2nd Conference on Production Systems and Logistics

Enabling The Smart Factory – A Digital Platform Concept For Standardized Data Integration

Julia Donnelly[1], Andreas John[2], Jonas Mirlach[3], Kilian Osberghaus[3], Silvia Rother[4], Christian Schmidt[2], Hannes Voucko-Glockner[3], Simon Wenninger[5]

[1]*FIM Research Center, University of Augsburg, Project Group Business & Information Systems Engineering of the Fraunhofer FIT, Germany*
[2]*soffico GmbH, Augsburg, Germany*
[3]*FIM Research Center, University of Augsburg, Germany*
[4]*University of Augsburg, Germany*
[5]*FIM Research Center, University of Applied Sciences Augsburg, Project Group Business & Information Systems Engineering of the Fraunhofer FIT, Germany*

Abstract

The digital transformation of industrial manufacturing companies is still seen as a challenge on the path to the smart factory and efficient and transparent production. Companies have already been dealing with concepts such as Industry 4.0 and the associated tasks of digitization and process automation for years. More recently, data-driven methods of machine learning and artificial intelligence, have increased the demands on data integration in industrial applications and the need for seamless and automated communication within information systems. This facilitates the creation of entirely new business models or the adaption of new approaches such as predictive analytics (e.g. for predictive maintenance) or data mining methods (e.g. for anomaly detection) to increase productivity. A multitude of partly proprietary standards for communication between machines and systems, and interface definitions complicates the integration of systems and data. To minimize the challenges of system and data integration, we have developed a digital platform concept as a solution to standardized data integration issues. In a first step, through literature research and expert interviews, we identified current industrial trends and key relevant standards and processes. In a second step, we developed a concept for a digital platform - a Service Hub - through which the identified standards and integration processes can be marketed. The Service Hub supports companies in their digital transformation and offers providers of various integration solutions an opportunity for individualized marketing of frequently used (integration) processes.

Keywords

Smart Factory; Data Integration; Digital Transformation; Industry 4.0; Digital Platform

1. Introduction and method

New digital technologies and Industry 4.0 are having a significant impact on companies' strategies and business models, as well as on their processes and routines. On the way to efficient and transparent production in the smart factory, companies must perform a digital transformation to remain competitive in international markets. In the context of Industry 4.0, data and the connectivity of machines and systems across all levels of automation play a central role [1]. The gathered volumes of data open up entirely new opportunities for business models and potential for efficiency gains and flexibility [2]. For instance,

DOI: https://doi.org/10.15488/11275

applications of machine learning and artificial intelligence methods are becoming increasingly important in areas such as process mining or predictive maintenance [3]. These applications require data integration and workflows for the automated and flawless communication of various information systems. However, despite existing technology and the use of middleware software, manufacturing companies still face major problems in integrating data-driven applications for optimisation and automation tasks [2]. A multitude of partly proprietary communication standards and interface definitions as well as non-convenient provision of integration solutions are considered to be key challenges in data integration [2]. Platform approaches to this problem already exist, but they are often specifically tailored to the products and services of the respective provider and use proprietary interfaces and communication standards instead of open standards [4–6]. However, it affects the interaction with external systems and thus counteracts the generative approach of the platform and leads to lock-in effects [5]. To address this issue, we formulate our guiding research question (RQ) as follows:

How can software vendors improve data integration offerings using a digital platform to facilitate data integration and enable a smart factory for manufacturing companies?

