 (2014)
6. Yoo, Y., Henfridsson, O., Lyytinen, K.: The new organizing logic of digital innovation: An agenda for information systems research. Information Systems Research 21(4), 364–380 (2010)
7. Lee, E., A.: Cyber physical Systems: Design challenges. In: Proceedings of the 11th IEEE International Symposium on Object Oriented Real-Time Distributed Computing. pp. 363-369. IEEE Computer Society, Washington (2008)
8. Schönhofen, F., Petrik, D., Schockert, S., Herzwurm, G.: Analysis of platform-based business models using quality function deployment. In: Proceedings of the 23rd International Symposium on Quality Function Deployment, pp. 65-80 (2017)
9. Krause, T., Strauß, O., Scheffler, G., Kett, H., Lehmann, K., Renner, T.: IT-Plattformen für das Internet der Dinge (IoT). Basis intelligenter Produkte und Services. Fraunhofer Verlag, Stuttgart (2017)
10. Tiwana, A.: Platform ecosystems: aligning architecture, governance, and strategy. Morgan Kaufman, Waltham (2013)
11. Gawer, A., Cusumano, M. A.: Platform leadership: How Intel, Microsoft, and Cisco drive industry innovation. Harvard Business School Press, Boston (2002)
12. Bruhn, M., Hadwich, K.: Dienstleistungen 4.0: Erscheinungsformen, Transformationsprozesse und Managementimplikationen – Methoden – Instrumente. In: Bruhn, M., Handwich, K. (eds.) Dienstleistungen 4.0: Konzepte – Methoden – Instrumente, pp. 3-43. Springer Gabler, Wiesbaden (2017)
13. Gawer, A., Cusumano, M., A.: Industry Platforms and Ecosystem Innovation. Journal of Product Innovation Management 31(3), 417-433 (2014)
14. Monostori, L., Kádár, B., Bauernhansl, T., Kondoh, S., Kumara, S., Reinhart, G., Sauer, O., Schuh, G:, Sihn, W., Ueda, K.: Cyber-physical systems in manufacturing. In: CIRP Annals – Manufacturing Technology 65, pp. 621-641 (2016)
15. Hartmann, M., Halecker, B.: Management of Innovation in the Industrial Internet of Things. In: Proceedings of the International Society for Professional Innovation Management (ISPIM), pp. 1-17 (2015)

16. Gubbi, J., Buyya, R., Marusic, S., Palaniswami, M.: Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems, 29(7), 1645-1660 (2013)
17. Serpanos, D., Wolf, M.: Internet-of-Things (IoT) Systems. Architectures, Algorithms, Methodologies. Springer Nature, Cham (2018)
18. Lenz, J., Wuest, T., Westkämper, E.: Holistic Approach to Machine Tool Data Analytics. Journal of Manufacturing Systems 48(C), 180-191 (2018)
19. Iansiti, M., Levien, R.: They Keystone Advanteage: What the New Dynamics of Business Ecosystems Mean for Strategy, Innovation, and Sustainability. Harvard Business Press, Boston (2004)
20. Rochet, J., Tirole, J.: Platform competition in two-sided markets. Journal of the European Economic Association 1(4), 990–1029 (2003)
21. Siemens, https://store.mindsphere.io/mindsphere/Applications, (Accessed: 06.12.2018)
22. PTC, https://www.ptc.com/en/marketplace, (Accessed: 06.12.2018)
23. Tranfield, D., Denyer, D., Smart, P.: Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British Journal of Management 14, 207–222 (2003)
24. Fink, A.: Conducting research literature reviews: from the internet to paper. Sage Publications, Los Angeles (2013)
25. Webster, J., Watson, R. T.: Analyzing the past to prepare for the future: Writing a literature review. MIS Quarterly 26, XIII–XXIII (2002)
26. Rashman, L., Withers, E., Hartley, J.: Organizational learning and knowledge in public service organizations: A systematic review of the literature. International Journal of Management Reviews 11, 463–494 (2009)
27. Soni, G., Kodali, R.: A critical analysis of supply chain management content in empirical research. Business Process Management Journal 17, 238–266 (2011)
28. Winter, M., Knemeyer, A. M.: Exploring the integration of sustainability and supply chain management: Current state and opportunities for future inquiry. International Journal of Physical Distribution & Logistics Management 43, 18–38 (2013)