We answer the RQ by developing and designing a conceptual model of a digital platform which supports companies in their digital transformation by offering (data) integration solutions via individualized marketing of frequently used (integration) processes. In doing so, we rely on existing solutions and classify our solution and our contribution to practice and the theoretical body of literature as "exaptation", which is characterized by an extension of known solutions to new problems [7]. The aim of the work is to develop a concept that helps companies to circumvent the problem of data integration. This concept can then be a basis for products and services of software vendors offering data integration solutions. Therefore, research in this paper has been organized by an adapted design science in information systems research framework combining behavioural science and design science paradigms [8]. In a first step we identified current industrial trends and relevant standards and processes for typical data integration tasks as a basis for our work by conducting a semi-structured literature review in the databases Science Direct, AIS eLibrary, Springer, and Research Gate with the keywords "IoT", "Industry 4.0" "platform", and "data integration". We then enrich the findings from literature with additional expert interviews and compare them to practical issues to address the needs of manufacturing companies. We therefore reviewed 10 experts who were asked to give their assessment of current trends and the status quo of data integration in (their) industry. These experts work either as consultants or in manufacturing companies and have prior knowledge in the subject matter covered. Using both perspectives allows us to identify and highlight similarities and differences from research a practice. These compiled findings are then used to develop our conceptual model. We structure our paper with the topic of drivers, trends, and standards for data integration in chapter 2, before also describing existing approaches to data integration and providing an overview of digital platforms, with the topics of cloud computing and payment models being highly relevant. Subsequently in chapter 3, we develop a concept for a digital platform - a Service Hub - through which the identified standards and integration processes can be commercialized present our developed Service Hub and describe its cloud-based usage and billing models. Both perspectives from the first two steps contributed to the design phase as well as in the evaluation and refinement of the Service Hub. In chapter 4, we discuss its usage in business, limitations and prospects for further research before we conclude in chapter 5.

2. Theoretical background

2.1 Drivers, trends, and standards for data integration in manufacturing companies

Analyzing literature on current drivers and trends in manufacturing shows the relevance of a seamless data integration. Current trends in manufacturing are primarily shaped by the digital transformation which has been driven by the Internet of Things, Internet of Services, and Big Data for more than a decade. It enables organizations to create novel business models and thereby achieve competitive advantages and outperform within its own industry [9,10]. Nowadays, companies can in particular establish competitive advantages by exploiting technological enhancements in terms of managing and orchestrating data and information. This includes the integration of cyber physical systems, artificial intelligence, machine learning or Distributed Ledger Technologies, such as Blockchain applications within internal processes [10]. In fact, companies are evolving from product providers to service providers through these data-driven technologies. Data-driven analyses or data mining methods, for instance, predictive analytics, especially predictive maintenance and predictive sales require the efficient integration of relevant data to provide real-time forecasts of future developments and risks [11]. In addition, data mining methods enable the identification of valuable new patterns from data. e.g. in customer relationship management (CRM) systems or enterprise resource planning (ERP) systems, leading to increased efficiency and flexibility of a company.

Data or information integration is understood as the consolidation of redundancy-free data and information from different application areas and systems. This requires extracting and evaluating the same data from different systems and different data from the same systems to provide the data to the correct users/systems at the right time [12]. As systems are often incompatible, interfaces are the key for data integration. A middleware is a software abstraction layer that provides those interfaces to help manage the complexity and heterogeneity between different systems [13]. As a result companies can benefit from a higher data integrity, referred to as the correctness and completeness of data, and can thus optimize information flows, process integration, and decision-making in an enterprise [14].

Data integration is considered an ongoing task of information system (IS) management, such as CRM or ERP systems, and the administration of database systems [14]. For information exchange the Extensible Markup Language (XML) and Java Script Object Nation (JSON) have established themselves as a text-based standard structuring language describing the structure of a data set [15,14]. Both may include additional records, enabling the creation of deep nested structures, and allow the exchange and processing of data between software and hardware applications. XML, JSON, and other standard structuring languages therefore form the basis for many software standards.

Table 1: Selection of frequently used data integration standards in the industry

Abbreviation	Notation	Description
-	MTConnect	An XML-based standard which retrieves process information from manufacturing machines via Transmission Control Protocol connections.
HTTP	Hypertext Transfer Protocol	An internet protocol that enables data transfer and communication between internet-connected applications using Representational State Transfer architectures.
OPCUA	Open Platform Communications Unified Architecture	A machine-to-machine communication technology standard based on which multiple devices, sensors and machines can be linked via a single communication thread.
MQTT	Message Queue Telemetry Transport	An open protocol to enable the exchange of data by transmitting data in the form of messages to multiple clients.
AMQP	Advanced Message Queuing Protocol	An open standard for business communication, which enables the transfer of information between companies and applications via a network protocol.

Table 1 lists a selection of frequently used standards for data integration in industry and business based on literature. While every private web user worldwide uses Hypertext Transfer Protocol (HTTP) links when accessing web browsers, OPC UA, MQTT and AMQP represent standards for industrial and business-relevant applications. These standards should be interoperable with the digital platform concept.

To enrich our above findings from literature we also conducted expert interviews. 10 experts from industry were questioned on the current status quo, development and actions taken within their companies with regard to data integration as well as their outlook what additional action should be taken, whether this should be done in the short or long term and where barriers arise in the short and long term. The analysis of the current state revealed that only half of the respondents are intensively dealing with data integration and only 30% have integrated a general standard such as OPC UA. Alternative predominantly proprietary solutions are still widely used. Nevertheless, all experts recognize the need for increasing data integration and its associated potential. Potential is primarily expected in newly enabled interdisciplinary information flows, which will allow for deeper insights and knowledge to be gained and, at the same time, a better understanding of how this knowledge can be protected and applied. In addition, an expected higher data quality offers advantages in terms of efficiency and cost by, for example, automatically identifying and correcting erroneous values. Among the barriers preventing more advanced data integration, both organizational and technical capabilities are considered. From an organizational perspective, the lack of awareness for data integration and its benefits for all stakeholders of a company is a key barrier. In addition, the management levels have often not yet been sensitized to the issue. At the same time, prevailing silo structures must be broken down to enable holistic cross-departmental data integration which requires management support. Moreover, companies often lack technical know-how and transparent documentation of existing processes, systems, and data flows. From a technical perspective, reasons for the lack of overarching data integration standards are primarily seen in historically and often isolated implemented systems with proprietary solutions. However, the simultaneous integration of internal and external data sources while taking data protection principles into account also often proves difficult. In contrast, financial hurdles are currently the smallest barrier to efficient data integration. Most experts agree that the topic of data integration must be addressed in the short term, in a period of less than six years, in order not to be displaced by competitors within the industry. Here, the technical capabilities mentioned above represent the greatest challenge. In the long term, data protection requirements, know-how protection, data security and the allocation of responsibility in the event of data loss are considered to be the main challenges, while at the same time complying with regulatory requirements.

Whereas the literature analysis gives an overview of a variety of possibilities for data and information integration, the evaluation of the survey reflects the current state in the industry. Theory and practical application are currently still far apart. The literature research revealed that functional standards such as MQTT already exist, but that they are more of a wish than a reality in application. Despite this, there is an evident willingness to change. Standardized solutions for connecting and integrating machines can support manufacturing companies in their digital transformation to Industry 4.0 standards and reduce challenges. Furthermore, data integration is necessary to establish new business models and thus to remain competitive, emphasizing the relevance of the Service Hub.

According to literature, several approaches for simplifying data integration already exist, however these approaches seem rather technically focused and mostly concern the standardization of protocols [5]. For example, Sanderson et al. [12] introduce an architectural data integration approach for production enterprises using data distribution services whereas Schuh et al. [16] present the “Internet of Production” as an enabler of cross-domain collaboration for production, development and usage data. With the success of digital platforms, e.g. as app stores in the consumer sector, digital platforms are also increasingly being used in industry and promise future potential for various applications [1].

2.2 Digital platforms

Digital platforms are an emerging and ubiquitous phenomenon in the private sphere as well as across industries [17]. Digital platforms change the way digital products and services are consumed, delivered, and mediated. Established companies are being forced to innovate and transform their current business model to remain competitive. In contrast to the common value creation within companies or linear supply chains, digital platforms enable the co-creation of value in an ecosystem of independent actors and stakeholders [17]. Constantly evolving information technology, such as cloud computing and analytic solutions for Big Data, provide the technological foundation for digital platforms and enable entirely new business models, distribution opportunities as well as payment and tariff models [18,19].