29. Axelsson, J., Papatheocharous, E., Andersson, J.: Characteristics of software ecosystems for Federated Embedded Systems: A case study. Information and Software Technology 56(11), 1457-1475 (2014)
30. Axelsson, J., Skoglund, M.: Quality assurance in software ecosystems: A systematic literature mapping and research agenda. Journal of Systems and Software 114, 68-81 (2016)
31. Babiceanu, R., F., Seker, R.: Big Data and virtualization for manufacturing cyber-physical systems: A survey of the current status and future outlook. Computers in Industry 81, 128-137 (2016)
32. Chen, D.: A methodology for developing service in virtual manufacturing environment. Annual Reviews in Control 39, 102-117 (2015)
33. Eklund, V., Bosch, J.: Architecture for embedded open software ecosystems. Journal of Systems and Software 92, 143-148 (2014)
34. Eloranta, V., Orkoneva, L., Hakanen, E., Turunen, T.: Using platforms to pursue strategic opportunities in service-driven manufacturing. Service Science 8, 344-357 (2016)
35. Eloranta, V., Turunen, T.: Platforms in service-driven manufacturing: Leveraging complexity by connecting, sharing, and integration. Industrial Marketing Management 5, 178-186 (2016)
36. Farahzadi, A., Shams, P., Rezazadeh, J., Farahbakhsh, R.: Middleware Technologies for Cloud of Things – a survey. Digital Communications and Networks 4(3), 176-188 (2018)

37. Gawer, A.: Bridging differing perspectives on technological platforms: Toward an integrative framework. Research Policy 43, 1239-1249 (2014)
38. Herterich, M., M., Uebernickel, F., Brenner, W.: The impact of cyber-physical systems on industrial services in manufacturing. In: Procedia CIRP 30, pp. 323-328 (2015)
39. Hohwieler, E., Berger, R., Geisert, C.: Condition monitoring services for e-Maintenance. In: IFAC Proceedings Volumes 37, pp. 239-244 (2004)
40. Jesse, N.; Internet of Things and Big Data – The Disruption of the Value Chain and the Rise of New Software Ecosystems. In: IFAC-PapersOnLine 49(29), pp. 275-282 (2016)
41. Mikusz, M.: Towards a Conceptual Framework for Cyber-Physical Systems from the Service-Dominant Logic Perspective. In: Procedia CIRP 16, pp. 385-389 (2014)
42. Mikusz, M., Csiszar, A.: CPS Platform Approach to Industrial Robots: State of the Practice, Potentials, Future Research Directions. In: PACIS 2015 Proceedings, pp.176 (2015)
43. Shariazhadeh, N., Lundholm, T., Lindberg, L., Sivard, G.: Integration of digital factory with smart factory based on Internet of Things. In: Procedia CIRP 50, pp. 512-517 (2016)
44. Soeldner, C., Roth, A., Danziger, F., Moeslein, K.: Towards open innovation in embedded systems. In: Proceedings of the Nineteenth Americas Conference on Information Systems (AMCIS), (2013)
45. Tantik, E., Anderl, R.: Integrated Data Model and Structure for the Asset Administration Shell in Industrie 4.0. In: Procedia CIRP 60, pp. 86-91 (2017)
46. Tedeschi, S., Mehnen, J., Tapoglou, N., Rajkumar, R.: Security aspects in Cloud based condition monitoring of machine tools. In: Procedia CIRP 39, pp. 47-52 (2015)
47. Thames, L., Schaefer, D.: Software-defined cloud manufacturing for Industry 4.0. In: Procedia CIRP 52, pp. 12-17 (2016)
48. Waibel, M., W., Steenkamp, L., P., Moloko, N., Oosthuizen, G., A.: Investigating the effects of smart production systems on sustainability elements. In: Procedia Manufacturing 8, pp. 731-737 (2017)
49. Yue, X., Cai, H., Yan, H., Zou, C., Zhou, K.: Cloud-assisted industrial cyber-physical systems: an insight. Microprocessors and Microsystems 39(8), 109-118 (2005)
50. Mautsch, L., M.: Softwareplattformen für Unternehmenssoftwareökosysteme. Eul, Lohmar (2015)
51. Herzwurm, G.: Kundenorientierte Softwareproduktentwicklung. B. G. Teubner, Stuttgart, Leipzig, Wiesbaden (2000)
52. De Reuver, M., Sorensen, M., Basole, R., C.: The digital platform:a research agenda. Journal of Information Technology 33(2), 124-135 (2018)