The ecosystem of digital platforms typically consists of a platform provider, one or more value-adding mechanisms, and complementors. The platform provider implements governance mechanisms to enable value-creating mechanisms on a digital platform between the platform provider and an ecosystem of autonomous complementors and customers [17,20]. Value-creating mechanisms are divided into two overarching mechanisms and are central for the success of digital platforms. First, there is the value-creating mechanism of transaction facilitation describing the digital interaction between complementors and consumers by, for example, directly matching supply to demand and proposing possible transactions or offers to consumers. The second value-creating mechanism is the mechanism of enabling complementors to jointly create synergistic solutions. Complementors can be providers of different products or services [21,22].

From a technical point of view, a digital platform is a software-based platform that, in addition to basic functionality, provides the option of adding modular services, replacing them, and maintaining a stable core. Each module extends the functionality of the platform and may be implemented by both external parties (complementors and platform provider). Furthermore, the design of digital platforms creating a two-sided or multi-sided market, combined with highly customizable digital technologies, enables high levels of scalability by leveraging network effects [23]. This offers digital platforms the opportunity to easily acquire new customers and to grow with existing customers.

In today's digital society, cloud computing is indispensable. Cloud services gradually replace on-premise systems for data processing in companies and also represent a key technology for digital platforms [23]. Cloud computing enables on-demand computing services to be provided with high reliability, availability, and scalability in a distributed environment [24]. A variety of different service models already exist in cloud computing, which allow the customer to purchase individualized and highly customized infrastructure.

These individualized and highly customized infrastructures can be priced very differently which is reflected in the development of various new and innovative payment models with the ongoing digitalization leading to digital hybrid value creation processes and a shift from product-only providers to service providers [25]. With payment models being a relevant component of business models, we conducted a literature research on different payment models and compared them to the results of the conducted expert interviews, allowing us to enhance the design of the Service Hub. Considering digital transformation and customer needs, platform providers are primarily focusing on pay-per-use models, subscription models, and one-time purchases. In a pay-per-use model, the user pays according to his individual scope of use resulting in individual prices for each user [26]. There are no acquisition costs, capital commitment or software maintenance costs [27]. In a subscription model a fixed price is paid on a regular basis and does not depend on the actual scope of use of the product [28]. In the case of a one-time purchase, ownership of the product is transferred to the buyer who can use the product for its entire lifetime.

Following the literature review on the three predominant payment models, we questioned the experts about their preference to take the needs of potential platform customers into account for our newly developed concept of a digital platform. We distinguished between payment models for a basic version of a middleware and additional individual modules for specific data integration processes. 75% of the experts consider Pay-per-use and subscription models as preferred models for the basic version, whereas pay-per-use was favoured by the majority for additional modules. In addition to the selection of payment models the experts' choice is strongly dependent on the scope of services, including support and updates, as well as the scope of use. If support and updates are included in the basic version, acceptance of the subscription model increases compared with pay-per-use. If the product is not guaranteed to be up to date, experts recommend that the pay-per-use model be degressive, resulting in a choice of this payment model. Consequently, the scope of services and the scope of use must be defined in advance for the design of various payment models, which differ between the basic version and additional modules.

3. A digital platform concept for standardized data integration

With the RQ initially defined, we developed a conceptual model of a digital platform - the Service Hub - based on the presented results from the literature research and the expert interviews. It may support companies in their digital transformation by offering (data) integration solutions via individualized marketing of frequently used (integration) processes. The main idea of our solution is based on that of established app stores. In these app stores, customers buy applications, which can be implemented and used on the customers' (mobile) device. In the business-to-business area it works the same way but individualized and highly specified data integration solutions are required. The design of the digital platform concept from a business model perspective is conceptually illustrated in Figure 1. It incorporates the three central elements platform provider, complementor, and value creating mechanisms. In addition, the model depicts all relevant connections, dependencies, and flows, showing that both payments and communication can be processed exclusively via the Service Hub.

With the Service Hub, two elementary products are to be distributed and made available in order to address the individual specifics of companies in terms of data integration. The core product is a basic version of software including several fundamental functions of a middleware for data integration. In addition, individual yet standardized modules for data integration are offered to adapt the basic version to the company-specific requirements. Based on the results of the literature research and the expert interviews, a subscription for the basic version seems suitable. Depending on whether the basic version of the software is easy to procure and does not need to be specially implemented at the customer' site, purchasing and procurement can be operated directly via the Service Hub. In the case of more complex implementation, an on-site implementation is also possible as an additional service from the software vendor. Offering these modules with a pay-per-use payment model might be appropriate, according to the expert interviews. The basic version and the modules together then result in the customer's individual version.

The platform provider, being one of the central elements of digital platforms, is implicitly represented by the platform itself and the software vendor, who at the same time also be a complementor. Thus, the integration of additional software vendors as complementors is an option for integrating third parties in the future platform design. Lastly, there is the customer represented by an industrial company that intends to purchase the corresponding solutions for data integration. By dividing the platform into a basic version and additional modules, the platform provider can benefit from future growth opportunities of the platform and at the same time profit from the growth and the need for data integration solutions of its customers [17]. The individual software version should be available both cloud-based and on premise, so that the customer can choose freely. The cloud infrastructure can be operated by the software vendor or sourced externally.

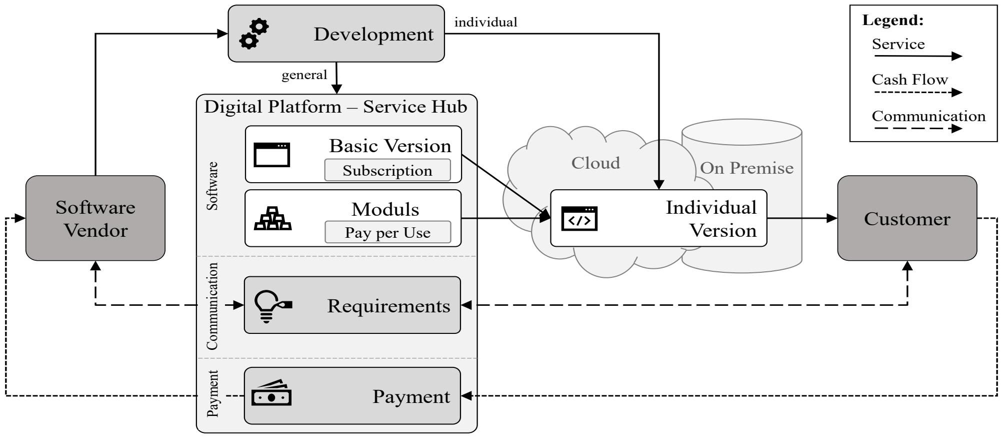

Figure 1: Design of the digital platform concept from a business model perspective (Service Hub)

Referring once again to the basic idea of an app store, one central difference can be noted. Unlike an app store, our various modules interact with each other and are therefore coordinated. In this solution, these modules can be used both on premise and in a cloud, which is often different with an app store. Thus, our approach complements the in literature identified gap of missing data integration solutions in the middleware area.

For the operation of the Service Hub, the following recommendations for action can be derived. In order to make the use of the Service Hub as convenient and simple as possible while still maintaining customer contact, it makes sense to design the payment flow as well as the communication between the customer and the software vendor directly via the platform. For communication, a forum, contact forms and other common methods may be implemented, analogous to conventional platforms. Via these interfaces needs, requirements and requests can be effectively communicated and documented. Analysis and evaluation of the correspondence will enable the platform provider to better understand the customer and facilitate continuous development of the platform. It supports continuous expansion of the range of available modules and adaption to the specific needs of the customer. However, since not all modules required in the long term might be available when Service Hub launches, the platform provider should focus initially on the most prioritized modules and then strategically expand the portfolio of modules as required.

4. Discussion and Limitation

The developed concept of the Service Hub offers several advantages and disadvantages as well as various future design options. A crucial advantage for the provider results from the marketing of standardized modules, which avoid new developments and the implementation for individual requests of data integration solutions, leading to a significant reduction of effort and costs [29]. Furthermore, the platform concept offers the possibility of flexible growth both with existing customers and new customers by improving the modules and adding new modules. Depending on the design of the platform, mixed forms of distribution are possible, in which the basic version or specific complex modules are installed in the traditional way and the platform is only used to offer further modules. In some cases, this can be technically easier to implement. In addition, it can be advantageous to expand the range of data integration options by opening the Service Hub to software solutions and modules from third-party providers to may increase the attractiveness of the Service Hub and to make it possible to profit financially from third-party providers by brokering their offerings. One advantage for the customer is the new convenience of purchasing data integration solutions. For an implementation or extension of the services, it is no longer necessary to contact the software provider for every single addition. Customers can conveniently make their adjustments according to the self-service system. In contrast, however, there are also drawbacks for both sides. Primarily, the direct, personal customer contact is reduced, which leads to disadvantages such as the software provider possibly losing sight of the customer's needs, which can affect the relevance of the product. It is therefore important to keep customer contact and communication as high as possible, both via the platform and in person. Additionally, there is a financial risk for the software provider, as the initial construction and implementation of the platform can lead to higher costs than a classic implementation, which may only pay off with a high number of customers in the future.

Besides advantages and disadvantages of our platform concept itself, our study naturally disposes of limitations and prospects for further research. First, there are limitations with regard to an industry-wide representativeness of our study, as we only conducted a sample of 10 expert interviews in the industry. Second, we did not consider the technical feasibility of our developed digital platform concept in detail and thus did not consider possible technical limitations as well as the trade-off between possible implementation costs and the benefits of our concept. Further research could address these limitations and include interviewing more experts and analysing the trade-off between the costs of technical implementation and the benefits of the concept in a business case. When compared to existing approaches, the Service Hub is to be understood as an integrative approach that allows existing technical solutions to be offered to the customer. Summarizing, the contribution of our approach is rather to be classified as an exaptation than a ground-breaking invention, since we apply known solutions to a new problem.

5. Conclusion

Due to various drivers and the resulting trends, it is likely that data integration will become increasingly important in manufacturing companies in the future. In our study, we therefore developed a conceptual model of a digital platform - the Service Hub - based on literature research and expert interviews. The Service Hub supports companies in their digital transformation by offering (data) integration solutions via individualized marketing of frequently used data (integration) processes. Despite the limitations outlined in this study, we have demonstrated a viable concept to easily commercialize various data integration processes that can help software and middleware vendors improve their business model.

References

[1] Bauer, D., Hieronymus, A., Kaymakci, C., Köberlein, J., Schimmelpfennig, J., Wenninger, S., Zeiser, R., 2020. Wie IT die Energieflexibilitätsvermarktung von Industrieunternehmen ermöglicht und die Energiewende unterstützt. HMD, 1–14.

[2] Reinhart, G., Bank, L., Brugger, M., Hieronymus, A., Köberlein, J., Roth, S., Bauernhansl, T., Sauer, A., Bauer, D., Kaymakci, C., Schel, D., Schlereth, A., Fridgen, G., Buhl, H.U., Bojung, C., Schott, P., Weibelzahl, M., Wenninger, S., Weigold, M., Lindner, M., Ronge, K., Oeder, A., Schimmelpfennig, J., Winter, C., Jarke, M., Ahrens, R., 2020. Konzept der Energiesynchronisationsplattform: Diskussionspapier V3.

[3] Kaymakci, C., Wenninger, S., Sauer, A., 2021. A Holistic Framework for AI Systems in Industrial Applications. Wirtschaftsinformatik 2021 Proceedings.

[4] Bauer, D., Stock, D., Bauernhansl, T., 2017. Movement Towards Service-orientation and App-orientation in Manufacturing IT. Procedia CIRP 62, 199–204.

[5] Roesch, M., Bauer, D., Haupt, L., Keller, R., Bauernhansl, T., Fridgen, G., Reinhart, G., Sauer, A., 2019. Harnessing the full potential of industrial demand-side flexibility: an end-to-end approach connecting machines with markets through service-oriented IT platforms. Universität Augsburg; MDPI AG, Augsburg, Online-Ressource.

[6] Schott, P., Ahrens, R., Bauer, D., Hering, F., Keller, R., Pullmann, J., Schel, D., Schimmelpfennig, J., Simon, P., Weber, T., Abele, E., Bauernhansl, T., Fridgen, G., Jarke, M., Reinhart, G., 2018. Flexible IT platform for synchronizing energy demands with volatile markets. it - Information Technology 60 (3), 155–164.

[7] Gregor, Shirley, Alan R. Hevner, 2013. Positioning and Presenting Design Science Research for Maximum Impact. MIS Quarterly 37 (2), 337–355.

[8] Hevner, A., March, S.T., Park, J., Ram, S., 2004. Design Science in Information Systems Research. MIS Quaterly (28 (1)), 75–105.

[9] Berger, S., Bitzer, M., Häckel, B., Voit, C., 2020. Approaching Digital Transformation - Development of a Multi-dimensional Maturity Model. ECIS 2020 Research Papers.

[10] Gimpel, H., Röglinger, M., 2015. Digital Transformation: Changes and Chances – Insights based on an Empirical Study, Project Group Business and Information Systems Engineering (BISE) of the.

[11] Siepermann, M., 2018. Predictive Analytics. https://wirtschaftslexikon.gabler.de/definition/predictive-analytics-54501/version-277530. Accessed 5 January 2021.

[12] Sanderson, D., Chaplin, J.C., Ratchev, S., 2020. Affordable Data Integration Approach for Production Enterprises. Procedia CIRP 93, 616–621.

[13] Cereda, P.R.M., Neto, J.J., 2017. A middleware architecture for adaptive devices. Procedia Computer Science 109, 1158–1163.

[14] Mertens, P., Bodendorf, F., König, W., Schumann, M., Hess, T., Buxmann, P. (Eds.), 2017. Grundzüge der Wirtschaftsinformatik. Springer Berlin Heidelberg, Berlin, Heidelberg.

[15] Bourhis, P., Reutter, J.L., Vrgoč, D., 2020. JSON: Data model and query languages. Information Systems 89, 101478.

[16] Schuh, G., Prote, J.-P., Gützlaff, A., Thomas, K., Sauermann, F., Rodemann, N., 2019. Internet of Production: Rethinking production management, in: Wulfsberg, J.P., Hintze, W., Behrens, B.-A. (Eds.), Production at the leading edge of technology. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 533–542.

[17] Hein, A., Schreieck, M., Riasanow, T., Setzke, D.S., Wiesche, M., Böhm, M., Krcmar, H., 2020. Digital platform ecosystems. Electron Markets 30 (1), 87–98.

[18] Evans, D.S., Schmalensee, R., 2012. The Antitrust Analysis of Multi-Sided Platform Businesses: Law & Economics Working Papers. University of Chicago Institute for Law & Economics Olin Research Paper (No. 623).

[19] Jovanovic, M., Sjödin, D., Parida, V., 2021. Co-evolution of platform architecture, platform services, and platform governance: Expanding the platform value of industrial digital platforms. Technovation, 102218.

[20] Foerderer, J., Kude, T., Schuetz, S.W., Heinzl, A., 2019. Knowledge boundaries in enterprise software platform development: Antecedents and consequences for platform governance. Info Systems J 29 (1), 119–144.

[21] Constantinides, P., Henfridsson, O., Parker, G.G., 2018. Introduction—Platforms and Infrastructures in the Digital Age. Information Systems Research 29 (2), 381–400.

[22] Hein, A., Schreieck, M., Wiesche, M., Böhm, M., Krcmar, H., 2019. The emergence of native multi-sided platforms and their influence on incumbents. Electron Markets 29 (4), 631–647.

[23] Song, P., Xue, L., Rai, A., Zhang, C., 2018. The Ecosystem of Software Platform: A Study of Asymmetric Cross-Side Network Effects and Platform Governance. MISQ 42 (1), 121–142.

[24] Mesbahi, M.R., Rahmani, A.M., Hosseinzadeh, M., 2018. Reliability and high availability in cloud computing environments: a reference roadmap. Hum. Cent. Comput. Inf. Sci. 8.

[25] Übelhör, J., 2019. Industrieunternehmen und die Transformation von Geschäftsmodellen im Kontext der Digitalisierung – Eine empirische Studie über die Auswirkungen anhand des Business Model Canvas. HMD 56 (2), 453–467.

[26] Sousa-Zomer, T.T., Magalhães, L., Zancul, E., Cauchick-Miguel, P.A., 2018. Exploring the challenges for circular business implementation in manufacturing companies: An empirical investigation of a pay-per-use service provider. Resources, Conservation and Recycling 135, 3–13.

[27] Lipinski, K., Lackner, H., Laué, O.P., Kafka, G., Niemann, A., Raasch, E., Schoon, B., Radonic, A., 2019. Pay-per-Use. https://www.itwissen.info/Pay-per-Use-pay-per-use.html. Accessed 10 December 2020.

[28] Behrens, B.-A., Brosius, A., Hintze, W., Ihlenfeldt, S., Wulfsberg, J.P., 2021. Production at the leading edge of technology. Springer Berlin Heidelberg, Berlin, Heidelberg.

[29] Böhmann, T., Krcmar, H., 2004. Servicedatenmanagement für modulare Dienstleistungen, in: , Betriebliche Tertiarisierung : der ganzheitliche Wandel vom Produktionsbetrieb zum dienstleistenden Problemlöser. Dt. Univ.-Verl., Wiesbaden, pp. 149–178.

Biography

Julia Donnelly (*1994) is working at the FIM Research Center of the University of Augsburg and at the Project Group Business & Information Systems Engineering of the Fraunhofer FIT and focuses on research in the fields of digital transformation and digital business models.

Andreas John (*1995) is working as an IT consultant in the field of Industry 4.0 at soffico GmbH.

Jonas Mirlach (*2000) is studying Industrial Engineering at the University of Augsburg and is working at the FIM Research Center of the University of Augsburg with a research focus in the fields of digitalisation and IoT.

Kilian Osberghaus (*1999) is studying Industrial Engineering and Economics at the University of Augsburg and is working at the FIM Research Center of the University of Augsburg with a research focus in the field of digital health.

Silvia Rother (*1995) is studying Industrial Engineering at the University of Augsburg and is working in the process and quality management of the drive development at Hilti Entwicklungsgesellschaft mbH, Kaufering.

Christian Schmidt (*1991) is working as a Senior IT consultant and system architect for decentral communication patterns in the field of Industry 4.0 at soffico GmbH.

Hannes Voucko-Glockner (*1999) is studying Economics at the University of Augsburg and is working at the FIM Research Center of the University of Augsburg with a research focus in the field of data-based services in Industry 4.0 and smart and sustainable cities.

Simon Wenninger (*1995) is working at the FIM Research Center of the University of Applied Sciences Augsburg and at the Project Group Business & Information Systems Engineering of the Fraunhofer FIT and focuses on research in the fields of data analytics in an industrial and energy context.